



**SCHOOL OF GRADUATE STUDIES  
ADDIS ABABA INSTITUTE OF TECHNOLOGY (AAiT)  
DEPARTEMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**DEVELOPING CORRELATION BETWEEN INDEX PROPERTIES AND SWELLING  
POTENTIAL OF EXPANSIVE SOILS FOUND IN SENDAFA TOWN, ETHIOPIA**

**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 School of Civil and  
Environmental Engineering (Geotechnical Engineering)**

Advisor: Messele Haile (Dr. Ing)

By  
Mindaye Teshome Zemedkun  
November 2015

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Approved by board of examiners

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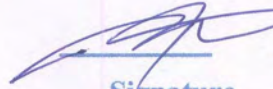
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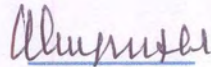
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## Declaration

I, the undersigned, declare that this thesis is my original work performed under the supervision of my research advisor Messele Haile (Dr. Ing) and has not been presented as a thesis for a degree in any other university. All sources of materials used for this thesis have been duly acknowledged.

Candidate's name: - Mindaye Teshome Zemedkun

Signature \_\_\_\_\_

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## Lists of symbols and Abbreviations

AASHTO – American Association of State Highway and Transport Officials

$A_c$  – Activity

Adj.  $R^2$  – Adjusted Correlation Coefficient (Multiple R)

ASTM - American Standard of Testing Materials

$a_0, a_1$  – Coefficients of single linear regression equation

$b_0, b_1, b_2, b_n$  - Coefficients of multiple linear regression equation

C – Percentage of clay size

c – Residual of regression equation

$Ca^{++}$  - Calcium ion

Cc - Coefficient of Curvature

CE – Cation Exchange

CH – Inorganic clay of high compressibility

Chroma - a notation indicates color's strength

CM - Inorganic clay of medium compressibility

CL - Inorganic clay of low compressibility

Cu - Uniformity Coefficient

D – Designation

EQ – Equation

$F_s$  - Free Swell

G – Gravel

GI – Group Index

GSA – Grain Size Distribution

Gs- Specific Gravity

H - High Plastic

Hue – a notation indicates color's relation

h- Initial soil height

$H^+$  - Hydrogen ion

IP - Plastic Index

IS – International System

K – Constant, (which is equal to  $3.6 \times 10^{-5}$ )

$K^+$  - Potassium ion

L - Low Plasticity

LI – Liquid Index

LL - Liquid Limit

M - Silt (from Swedish word “Mo”)

m - Meter

Mg<sup>++</sup> - Magnesium ion

MH - Inorganic silts of high compressibility

ML - Inorganic silts of low compressibility

MM - Inorganic silts of medium compressibility

MPE – Mean Percent Error

n – Number of samples

NH<sub>4</sub><sup>+</sup> - Ammonium ion

NMC – Natural Moisture Content

O – Organic

OH - Organic clay of high compressibility

P - Poorly Graded

PE- Potentially Expansive

PL - Plastic Limit

P<sub>s</sub> - Swelling Pressure

Pt – Peat

P-Value – Overall significance of regression equation

P<sub>200</sub> – Percent pass sieve number 200 (or 75µm sieve opening)

R – Correlation Coefficient (Multiple R)

RF – Rain fall

R<sup>2</sup> - Correlation Coefficient (Multiple R Square)

S – Sand

SE – Standard Error

SL – Shrinkage Limit

S<sub>p</sub> - Swelling Potential

S. No. – Serial Number

TP – Test Pit

USCS - Unified Soil Classification System

U.S – Unite State

Value - a notation indicates color’s lightness

V - Final Volume after free swell

Vo - Volume of dry soil

W - Well Graded

w - Water Content

Ws- Weight of solids

Ww-Weight of water

$x_1, x_2, \dots, x_n$  – Independent variables of linear regression

Y - Dependent variables of linear regression

% Clay – Percentage of clay content in the soil sample (i.e. C)

$\gamma_d$  - Dry Density

$\gamma_s$  - Unit weight of Solids

$\gamma_o$  - Unit weight of water

$\delta_h$  – Amount of vertical swell

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## Abstract

In this study, the relationship between index properties and swelling potential of expansive soil of Sendafa Town is examined.

Soil swelling is a term generally applied to the ability of a soil to undergo large changes in volume due to increased moisture content. One of the most important laboratory tests on expansive soils is the swell test and indices. Commonly used laboratory index tests, (namely natural moisture content, Atterberg limits, grain size analysis), and swelling pressure tests were conducted in order to estimate the swelling potential of the Sendafa expansive soil.

The soil is classified under AASHTO and USCS classification system. The AASHTO classification of the study area soil falls under A-7-5 and A-7-6 and this means the soil is plastic clay which has a high volume change capacity between wet and dry states. The USCS classification indicates the soil is inorganic clay of high plasticity (CH) with a potential of expansion.

Empirical correlations were proposed to relate index property parameters and swelling potential using single and multiple linear regression analysis methods using Microsoft Excel program. From single linear regression analysis plastic index has a better correlation than that of the other parameters (indices) with comparison factors of  $R^2$  and P-Value. In the case of multiple linear regression analysis dry density and plasticity index have a good combination effects with swelling. Results of the validity of the newly developed correlation with control test results shows that, the correlation of swelling potential value with soil index properties is valid for preliminary design purposes and estimation of swelling potential of soils.

# 1. Introduction

## 1.1 Background

Expansive soils are causing greater damage to civil engineering structures constructed on them, especially the light weight structures as they lack the counter balancing force as compared to the swelling pressure of such soils. The behaviour of expansive soils is highly dependent upon moisture content as such soils expand when subjected to moisture and shrink when they lose moisture. The alternate expansion and shrinking leads to structural distress within the system and finally failure of the structure occurs.

The soil profile of the Sendafa town varies from place to place. However, expansive soil covers different parts of the town (especially the industry zone and the newly to be establishing residential areas). From visual observation of the site soil, expansive soil related cracks and discussion with residents the soil in the town is to be expansive soil. Therefore, it is necessary to study the index properties and swelling potential and developing a relationship between these properties.

## 1.2 Objective

The general or major objectives of this paper are:-

- To study the index properties of expansive soil of the Sendafa town
- To study the swelling characteristics of expansive soils of the town.
- Finally, correlating between index properties and swelling potential of these soils is done.

## 1.3 Methodology

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

- Preliminary information about the areas where expansive soils found were selected.
- 20 disturbed and 20 undisturbed samples were taken, which are done by excavating 0.9 to 3.0m depths from ground surface. These samples were collected from 13 representative test pits.
- Laboratory tests;

The following laboratory tests were conducted:

- Moisture content
- Dry Density
- Specific gravity
- Atterberg limits
- Grain size analysis
- Free swell tests
- Swelling pressure tests were done for all the 20 undisturbed samples
- Finally, correlation of the index properties and swelling potential were done and best fit equations are selected.

## 1.4 Organization

This thesis is organized into seven Chapters. In the first Chapter back ground of the thesis, objectives of the research and methodology of the thesis are given. The second Chapter deals with literature review. The third Chapter addresses description of the study area. The fourth Chapter describes laboratory and field tests and their results. The fifth Chapter deals with soil classification. The sixth Chapter deals with correlation and regression analysis of representative samples. The seventh Chapter is discussion of the laboratory and correlation results obtained. Chapter eight is conclusion and recommendation.

## 2. Literature review

### 2.1 Introduction

The term 'clay' refers to a naturally occurring material composed primarily of fine-grained minerals, which is generally plastic at appropriate water contents and will harden when dried or fired. Although clay usually contains phyllosilicates, it may contain other materials that impart plasticity and harden when dried or fired. [12]

Expansive soil is a term generally applied to any soil or rock material that has a potential for shrinking or swelling under changing moisture conditions. These soils are not collapsible soils. [3] They can only be seen with an electron microscope, since they are very small crystals, of platy-like shape and of colloidal size. [10]

The problem of expansive soils was not recognized by soil engineers until the latter part of 1930. Prior to 1920, most of the lightly loaded buildings in the United States consisted of frame dwellings. Such structures could withstand considerable movement without exhibiting noticeable cracks. [5]

In Ethiopia also the problems associated with expansive soils were not recognized for many years. In the last 35 years, however, residual buildings were erected in areas where expansive soils are predominant. These are clay soils which may be black or grey in color. They have a potential for heaving with an increase of moisture content and they shrink with a corresponding decrease in moisture content. [6]

The primary problem that arises with regard to expansive soils is that deformations are significantly greater than elastic deformations and they cannot be predicted by classical elastic or plastic theory. Movement is usually in an uneven pattern and of such a magnitude as to cause extensive damage to the structures and pavements resting on them. This soil causes more damage to structures, particularly light buildings and pavements, than any other natural hazard, including earthquakes and floods. [4]

### 2.2 Origin of Expansive Soils

All clay minerals are crystalline hydrous alumino-silicates having a lattice structure in which the atoms are arranged in several layers, similar to the pages of a book. The arrangement and the chemical composition of these layers determine the type of clay mineral. The basic building blocks of the clay minerals are the silica tetrahedron and the alumina octahedron. These blocks make tetrahedral and octahedral layers and different combinations of which produce a unit sheet of the various types of clays.

A single particle of clay may consist of many sheets or films piled on one another. Because each sheet or film has a definite thickness but is not limited in dimensions at right angles to its thickness, clay particles are likely to exhibit flat or curved terraced surfaces. The surfaces carry residual negative

electrical charges, but the broken edges may carry either positive or negative charges in accordance with the environment.

In problems of interest to the civil engineer, clay particles are always in contact with water. The interactions among the clay particles, the water, and the various materials dissolved in the water are primarily responsible for the properties of the soil consisting of the particles. [8]

## 2.3 Mineralogical Composition

Most soil classification systems arbitrarily define clay particles as having an effective diameter of two microns (0.002mm) or less. Particle size alone does not determine clay mineral. The most important grain property of fine-grained soils is the mineralogical composition. For small size particles, the electrical forces acting on the surface of the particle are much greater than the gravitational force. [5]

The parent materials of expansive soils may be classified into two groups. The first group comprises the basic igneous rocks such as basalt, dolerite sills and dykes, gabbros, etc., where feldspar and pyroxene minerals of the parent rocks decompose to form montmorillonite (the predominant mineral of expansive) and other secondary minerals. The second group comprises sedimentary rocks that contain montmorillonite; and break down physically to form expansive soils. [6]

The three most important groups of clay minerals are montmorillonite, illite and kaolinite, which are crystalline hydrous aluminosilicates. The most common clay minerals with three-layer sheets are illite and montmorillonite. Illite layers are bonded together by potassium ions. Montmorillonite has a similar structure to illite. However, unlike illite there are no potassium ions present, and a large amount of water is attracted into the space between the three-sheet layers. [13]

These units combine to form sheet structures, which are usually represented graphically in the form shown in Figure 2.1. Absorption of water by clays leads to expansion. From the mineralogical standpoint, the magnitude of expansion depends upon the kind of clay minerals present, their exchangeable ions, electrolyte content of aqueous phase, and the internal structure. [16]

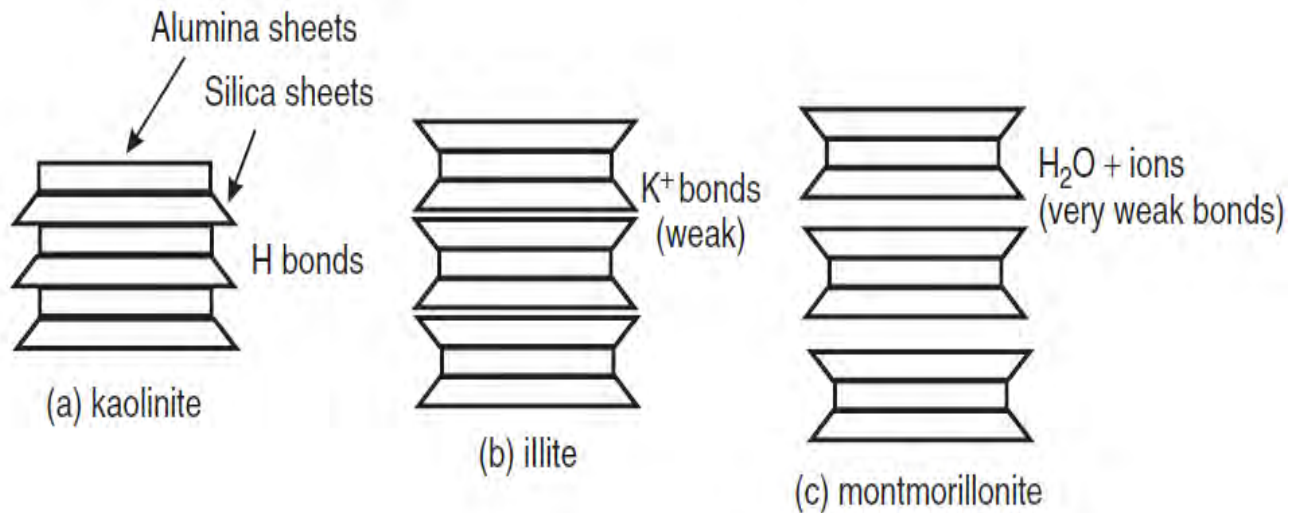


Fig 2.1 Schematic of clay minerals [16]

### 2.3.1 Formation of clay minerals

The clay minerals are formed through a complicated process from an assortment of parent materials. The alteration process that takes place on land is referred to as weathering and that on the sea floor or lake bottom as halmyrolysis. The alteration process includes disintegration, oxidation, hydration and leaching. [5]

### 2.3.2 Cation Exchange (CE)

Clay minerals have the property of absorbing certain anions (negative ions) and cations (positive ions) and retaining them in an exchangeable state. The exchangeable ions are held around the outside of the silica-alumina clay-mineral structure unit, and the exchange reaction does not affect the structure of the silica-alumina pocket. In clay minerals, the most common exchangeable cations are  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{H}^+$ ,  $\text{K}^+$ ,  $\text{NH}_4^+$  and  $\text{Na}^+$ . The existence of such charges is indicated by the ability of clay to absorb ions from the solution. Cations are more readily absorbed than anions; hence, negative charges must be predominant on the clay surface. Cation exchange is the process of replacement by excess cations. [21]

### 2.3.3 Clay Structure

The two fundamental molecular structures as basic units (blocks) of the lattice structures are silica tetrahedron and the alumina octahedron. The silica tetrahedron consists of a silicon atom surrounded tetrahedrally by four oxygen ions and the alumina octahedron consists of an aluminum atom surrounded octahedrally by six oxygen ions. When each oxygen atom is shared by two tetrahedral, a plate-shaped layer is formed. Similarly, when each aluminum atom is shared by two octahedrons, a sheet is formed. The silica and alumina sheets combined to form the basic structural units of the clay particles (or produce the various types of clays). The arrangement and the chemical composition of these sheets determine the type of clay mineral.

Kaolinite is a typical two-layer mineral having a single tetrahedral sheet joined by a single octahedral sheet. Montmorillonite is a three-layer mineral having a single octahedral sheet sandwiched between two tetrahedral sheets. Illite has similar structure with that of montmorillonite, but some of the silicon atoms are replaced by aluminum and in addition  $K^+$  ions are present between the tetrahedral sheet and adjacent crystals. [22]

## 2.4 Recognition of Expansive Soils

There are three different methods of classifying potentially expansive soils. These are Mineralogical, Indirect and Direct methods.

### 2.4.1 Mineralogical Identification

The mineralogical composition of expansive soils has an important bearing on the swelling potential. The swelling potential of any clay can be evaluated by identification of the constituent mineral of the clay. There are five techniques for mineralogical identifications and they are used in combination. [5]

#### 2.4.1.1 X-Ray Diffraction Method

This method is used in determining the proportion of the various minerals present in colloidal clay consists essentially of comparing the ratios of the intensities of diffraction lines from the different minerals with the intensities of lines from the standard substance.

#### 2.4.1.2 Differential Thermal Analysis

Is used in conjunction with X-ray diffraction and chemical analysis enables the identification of otherwise difficult materials. The use of this technique in identifying expansive soil is not always accurate.

#### 2.4.1.3 Dye Adsorption

Dyestuffs and other reagents which exhibit characteristics colors when adsorbed by clay have been used to identify clay. When a clay sample has been pretreated with acid, the color assumed by the adsorbed dye depends on the Base Exchange capacity of the various clay minerals present.

#### 2.4.1.4 Chemical Analysis

It can be a valuable supplement to other methods such as X-ray analysis in identifying clays. In the montmorillonite group of clay minerals, chemical analysis can be used to determine the nature of isomorphism and to show the origin and location of the charge on the lattice.

#### 2.4.1.5 Electron Microscope Resolution

Microscopic examination of clay minerals offers a direct observation of the material. Two clays may give the same X-ray pattern and the same differential thermal curve but will show up distinct morphological characteristics under electron microscope resolution. The main purpose of this technique is to determine mineralogical composition, texture and internal structure.

### 2.4.2 Indirect Measurement

The soil Potential Volume Change (PVC) meter is a standardized apparatus for measuring the swelling pressure of a compacted sample. The PVC meter can be used in the field or laboratory. The advantages of the test are its simplicity and standardization. [3] It should be pointed out that the PVC meter test in itself does not measure the swell potential. [5]

### 2.4.3 Direct Measurement

The most satisfactory and convenient method of determining the swelling potential and swelling pressure of an expansive clay is by direct method. Direct measurement of expansive soils can be achieved by the use of the conventional one-dimensional consolidometer. The load can be applied (7kPa) as sitting load with air by direct weight as in the case of cantilever consolidometer. The soil sample is enclosed between two porous plates and confined in a metal ring. The diameter of the sample is 50mm and its height is 20mm. Then finally the soil sample is filled with water. Vertical expansion measurement in percentage is referred to as the percent of swell (swelling potential). After the soil reaches its maximum volume increase, the sample can be reloaded and swelling pressure (the pressure that returns the volume increase to the sample initial height) determined. In the swell test important variables involved are:

- **State of sample:** For an undisturbed samples, sampling method and stress history of the sample. For remolded samples, method of compaction, curing time before and after compaction and compaction density.
- **Moisture Content:** the lower the initial moisture content the higher the swell. The initial moisture content is affected by the time allowed for the sample to remain in the ring before wetting, the extent of evaporation allowed while the sample is in the ring and the laboratory and humidity of the laboratory.
- **Surcharge Load:** Increasing the applied load will reduce the magnitude of swell.
- **Time Allowed:** The time required to fully complete the swell process may vary considerably and depends on the permeability of the clay, the molding water content, the dry density and the thickness of the sample.

The direct measurement method is the most important and reliable test on expansive soils. By standardizing the above variables, a reliable reproducible test can be obtained. [5]

## 2.5 Methods of Preventing Damages Due to Expansive Soils

In order to eliminate or minimize damages of buildings due to expansive soils are prevented by the following methods: [6]

### 2.5.1 Moisture control

The main cause of heaving and shrinkage is the fluctuation of moisture under and around the structure. In addition to the fluctuation of the ground water one should also consider free water which may seep under foundations, or the effect of evaporation which would cause moisture migration. The solution to this problem is an economical stabilizing of this soil moisture. In the other way, some on refer to keep the soils as wet as possible throughout the year. There are two methods:

- Sand drains and
- A flexible water-proof apron with sand drains. And this method is more effective and applied with reasonable success.

The other approach is providing or installation of horizontal and vertical barriers around a building in the form of membrane to prevent excessive intake of surface moisture.

Proper surface drainage and roof downspouts are must be directed to drain the water away from the structure in all directions.

### 2.5.2 Soil Stabilization

Soil stabilizations are:

- Prewetting or flooding the in-situ soil to achieve swelling prior to construction.
- Compaction control (i.e. decreasing the density of the foundation soil).
- Soil replacement (i.e. replacing the swelling soil by non-heaving soil).
- Chemical stabilization (i.e. changing the swelling characteristic of the soil by addition of chemicals).

### 2.5.3 Structural Measure

In order to minimize or to eliminate damages of structures due to heaving are dependent on the design of structure. The following three methods are used for structural measures:

- Floating Foundation (i.e. stiffened slabs, rigid rafts and flexible rafts)
- Reinforcement of brick walls and
- Foundations on piles.

### 3. Description of the Study Area

#### 3.1 Introduction

Sendafa is one of the fast growing towns and commercial centers in the Oromia Special Zone. It is 39km from Addis Ababa on Addis Ababa- Debreberhan road.

Currently Sendafa is developing by constructing buildings, new roads and industries. There is still a great potential for investment expansion in the zone mainly as a result of its location near to the capital. The relative location of the town and the coordinates of sampling areas are shown in Fig 3.1 and Table 3.1 below respectively.

The soil profile of the town varies from place to place. However, expansive soil covers different parts of the town (especially the industry zone and the newly to be establishing residential areas). From visual observation of the site soil, expansive soil related cracks and discussion with residents the soil in the town is to be expansive soil. Therefore, it is necessary to study the index properties and swelling potential and developing a relationship between these properties.

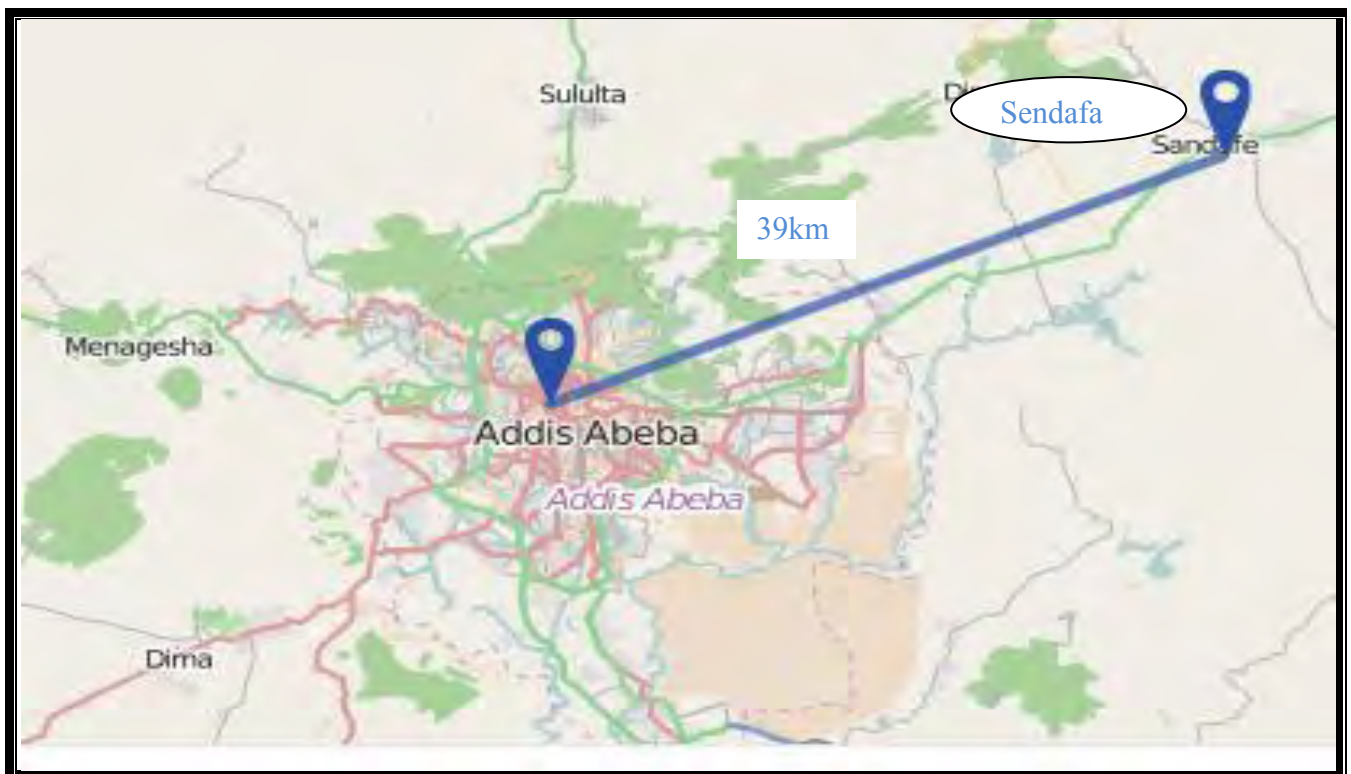


Fig3.1 Relative Location of Sendafa Town

Table3.1 Coordinates of sampling areas

S. No	Location	Pit No.	GPS Data (UTM)		
			Easting	Northing	Elevation(m)
1	BekeKebele 02	TP1	1012576.90	506112.20	2591
2	Beke St. Merry	TP2	1012367.60	507236.50	2563
3	Beke Got 3	TP3	1013220.10	507009.30	2583
4	Sendafa&Beke Border	TP4	1012440.30	504174.90	2561
5	KebtTera	TP5	1010866.60	503528.70	2536
6	High School	TP6	1010907.00	502098.50	2530
7	Amanuel Church	TP7	1010241.80	500988.80	2533
8	Zenbaba Grocery	TP8	1009678.00	500199.60	2535
9	Municipality	TP9	1011255.40	503197.20	2545
10	Dabe1	TP10	1008852.50	499747.30	2506
11	Dire Mazoria	TP11	1007732.10	498914.00	2511
12	Dabe2	TP12	1008119.10	500338.80	2509
13	Dire Café	TP13	1006692.90	498531.30	2512

## 3.2 Climate

### 3.2.1 Rain fall (Appendix C)

Data collected for 38 years show that the mean annual rain fall of Sendafa town is 1071mm. As we can observe from the table below the highest record is in the summer season time. [7]

Table3.2. Mean monthly rainfall distribution of Sendafa town (1975 - 2014)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rain Fall (mm)	17.3	23.9	48.0	69.7	54.5	102.4	312.7	322.3	90.2	20.5	5.7	4.2

### 3.2.2 Temperature

Unlike rain fall the National Metrology Agency of Ethiopia has no temperature recorder at sendafa, therefore, it is not included. [7]

## 4. Field and Laboratory Tests; and Their Results

### 4.1 Field Tests and Observations

#### 4.1.1 Introduction

ASTM D2488: Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) [18]. In this section, a method is presented to allow engineers and technicians to quickly perform USCS soil classification using a qualitative “visual-manual” approach. Here the color criterion is jointed as an additional tool to classify the soil.

#### 4.1.2 Designation of Soil Color

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

The Hue notation indicates the color’s relation to Red, Yellow, Green Blue and Purple; the Value notation indicates its lightness; and the Chroma notation indicates its strength (or departure from a neutral of the same lightness).

The colors displayed on the individual soil color charts are of constant Hue (arranged in radial, or from one chart to the next charts). Vertically, the colors become successively lighter from the bottom of the card to the top by visually equal steps, their Value increases. Horizontally they increase in Chroma to the right and become grayer to the left.

The two complementary systems of soil nomenclature are color name and the Munsell notation. Neither of these alone is adequate for all purposes.

The Munsell notation is used to supplement the color names wherever greater precision is needed, as a convenient abbreviation in field descriptions, for expression of the specific relations between colors and for statistical treatment of color data. The Munsell notation is especially useful for international correlation, since no translation of color names are needed. [15]

The color of soil is not a very reliable tool to geotechnical engineers because it can vary with moisture content. However, some colors are important, such as dark gray to black soil. These particular soils probably contain a large amount of organic material, which can be problematic in engineering designs. [14] Most of the study area soils’ colors are dark gray to black (Table4.1).

Table4.1 Color Designation of Study Area using MUNSELL Soil Color Charts when the soil sample is dry and wet. [15]

Test Pit	Depth (m)	Hue	When Dry			When Wet		
			Value	Chroma	Color	Value	Chroma	Color
TP1	1.2	10YR	4	1	Dark Gray	3	1	Very Dark Gray
	2.3	5YR	6	1	Gray	5	1	Gray
TP2	0.9	5YR	6	1	Gray	5	1	Gray
TP3	1.0	5YR	4	2	Dark Reddish Gray	3	1	Very Dark Gray
TP4	1.2	7.5YR	5	2	Brown	4	2	Dark Brown
	2.5	7.5YR	6	2	Pinkish Gray	5	2	Brown
TP5	1.5	5YR	4	1	Dark Gray	3	1	Very Dark Gray
	2.5	5Y	3	1	Very Dark Gray	2.5	2	Black
TP6	1.5	10YR	3	2	Very Dark Grayish Brown	3	1	Very Dark Gray
	3.0	5Y	4	1	Dark Gray	3	1	Very Dark Gray
TP7	1.5	10YR	6	2	Light Brownish Gray	5	1	Gray
	2.7	5YR	6	1	Gray	4	1	Dark Gray
TP8	1.3	10YR	4	2	Dark Grayish Brown	4	1	Dark Gray
TP9	1.4	2.5Y	4	2	Dark Grayish Brown	3	2	Very Dark Grayish Brown
TP10	1.5	5Y	2.5	1	Black	2	0	Black
	3.0	2.5Y	4	0	Dark Gray	3	0	Very Dark Gray
TP11	1.5	7.5YR	4	2	Dark Brown	3	2	Dark Brown
	3.0	5YR	4	2	Dark Reddish Gray	3	1	Very Dark Gray
TP12	1.5	5Y	4	1	Dark Gray	3	1	Very Dark Gray
TP13	1.7	7.5YR	3	0	Very Dark Gray	2	0	Black

## 4.2 Laboratory Tests and Results

### 4.2.1 General

Before samples are collected identification of the areas of expansive soils in the city were studied. After identification of these areas; thirteen (13) different test pits were selected from different locations. Twenty (20) disturbed and twenty (20) undisturbed samples were taken from depths (0.90m to 3.0m). In some test pits, smaller depths less than 1.50 meters were taken as other non-expansive soils were encountered at shallow depth. Sampling locations of the town are shown in Fig 4.1.

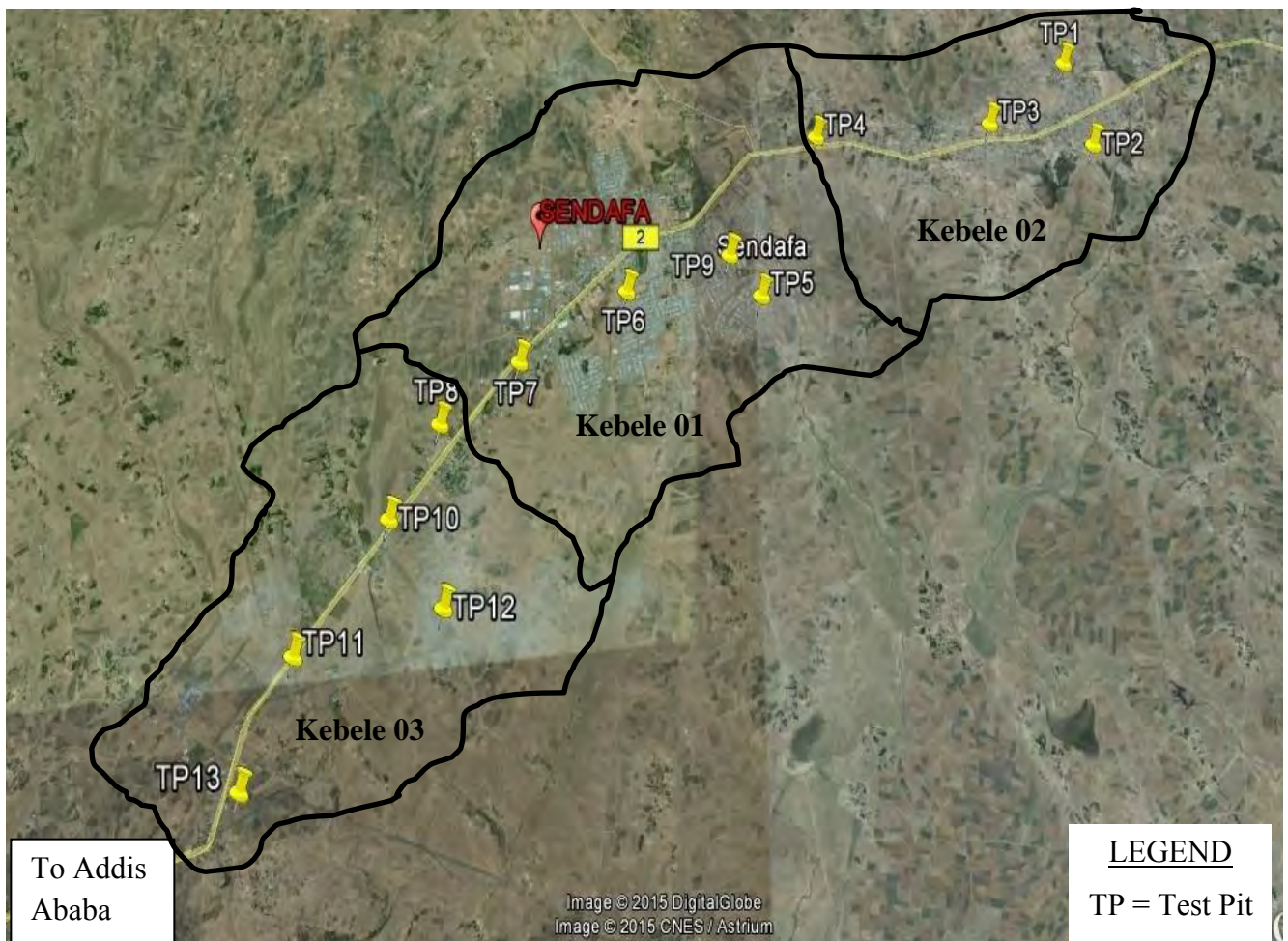


Fig4.1 Sampling Locations of study area [24]

## 4.2.2 Index Tests

### 4.2.2.1 Natural Moisture Content (NMC)

Moisture content of a soil mass is defined as the ratio of the weight of water to the weight of solids (dry weight) of the soil mass. The laboratory results of NMC of the study area fall in between (25.03 to 43.56) % (Table 4.2) and the range shows that, the soils are highly plastic. The procedure used for the determination of water content (ASTM Standards, D2216). [11]

Table 4.2 Natural Moisture Content Test Results of Soils of Study Area (Appendix A section 1)

S. No.	Location	Test Pit Design.	Depth(m)	NMC (%)
1	Beke Kebele 02	TP1	1.20	36.84
2			2.30	39.97
3	Beke St. Merry	TP2	0.90	32.96
4	Beke Got 3	TP3	1.00	27.64
5	Sendafa & Beke Border	TP4	1.20	38.02
6			2.50	37.29
7	Keft Tera	TP5	1.50	33.96
8			2.50	39.33
9	High School	TP6	1.50	37.40
10			3.00	34.85
11	Amanuel Church	TP7	1.50	25.03
12			2.70	28.97
13	Zenbaba Grocery	TP8	1.30	25.70
14	Municipality	TP9	1.40	31.02
15	Dabe1	TP10	1.50	41.34
16			3.00	39.92
17	Dire Mazoria	TP11	1.50	28.01
18			3.00	25.94
19	Dabe2	TP12	1.50	34.79
20	Dire Café	TP13	1.70	43.56

#### 4.2.2.2 Specific Gravity ( $G_s$ )

The specific gravity  $G_s$ , of soil solids is the ratio of the unit weight of solids (absolute unit weight of soil)  $\gamma_s$ , to the unit weight of water  $\gamma_o$ , at the standard temperature. The laboratory test results fall in the range (2.64 to 2.79)% (Table4.3). The specific gravity of the study area shows that, the soils are inorganic soils. For the laboratory procedure (ASTM Standards, D854) is used. [11]

Table4.3 Specific Gravity Test Results of Soils of Study Area (Appendix A section 2)

S. No.	Test Pit Design.	Location	Depth	$G_s$
1	TP1	Beke Kebele 02	1.20	2.75
2			2.30	2.79
3	TP2	Beke St. Merry	0.90	2.75
4	TP3	Beke Got 3	1.00	2.64
5	TP4	Sendafa & Beke Border	1.20	2.77
6			2.50	2.78
7	TP5	Kebt Tera	1.50	2.73
8			2.50	2.74
9	TP6	High School	1.50	2.64
10			3.00	2.70
11	TP7	Amanuel Church	1.5	2.71
12			2.7	2.74
13	TP8	Zenbaba Grocery	1.3	2.76
14	TP9	Municipality	1.4	2.73
15	TP10	Dabe 1	1.5	2.64
16			3.0	2.71
17	TP11	Dire Mazoria	1.5	2.78
18			3.0	2.79
19	TP12	Dabe 2	1.5	2.75
20	TP13	Dire Café	1.7	2.72

### 4.2.2.3 Atterberg Limits

#### 4.2.2.3.1 Introduction

Atterberg, a Swedish scientist, considered the consistency of soils in 1911, and proposed a series of tests for defining the properties of cohesive soils. These tests indicate the range of the plastic state (plasticity is defined as the property of cohesive soils which possess the ability to undergo changes of shape without rupture) and other states. He showed that if the water content of a thick suspension of clay is gradually reduced, the clay water mixture undergoes changes from a liquid state through a plastic state and finally in to a solid state. The water contents corresponding to the transition from one state to another are termed as Atterberg Limits. The Atterberg limits are all expressed by their percentages of water contents

#### 4.2.2.3.2 Liquid, Plastic and Shrinkage Limits

**Liquid Limits (LL)** is the water content in percent of the dry weight at which two sections of a pat of soil barely touch each other but do not flow together when subjected in a cup to the impact of sharp blows from below. The LL laboratory test results of the study area fall in between (62.7 to 108.0) % (Table 4.4).

**Plastic Limit (PL)** is the water content at which the soil begins to crumble when rolled out into thin threads. [8] The laboratory results of the study area falls in between (18.4 to 41.6) % (Table 4.4).

**Shrinkage Limit (SL)** is the water content below which further loss of water by evaporation does not result in a reduction of volume. As soon as the soil passes below the shrinkage limit its color becomes slightly lighter. [9] The laboratory test of SL was conducted on five selected samples as shown in Table 4.4; because nineteen of the whole samples are in similar soil classifications category (Table 5.1). The shrinkage limit test is specified in ASTM D427. [11]

**Plastic Index (IP)** the range of water content within which a soil possesses plasticity is known as the plastic. [8] At this state the soil rolled in to threads of about 3mm diameter just crumbles [2]. Laboratory test result falls in the range (42.8 to 66.2) % except TP3 which is 28.7% (Table 4.4) and which shows that the soil is under a potential of highly expansive.

The IP value shows that the soil is under a potential of very high, except TP3 at depth 1.0m, which is highly expansive. On this test pit (TP3) the IP value is less. The reason for this is that, the sample is collected from around river area and the soil is may be leached or contaminated.

Laboratory test procedures for LL, PL and PI are specified under ASTM Standards D4318. [11]

**Liquidity Index (LI)** as the water content  $w$ , of a cohesive soil approaches the lower limit of the plastic range, the stiffness and degree of compaction of the soil increases. The laboratory result falls in between (-22.18 to 19.52) percent. In Table 4.4, as the water content of a natural soil stratum is greater than the liquid limit its liquidity index becomes positive and the reverse is negative.

Table 4.4 Atterberg Limit Test Results of the study Area (Appendix A section 3)

S. No.	Test Pit	Location	Depth (m)	NMC (%)	Atterberg Limit				
					LL (%)	PL (%)	IP (%)	LI (%)	SL (%)
1	TP1	BekeKebele 02	1.2	36.84	91.5	31.4	60.1	9.07	-
2			2.3	39.97	89.6	29.8	59.8	17.02	-
3	TP2	Beke St. Merry	0.9	32.96	84.2	28.0	56.2	8.80	-
4	TP3	Beke Got 3	1.0	27.64	62.7	34.0	28.67	-22.18	12.99
5	TP4	Sendafa & Beke Border	1.2	38.02	80.4	34.3	46.0	4.97	11.94
6			2.5	37.29	88.6	30.3	58.3	12.01	-
7	TP5	Keft Tera	1.5	33.96	90.6	34.8	55.8	-1.42	-
8			2.5	39.33	86.3	32.7	53.5	12.35	10.11
9	TP6	High School	1.5	37.40	78.4	31.8	46.6	11.98	-
10			3.0	34.85	82.5	30.4	52.2	8.55	17.86
11	TP7	Amanuel Church	1.5	25.03	86.6	29.9	56.7	-8.52	-
12			2.7	28.97	83.5	28.9	54.6	0.10	-
13	TP8	Zenbaba Grocery	1.3	25.70	87.0	29.9	57.1	-7.36	-
14	TP9	Municipality	1.4	31.02	78.8	31.6	47.2	-1.18	9.89
15	TP10	Dabe 1	1.5	41.34	108.0	40.0	68.0	1.96	-
16			3.0	39.92	97.0	33.3	63.7	10.32	-
17	TP11	Dire Mazoria	1.5	28.01	67.6	18.4	49.2	19.52	-
18			3.0	25.94	65.8	23.0	42.8	6.76	-
19	TP12	Dabe 2	1.5	34.79	89.8	29.6	60.2	8.57	-
20	TP13	Dire Café	1.7	43.56	107.8	41.6	66.2	2.91	-

#### 4.2.2.4 Grain Size Analysis (GSA)

Natural soils are mixtures of particles of various sizes and it is necessary to have a nomenclature for the various fractions comprising particles lying between certain specified size limits. [2]

According to the grain-size distribution analysis the laboratory result of soils of study area is gravel on average 1.08% which ranges from (0.03 to 10.78) %; sand (0.62 to 6.90) %; silt (24.37 to 64.01) %; clay (35.37 to 74.33) and percent passed sieve number 200 (or 0.075mm sieve opening) ( $P_{200}$ ) (85.55 to 99.38) % (Table 4.5). It is observed that from the grain size ranges above the soil has high content of clay.

Table 4.5 Grain Sizes Analysis Results of soils of study area (Appendix A section 4)

S. No.	Test Pit	Location	Depth	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	$P_{200}$ %
1	TP1	Beke Kebele 02	1.20	1.77	3.70	38.14	56.39	94.53
2			2.30	10.78	3.67	39.10	46.45	85.55
3	TP2	Beke St. Merry	0.90	2.44	2.93	38.83	55.80	94.63
4	TP3	Beke Got 3	1.00	0.62	4.06	51.57	43.75	95.32
5	TP4	Sendafa & Beke	1.20	0.15	2.26	53.95	43.64	97.59
6		Border	2.50	0.07	0.97	52.63	46.33	98.96
7	TP5	Kebt Tera	1.50	0.16	1.89	31.18	66.77	97.95
8			2.50	0.31	2.26	37.57	59.86	97.43
9	TP6	High School	1.50	0.03	0.62	64.01	35.37	99.38
10			3.00	1.63	3.84	37.07	57.46	94.53
11	TP7	Amanuel Church	1.50	0.48	1.99	47.45	50.08	97.53
12			2.70	0.17	2.11	37.26	60.46	97.72
13	TP8	Zenbaba Grocery	1.30	0.27	2.73	50.29	46.71	97.00
14	TP9	Municipality	1.40	0.77	2.79	34.51	61.94	96.44
15	TP10	Dabe 1	1.50	0.06	1.24	24.37	74.33	98.70
16			3.00	0.24	0.91	27.61	71.23	98.84
17	TP11	Dire Mazoria	1.50	0.14	1.02	39.39	59.45	98.84
18			3.00	0.11	3.31	48.38	48.20	96.58
19	TP12	Dabe 2	1.50	0.72	3.54	31.95	63.79	95.74
20		Dire Café	1.70	0.71	6.90	24.84	67.56	92.39

#### 4.2.2.5 Free Swell ( $F_s$ )

The free swell test consists of placing a known volume of dry soil passing the No. 40 sieve into a graduated cylinder filled with water and measuring the swelled volume after it has completely settled. [3]

$$F_s = \frac{V - V_o}{V_o} \times 100$$

Where:  $F_s$  = Free Swell

$V$  = Final Volume after swell

$V_o$  = Volume of dry soil

The laboratory test results fall in between (65.5 to 186) % (Table4.6). And of the 20 soil samples values of 85% are above 100% which indicates that the soil has a potential to expand.

Table4.6 Free Swell Test Results of Soils of the Study Area (Appendix A section 5)

S. No.	Location	Test Pit Design.	Depth	Free swell (%)
1	Beke Kebele 02	TP1	1.20	114.5
2			2.30	124.0
3	Beke St. Merry	TP2	0.90	117.0
4	Beke Got 3	TP3	1.00	65.5
5	Sendafa & Beke Border	TP4	1.20	120.5
6			2.50	126.0
7	Kebt Tera	TP5	1.50	112.5
8			2.50	123.5
9	High School	TP6	1.50	106.5
10			3.00	118.0
11	Amanuel Church	TP7	1.5	120.5
12			2.7	106.0
13	Zenbaba Grocery	TP8	1.3	142.5
14	Municipality	TP9	1.4	140.0
15	Dabe 1	TP10	1.50	123.5
16			3.00	111.0
17	Dire Mazoria	TP11	1.50	71.0
18			3.00	68.3
19	Dabe 2	TP12	1.50	128.5
20	Dire Café	TP13	1.70	186.0

### 4.2.3 Consolidation Tests

The most important laboratory test on expansive soils is the swell test. The standard one-dimensional consolidation test apparatus have been used to carry out these tests.

#### 4.2.3.1 Swelling Pressure ( $P_s$ ) and Swelling Potential ( $S_p$ )

Swelling potential of a soil is the amount of vertical swell (expressed as percent of initial sample thickness) obtained under a particular surcharge (usually 7kPa).

In this test, the specimen is inundated and allowed to swell vertically at the seating pressure (7kPa applied by the weight of the top porous stone and load plate) until primary swell is completed. Then the specimen is loaded after the primary swell has occurred until its initial void ratio or height is obtained. From the laboratory test the swelling pressure and potential of the study area are shown in Table4.7 below.

Table4.7 Swelling Potential and Pressure Test Results of Soils of Study Area (Appendix A section 6)

S. No.	Test Pit Designation	Depth (m)	Swelling Test		Unit Weight	
			Swelling Potential (%)	Swelling Pressure, kPa	Dry Density (kN/m <sup>3</sup> )	Bulk Density (kN/m <sup>3</sup> )
1	TP1	1.20	6.93	225.00	12.45	17.78
2		2.30	9.75	216.67	12.93	17.76
3	TP2	0.90	11.35	255.56	12.90	17.68
4	TP3	1.00	1.25	50.00	14.34	18.16
5	TP4	1.20	2.91	83.33	12.49	17.18
6		2.50	1.52	70.00	12.95	17.56
7	TP5	1.50	3.66	288.57	13.43	17.73
8		2.50	1.09	37.63	12.09	16.36
9	TP6	1.50	3.45	126.89	12.16	16.74
10		3.00	2.99	133.61	12.10	16.14
11	TP7	1.50	11.74	378.33	15.48	19.43
12		2.70	7.34	317.91	13.99	18.08
13	TP8	1.30	11.66	354.63	15.20	18.88
14	TP9	1.40	8.53	361.90	14.16	18.36
15	TP10	1.50	11.50	359.91	11.26	15.54
16		3.00	10.10	443.74	12.13	16.65
17	TP11	1.50	10.76	369.12	16.22	19.48
18		3.00	6.90	292.46	14.48	17.43
19	TP12	1.50	10.75	347.03	13.72	18.03
20	TP13	1.70	6.24	183.89	10.83	14.77

All index properties and swelling characteristics laboratory test results of Sendafa town expansive soils are summarized in Table4.8 below.

Table4.8 Summary of Laboratory Test Results of the Study Area

Test Pit	Depth (m)	Gs	NMC (%)	$\gamma_d$ (kN/m <sup>3</sup> )	Atterberg Limit			Swelling Test		Grain Size Test	
					LL (%)	PL (%)	PI (%)	Swelling Potential (%)	Swelling Pressure, kPa	% Clay	P <sub>200</sub> %
TP1	1.20	2.75	36.84	12.45	91.46	31.39	60.06	6.93	225.00	56.39	94.53
	2.30	2.79	39.97	12.93	89.61	29.79	59.83	9.75	216.67	46.45	85.55
TP2	0.90	2.75	32.96	12.90	84.18	28.02	56.16	11.35	255.56	55.80	94.63
TP3	1.00	2.64	27.64	14.34	62.67	34.00	28.67	1.25	50.00	43.75	95.32
TP4	1.20	2.77	38.02	12.49	80.36	34.31	46.04	2.91	83.33	43.64	97.59
	2.50	2.78	37.29	12.95	88.59	30.29	58.30	1.52	70.00	46.33	98.96
TP5	1.50	2.73	33.96	13.43	90.57	34.75	55.82	3.66	288.57	66.77	97.95
	2.50	2.74	39.33	12.09	86.26	32.72	53.54	1.09	37.63	59.86	97.43
TP6	1.50	2.64	37.40	12.16	78.42	31.82	46.60	3.45	126.89	35.37	99.38
	3.00	2.70	34.85	12.10	82.55	30.39	52.16	2.99	133.61	57.46	94.53
TP7	1.50	2.71	25.03	15.48	86.60	29.86	56.74	11.74	378.33	50.08	97.53
	2.70	2.74	28.97	13.99	83.50	28.92	54.59	7.34	317.91	60.46	97.72
TP8	1.30	2.76	25.70	15.20	87.01	29.90	57.11	11.66	354.63	45.55	97.00
TP9	1.40	2.73	31.02	14.16	78.79	31.58	47.21	8.53	361.90	61.94	96.44
TP10	1.50	2.64	41.34	11.26	108.0	40.00	68.00	11.50	359.91	74.33	98.70
	3.00	2.71	39.92	12.13	97.04	33.34	63.70	10.10	443.74	71.23	98.84
TP11	1.50	2.78	28.01	16.22	67.60	18.40	49.20	10.76	369.12	59.45	98.84
	3.00	2.79	25.94	14.48	65.80	23.05	42.76	6.90	292.46	48.20	96.58
TP12	1.50	2.75	34.79	13.72	89.80	29.63	60.17	10.75	347.03	63.79	95.74
TP13	1.70	2.72	43.56	10.83	107.8	41.64	66.15	6.24	183.89	67.56	92.39

## 5. Soil Classification

### 5.1 Introduction

The main objective of soil classification is to divide the soil into groups so that all the soils in a particular group have similar characteristics by which they may be identified. Soils consist of grains, usually rock fragments or clay particles, with water and gas, usually air or water vapor, in the void spaces between the grains. If there is no gas present the soil is saturated and if there is no water it is dry. If there is both water and gas in the voids the soil is unsaturated.

The mechanical properties of a soil (i.e. its strength and stiffness) depend principally on the nature of the grains (i.e. what they are) and the state of the soil (i.e. how the grains are packed together).

It is important to distinguish between soil description and soil classification. Description is simply what you see and how the soil responds to simple tests. A classification is a scheme for separating soils into broad groups, each with broadly similar behavior. There are various classification schemes for different purposes: these are agricultural classifications based on how soils support crops and geological classifications based on the age of the deposit or the nature of the grains. For civil engineering purposes soil classifications should be based mainly on mechanical behavior. [9]

For engineering purposes, there are two major systems that presently used are American Association of State Highway and Transportation Officials (AASHTO) Classification System and the Unified Soil Classification System (USCS).

### 5.2 AASHTO Classification System

In this soil classification system, soils are generally placed in seven major groups: A-1, A-2, A-3, A-4, A-5, A-6 and A-7. Group A-1 is divided into two subgroups: A-1-a and A-1-b. Group A-2 is divided into four subgroups: A-2-4, A-2-5, A-2-6 and A-2-7. Soils under group A-7 are also divided into two subgroups: A-7-5 and A-7-6. This system is also presently included in ASTM under test designation D-3284. [13] The required parameters for this classification system are grain size analysis, liquid limit and plastic index. [14]

By referring Table 5.1 The study area soils fall under A-7-5 and A-7-6 groups and plastic clay soil type, and it uses fair to poor sub grade rating material. Any soil containing fine-grained material is further identified by its group index; the higher the index, the less suitable the soil. The group index is calculated from the formula.

$$GI = 0.2a + 0.005ac + 0.01bd$$

Where: - a – That portion of percentage of particles passing No. 200 sieve greater than 35% and not exceeding 75%, expressed as positive whole number (0 to 40)

b – That portion of percentage of particles passing No. 200 sieve greater than 15% and not exceeding 55%, expressed as positive whole number (0 to 40)

c – That portion of the liquid limit greater than 40 and not exceeding 60, expressed as positive whole number (0 to 20)

d – That portion of the plastic index greater than 10 and not exceeding 30, expressed as positive whole number (0 to 20)

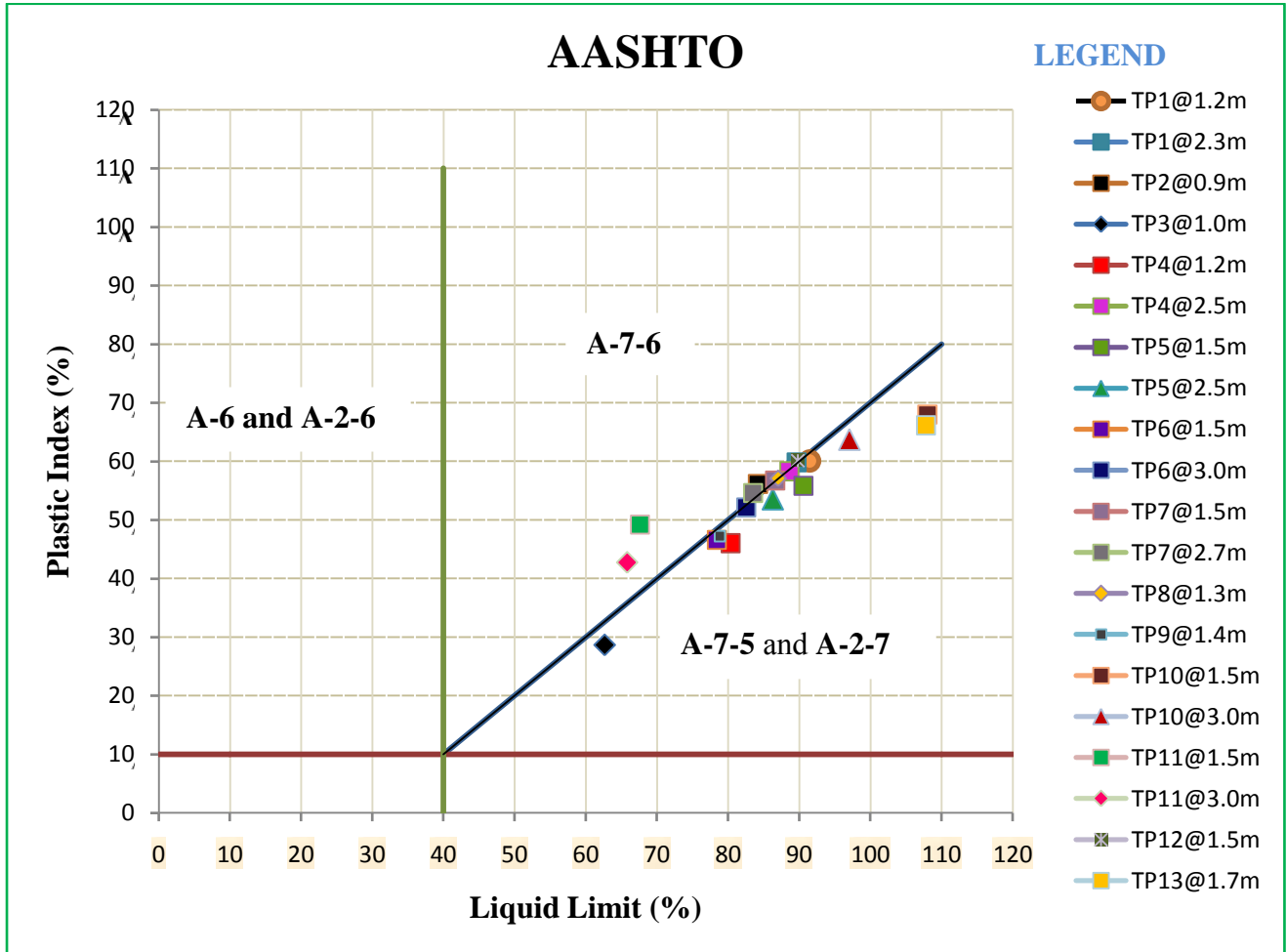


Fig. 5.1 Classification of the Soil of the Study Area According To AASHTO System

### 5.3 Unified Soils Classification System

The Unified soil classification system was originally developed by A. Casagrande and adopted by the U.S. Corps of Engineers in 1942 as „Airfield Classification“. It was later revised for universal use and redesignated as the „Unified Soil Classification“ in 1957. [1]

1. Coarse-grained soils with up to 50% passing No. 200 ASTM Sieve (No. 75- $\mu$  IS Sieve)
2. Fine-grained soils with more than 50% passing No. 200 ASTM Sieve (No. 75- $\mu$  IS Sieve) [11]
3. Organic soils

Each soil component is assigned a symbol as follows:

Fine-grained soils

Gravels: G	Silt: M (from the Swedish word „Mo“ for silt)	Organic: O
Sand: S	Clay: C	Peat: Pt

#### 5.3.1 Plasticity Chart

Using the Atterberg limits, the plasticity chart was developed (after Casagrande 1932) and is used in the USCS to classify soils. The plasticity chart is a plot of LL versus IP. The study area soils are fall under inorganic clays of high plasticity.

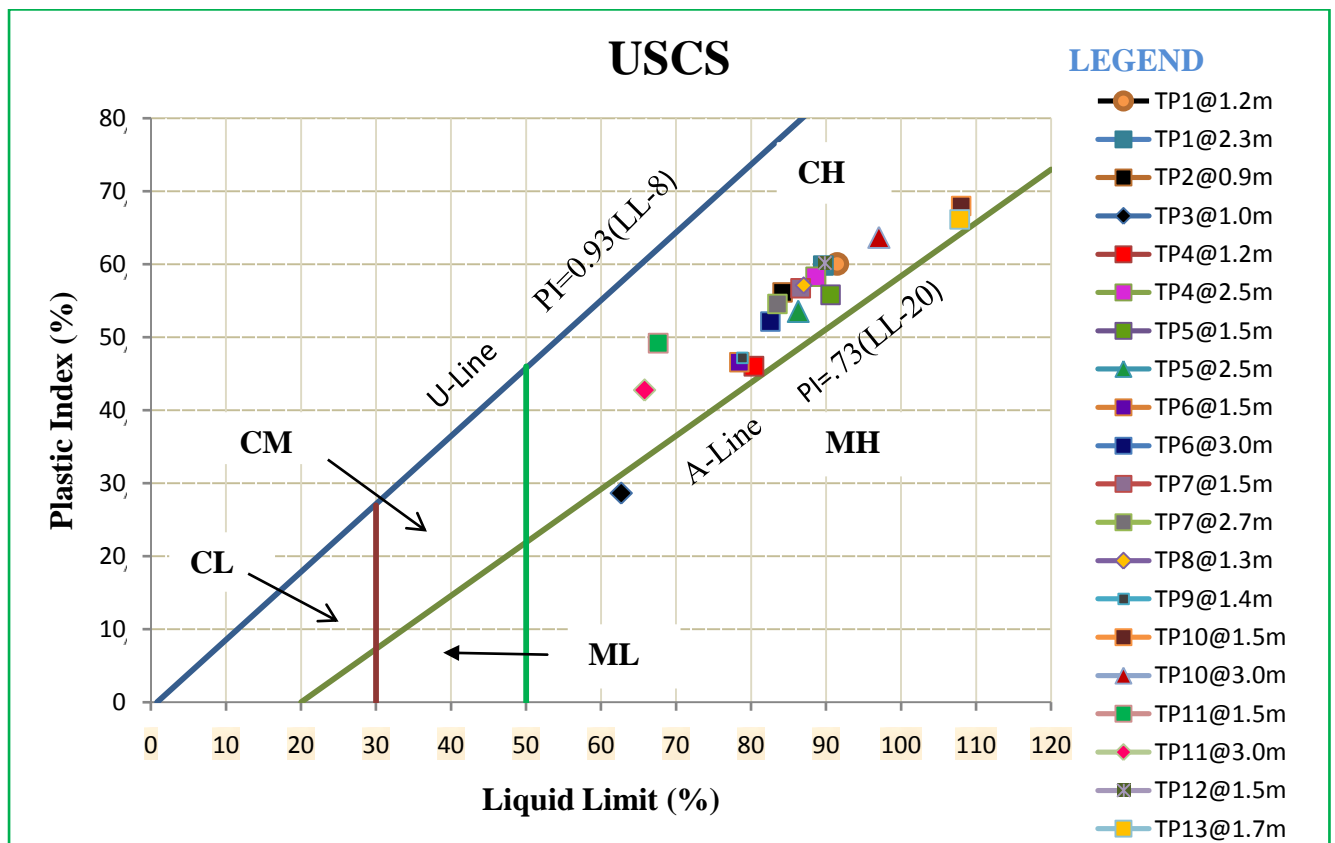


Fig.5.2 Plasticity Chart according to USCS

### 5.3.2 Activity

The presence of even small amounts of certain clay minerals can have significant effect on the properties of the soil. The identification of clay minerals requires special techniques and equipment. The techniques include microscopic examination, X-ray diffraction, differential thermal analysis, optical property determination and electron micrographic. Even qualitative identification of the various clay minerals is adequate for many engineering purposes. Detailed treatment of clay minerals is considered out of scope of the present text. An indirect method of obtaining information on the type and effect of clay mineral in a soil is to relate plasticity to the quantity of clay-size particles. It is known that for a given amount of clay mineral the plasticity resulting in a soil will vary for the different types of clays. Activity ( $A_c$ ) is defined as the ratio of plasticity index (IP) to the percentage of clay-sizes(C) (*i.e.* particles of size less than 0.002mm). Activity can be determined from the results of the standard laboratory tests such as the wet analysis, liquid limit and plastic limit. Clays containing Kaolinite will have relatively low activity and those containing Montmorillonite will have high activity. [1]

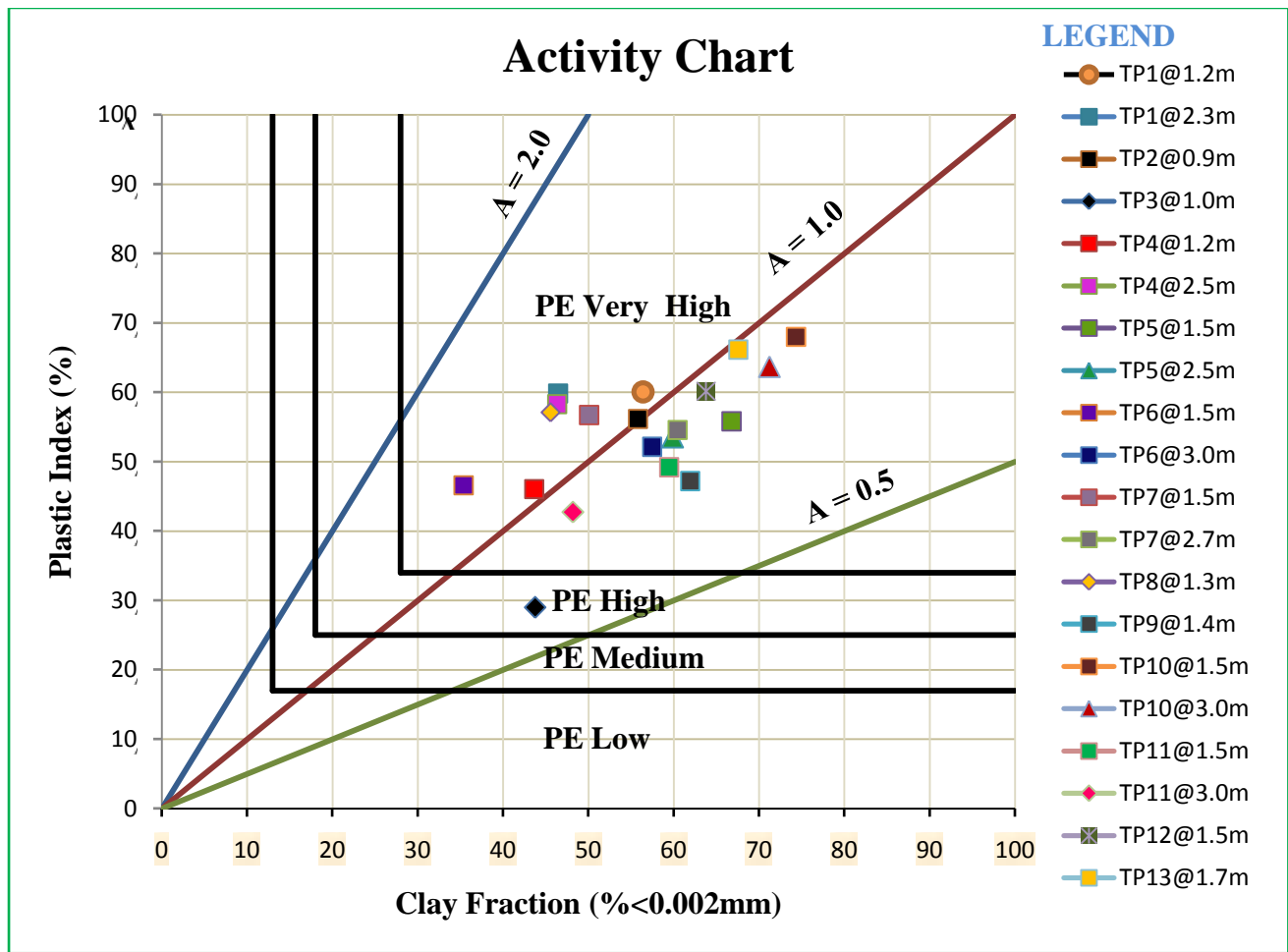


Fig. 5.3 Activity Chart of Study Area (V.D Merwe)

The plasticity chart devised after Casagrande is used for identification of fine grained soils. Table 5.1 shows that the AASHTO and USCS Classification of study area soils.

Table5.1 AASHTO and USCS Classification of Study Area Soil Test Results

S. No.	Test Pit Design.	Depth (m)	Atterberg Limits			Classification		
			LL (%)	PL (%)	Ip (%)	AASHTO		USCS
						classification	GI	
1	TP1	1.20	91.5	31.4	60.1	A-7-6	20	CH
2		2.30	89.6	29.8	59.8	A-7-5	20	CH
3	TP2	0.90	84.2	28.0	56.2	A-7-5	20	CH
4	TP3	1.00	62.7	34.0	28.7	A-7-5	20	MH
5	TP4	1.20	80.4	34.3	46.0	A-7-6	20	CH
6		2.50	88.6	30.3	58.3	A-7-6	20	CH
7	TP5	1.50	90.6	34.8	55.8	A-7-6	20	CH
8		2.50	86.3	32.7	53.5	A-7-6	20	CH
9	TP6	1.50	78.4	31.8	46.6	A-7-6	20	CH
10		3.00	82.5	30.4	52.2	A-7-6	20	CH
11	TP7	1.50	86.6	29.9	56.7	A-7-5	20	CH
12		2.70	83.5	28.9	54.6	A-7-5	20	CH
13	TP8	1.30	87.0	29.9	57.1	A-7-5	20	CH
14	TP9	1.40	78.8	31.6	47.2	A-7-6	20	CH
15	TP10	1.50	108.0	40.0	68.0	A-7-6	20	CH
16		3.00	97.0	33.3	63.7	A-7-6	20	CH
17	TP11	1.50	67.6	18.4	49.2	A-7-5	20	CH
18		3.00	65.8	23.0	42.8	A-7-5	20	CH
19	TP12	1.50	89.8	29.6	60.2	A-7-5	20	CH
20	TP13	1.70	107.8	41.6	66.2	A-7-6	20	CH

## 5.4 Sources of Error for Soil Classification

Error in soil classification is a result of error in the LL and IP or gradation tests. The most common error in LL and IP testing is allowing the plasticity index specimens to sit too long before obtaining their moist weight. This error would result in underestimating PL and overestimating IP, and may result in erroneously classifying low-plasticity soils as high-plasticity soils. The most common error in gradation testing is underestimating the percent of fines in soil by relying on mechanical sieve analysis rather than wet sieve analysis to calculate fines content. This may result in erroneously classifying silty or clayey sands and gravels as clean sands and gravels. [18]

Regarding to my research errors in LL and IP are avoided by weighting the samples immediately after the test and the gradation testing is conducted using wet sieve analysis.

## 5.5 Expansion Properties of Soils

Expansive soils are found extensively in tropical areas. These soils are characterized by the presence of a large proportion of highly active clay minerals of the Montmorillonite group which are responsible for the pronounced volume change capability of the soils. These soils are distributed geographically very widely covering large areas. Hence, identification and classification of such soils by degree of expansion using liquid limit and plasticity index is essential. Different researchers and code classified this soil based on liquid limit and plastic index as follows:

### 5.5.1 Using Liquid Limits

According to Chen, if the liquid limit is in between 40 to 60 the soil has high degree of expansion and if  $LL > 60\%$  it has very high degree of expansion. As a result, the whole soils of study area are grouped under very high degree of expansion.

The IS 1498 code shows, if the LL is (50-70) % high and (70-90) % Very high degree of expansion. [23] In this case except TP3 and TP11 all samples are under Very high degree of expansion.

### 5.5.2 Using Plastic Index

The plastic index range from 23 to 45% (Holtz & Gibbs), 20 to 55% (Chen) and 23 to 32% (IS 1498 code) classified the soil in high degree of expansion.

If plastic index of the soil is greater than 32 %, it is under very high expansion category (Holtz & Gibbs and IS 1498), but Chen estimates when plastic index exceeds 35%. [23] As a result, the study area soils are under very high potential of expansiveness, except TP3 is high degree of expansion due to its low consistency Table 5.2.

Table5.2 Prediction of Degree of Expansion by Liquid Limits and Plastic Index of Study Area Soil

Test Pit	Depth (m)	Atterberg Limit			By LL (%)		By IP (%)		
		LL (%)	PL (%)	IP (%)	Chen	IS 1498	Holtz & Gibbs	Chen	IS 1498
TP1	1.20	91.46	31.39	60.06	Very High	Very High	Very High	Very High	Very High
	2.30	89.61	29.79	59.83	Very High	Very High	Very High	Very High	Very High
TP2	0.90	84.18	28.02	56.16	Very High	Very High	Very High	Very High	Very High
TP3	1.00	62.67	34.00	28.67	Very High	High	High	High	High
TP4	1.20	80.36	34.31	46.04	Very High	Very High	Very High	Very High	Very High
	2.50	88.59	30.29	58.30	Very High	Very High	Very High	Very High	Very High
TP5	1.50	90.57	34.75	55.82	Very High	Very High	Very High	Very High	Very High
	2.50	86.26	32.72	53.54	Very High	Very High	Very High	Very High	Very High
TP6	1.50	78.42	31.82	46.60	Very High	Very High	Very High	Very High	Very High
	3.00	82.55	30.39	52.16	Very High	Very High	Very High	Very High	Very High
TP7	1.50	86.60	29.86	56.74	Very High	Very High	Very High	Very High	Very High
	2.70	83.50	28.92	54.59	Very High	Very High	Very High	Very High	Very High
TP8	1.30	87.01	29.90	57.11	Very High	Very High	Very High	Very High	Very High
TP9	1.40	78.79	31.58	47.21	Very High	Very High	Very High	Very High	Very High
TP10	1.50	108.0	40.00	68.00	Very High	Very High	Very High	Very High	Very High
	3.00	97.04	33.34	63.70	Very High	Very High	Very High	Very High	Very High
TP11	1.50	67.60	18.40	49.20	Very High	High	Very High	Very High	Very High
	3.00	65.80	23.05	42.76	Very High	High	Very High	Very High	Very High
TP12	1.50	89.80	29.63	60.17	Very High	Very High	Very High	Very High	Very High
TP13	1.70	107.8	41.64	66.15	Very High	Very High	Very High	Very High	Very High

## 6. Swelling Potential Prediction Model

### 6.1 General

The main purpose of this research is developing relationship between index properties and swelling characteristics of Sendafa expansive soils.

This chapter deals regression and correlation analysis using least-squares method. At the end using the laboratory test results the main objective of the thesis is analyzed.

### 6.2 Regression and Correlation

Many problems in engineering and science involve exploring the relationship between two or more variables. Regression analysis is a statistical technique that is very useful to model or study these types of problems. [17] One of the main purposes of curve fitting is to estimate one of the variables (the dependent variable) from the other (the independent variable). The process of estimation is often referred to as regression. If Y is to be estimated from X by means of some equation we call the equation a regression equation of Y on X. [19]

### 6.3 The Method of Least-Squares

In this analysis, the author has used the least-square method as regression method. Generally, more than one curve of a given data will appear to fit a set of data. To avoid individual judgment in constructing lines, parabolas, or other curves, it is necessary on their best-fittings. A curve having this property is called least-square regression curve or least-square curve. Out of all possible regression curves the least square curve has the smallest standard error of estimate. [19]

### 6.4 Linear Correlation Coefficient ( $R^2$ and Adjusted $R^2$ )

The sample correlation coefficient R measures how well the least-squares regression line fits the sample data. If the total variation is all explained by the regression line, (i.e.  $R^2 = 1$  or  $R = \pm 1$ ), we say that there is perfect linear correlation (and in such a case also perfect linear regression). In other words, a perfect fit would result in  $R^2 = 1$ , and a very good fit results in a value near 1. A very poor fit results in a value of  $R^2$  close to 0. As more variables are included,  $R^2$  increases. For best multiple regression equation we use adjusted coefficient of determination (Adj.  $R^2$ ) instead of  $R^2$ . The Adj.  $R^2$  is the multiple coefficient of determination  $R^2$  modified to account for the number of variables and the sample size. [20]

## 6.5 P-Value

The P-Value is a measure of the overall significance of regression equation. If the displayed P-value of 0.000 (rounded to three decimal places) is small, indicating that the multiple regression equation has good overall significance and is usable for prediction or it makes sense to predict. [20]

## 6.6 Single Linear Regression Analysis

The case of single linear regression we have to consider a single predictor or variable  $X$  and a dependent or response variable  $Y$ . Suppose that the true relationship between  $Y$  and  $X$  is a straight line and that the observation  $Y$  at each level of  $X$  is a random variable. The general representation of single linear regression model is:

$$Y = a_0 + a_1X + c_1 \quad (6.1)$$

Where, the slope ( $a_1$ ) and intercept ( $a_0$ ) of the single linear regression model are called regression coefficients and  $c_1$  is residual term.

Before analyzing the single linear regression analysis the swelling potential is taken as the dependent variable whereas the moisture content, dry density, liquid limit, plastic limit, plastic index, percent finer than 0.075mm and clay content are independent variables. And a scatter plot is created by using the Excel Spreadsheet, in order to study the relationships developed between the dependent and the independent variables so as to determine the model that best suits the test results (see Appendix B).

Single regression correlated equations between swelling potential and index parameters are tabulated as follows in Table 6.1 below.

Table 6.1 Developed Equations using Simple Linear Regression Method (Appendix C section 1)

S. No	Independent Variables	R <sup>2</sup> (%)	P-Value	Developed Equation	Descriptions	Equation No.	Order of Equation	Order of accuracy
1	w (%)	0.051	0.186094	$Sp = -0.154237065w + 12.28463872$	Not good: R <sup>2</sup> is << smaller & P-value is small, n = 20	EQ1	1	6 <sup>th</sup>
2	$\gamma_d$ (kN/m <sup>3</sup> )	0.108	0.357318	$Sp = 0.8957015\gamma_d - 4.8617355$	Not good: R <sup>2</sup> is << smaller & P-value is large, n = 20	EQ2	1	3 <sup>rd</sup>
3	LL (%)	0.070	0.603731	$Sp = 0.087420609LL - 0.438611286$	Not good: R <sup>2</sup> is << smaller & P-value is large, n = 20	EQ3	1	4 <sup>th</sup>
4	PL (%)	0.058	0.171240	$Sp = -0.185436858PL + 12.80486788$	Not good: R <sup>2</sup> is << smaller & P-value is small, n = 20	EQ4	1	5 <sup>th</sup>
5	IP (%)	0.227	0.225184	$Sp = 0.204749717IP - 4.064072831$	Relatively Better: R <sup>2</sup> is bigger and P-value is small, n = 20	EQ5	1	1 <sup>st</sup>
6	LI (%)	0.002	0.423152	$Sp = 0.0184951LI + 6.931017$	Not good: R <sup>2</sup> is << smaller & P-value is large, n = 20	EQ6	1	8 <sup>th</sup>
7	Clay (%)	0.108	0.559104	$Sp = 0.121780785\%Clay + 0.2355524$	Not good: R <sup>2</sup> is << smaller & P-value is large, n = 20	EQ7	1	2 <sup>nd</sup>
8	P200 (%)	0.015	0.529919	$Sp = -0.150990694P200 + 21.558753$	Not good: R <sup>2</sup> is << smaller & P-value is large, n = 20	EQ8	1	7 <sup>th</sup>
9	SL (%)	0.076	0.525092	$Sp = -0.258625SL + 6.602233$	Not compared with others, n = 5	EQ9	1	9 <sup>th</sup>

## 6.7 Multiple Linear Regression Analysis

Many applications of regression analysis involve situations in which there is more than one independent variable. In this section we focus on the multiple regression equation, the value of adjusted  $R^2$  and the P-value. The general form of the multiple linear regression equation is:

$$Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_nX_n + c_2 \quad (6.2)$$

Where, coefficients ( $b_0$ ), ( $b_1$ ), ( $b_2$ ) and ( $b_n$ ) are termed multiple regression coefficients and  $c_2$  is residual term.

After correlating the swelling potential in different combination with two and more index properties parameters, some better equations are selected and summarized in Table 6.2 below.

From the multiple linear regression analysis (plasticity index and moisture content), (dry density and plastic index) and (dry density, liquid limits and plastic limits) have a good combination effects with swelling potential of study area soil.

The main criterion to select these equations are the regression coefficients ( $\text{Adj. } R^2$ ), the overall significance (P-value), mean average error (ME) and standard error (SE).

The output of regression analysis of correlating Sp with (IP and w), (IP &  $\gamma_d$ ) and ( $\gamma_d$ , LL & PL) are given by the following multiple linear equations.

### **EQ10: Correlation of Swelling Potential (Sp) with Plasticity Index (IP) and Moisture Content (w)**

$$\text{Sp} = 0.365068\text{IP} - 0.467818\text{w} + 3.221451$$

$$(\text{Adj. } R^2 = 0.51, \text{P-Value} = 0.1556, \text{MPE} = 33.62 \ \& \ \text{SE} = 2.7222)$$

The results of the statistical out-put shows that the relationship developed between Sp with IP and w is relatively reasonable because (P-Value = 0.1556) is small and this shows existence of good relationship between the correlated variables, and the  $\text{Adj. } R^2$  value of the multiple linear regression analysis is improved than the  $R^2$  value of the single linear regression analysis. This equation has 2<sup>nd</sup> order of accuracy.

### **EQ11: Correlation of Swelling Potential (Sp) with Plasticity Index (IP) and Dry Density ( $\gamma_d$ )**

$$\text{Sp} = 1.805385\gamma_d + 0.328569\text{Ip} - 34.7185826$$

$$(\text{Adj. } R^2 = 0.53, \text{P-Value} = 0.00101, \text{MPE} = 34.82 \ \& \ \text{SE} = 2.2658)$$

The results of the statistical out-put shows that the relationship developed between Sp with IP and  $\gamma_d$  is reasonable because (P-Value = 0.00101) is too small and this shows existence of better relationship between the correlated variables, and the  $\text{Adj. } R^2$  value of the multiple linear regression analysis is improved than the  $R^2$  value of the single linear regression analysis. This equation has 1<sup>st</sup> order of accuracy.

**EQ12: Correlation of Swelling Potential (Sp) with Dry Density ( $\gamma_d$ ), Liquid Limits (LL) and Plastic Limits (PL)**

$$Sp = 1.743358\gamma_d + 0.328894LL - 0.353205PL - 33.1550$$

$$Adj. R^2 = 0.50, P\text{-Value} = 0.0404, MPE = 34.63 \ \& \ SE = 2.7381$$

The results of the statistical out-put shows that the relationship developed between Sp with IP and  $\gamma_d$  is relatively reasonable because (P-Value = 0.0404) is small and this shows existence of good relationship between the correlated variables, and the Adj.R<sup>2</sup> value of the multiple linear regression analysis is improved than the R<sup>2</sup> value of the single linear regression analysis. This equation has 3<sup>rd</sup> order of accuracy.

Table6.2 Developed Equations using Multiple Linear Regression Method (Appendix C section 2)

S. No	Independent Variables	Adj. R <sup>2</sup> (%)	P-Value	Developed Equation	Equation No.	Order of Equation	Order of accuracy
1	w & IP	50.83	0.15563	Sp = 0.365068IP - 0.467818w + 3.221451	EQ10	2	2 <sup>nd</sup>
2	IP & $\gamma_d$	53.13	0.00101	Sp = 1.805385 $\gamma_d$ + 0.328569IP - 34.7185826	EQ13	2	1 <sup>st</sup>
3	$\gamma_d$ , LL & PL	50.26	0.04046	Sp = 1.743358 $\gamma_d$ + 0.328894LL - 0.353205PL - 33.155015	EQ19	3	3 <sup>rd</sup>

Where: - Sp – Swelling Potential (%)

w – Natural moisture content (%)

IP – Plastic Index (%)

LL – Liquid limit (%)

$\gamma_d$  – Dry density (KN/m<sup>3</sup>)

PL – Plastic limit (%)

R<sup>2</sup> and Adj. R<sup>2</sup> – Correlation coefficients (%)

P-Value – Overall significance of the regression

n – Number of correlated samples

EQ – Equation

## 6.8 Previous Developed Models

There are different empirical equations developed to determine the swelling behavior of the soil. Some of them are presented by different researchers as follows:

- a) Anderson et al [6]

$$\mathbf{Sp} = 0.23\mathbf{IP} - 3.12 \dots\dots\dots (6.3)$$

- b) Seed, Woodward and Lundgren established the following simplified relationship [5]

$$\mathbf{Sp} = 60\mathbf{K} (\mathbf{IP})^{2.44} \dots\dots\dots (6.4)$$

- c) Holtz, Seed and Chen [5]

$$\mathbf{Sp} = 0.2558e^{0.0838 (\mathbf{IP})} \dots\dots\dots (6.5)$$

All the above researchers suggested empirical relation of swelling potential and plastic index. Like these researchers the study area soil single regression analysis shows that plastic index has a better relation than that of other index parameters. But, in general, one cannot predict or conclude a fair estimation of swelling potential relation with a single index parameter.

Where: - Sp – Swelling Potential

IP – Plastic Index

K =  $3.6 \times 10^{-5}$  and a constant

## 6.9 Validity Testing of Developed Equation

The control test values of swelling potential were determined from one-dimensional consolidometer test in the laboratory. As the same time the swelling pressure is also examined. These two swell-shrink characteristics of the study area soils have the relationship as follows and used for validity testing.

$$S_p = 0.0273114P_s + 0.387591269$$

The above equation is preferably selected from different alternatives to test validity of developed equation. The result is tabulated in Table 6.3 below.

Table 6.3 Control Test results and Calculated Values of Swelling Potential

Test Pit	Depth (m)	Control Test Result (Actual $S_p$ ) (%)	Calculated $S_p$ (%)
TP1	1.2	6.93	6.53
	2.3	9.75	6.31
TP2	0.9	11.35	7.37
TP3	1.0	1.25	1.75
TP4	1.2	2.91	2.66
	2.5	1.52	2.30
TP5	1.5	3.66	7.22
	2.5	1.09	1.42
TP6	1.5	3.45	3.85
	3.0	2.99	4.04
TP7	1.5	11.74	10.72
	2.7	7.34	9.07
TP8	1.3	11.66	10.07
TP9	1.4	8.53	10.27
TP10	1.5	11.5	10.22
	3.0	10.1	12.51
TP11	1.5	10.76	10.47
	3.0	6.9	8.38
TP12	1.5	10.75	9.87
TP13	1.7	6.24	5.41

Fig. 6.1 shows that the relation of actual laboratory result of swelling potential with the calculated values, which indicates some variations /deviations/ are incorporated due to uncontrolled factors during sampling and laboratory testing conditions. The expected errors are encountered during sampling time and the main deviation problem estimated was due to scarcity of consolidometer apparatus in the laboratory, the undisturbed samples are deposited for long time.

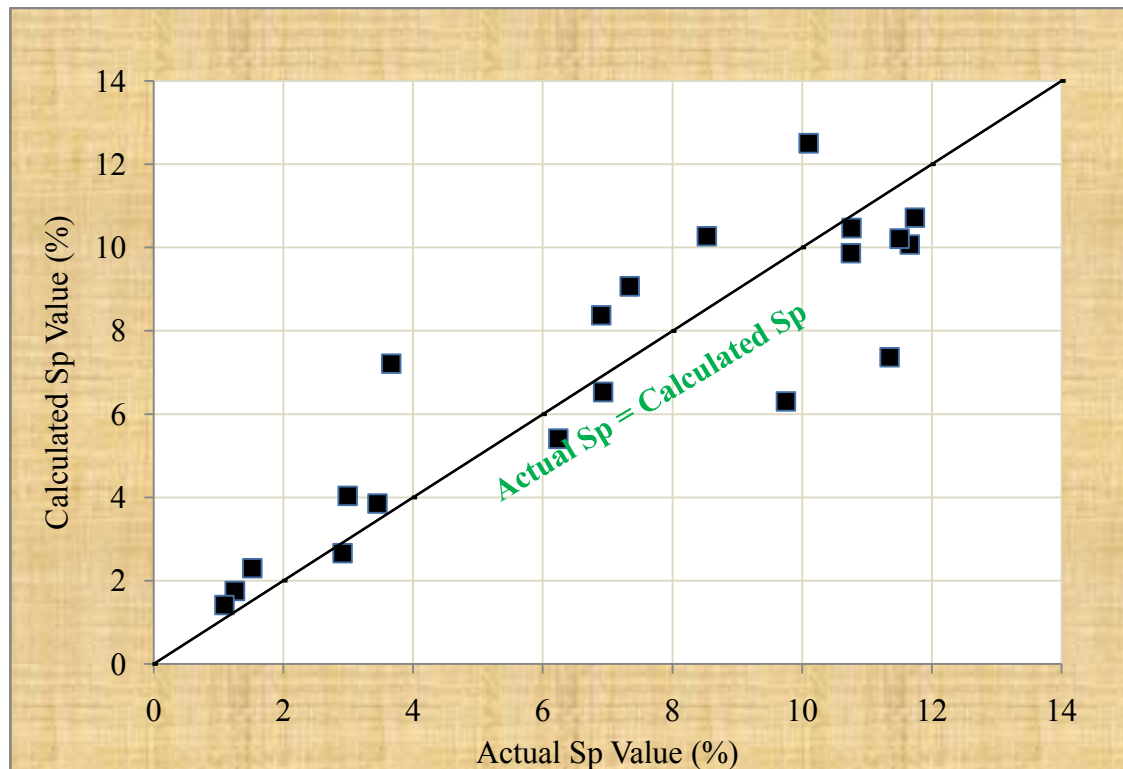


Fig 6.1 Relation between Actual Control test results with calculated values of Swelling Potential

### 6.10 Comparisons of Previous Researchers Equations with Actual Sp Values of Study Area

From Table 6.4 below one can see that Anderson et al swelling potential result deviated by 113.36% from the actual, which is over estimated. Holtz, Seed and Chen correlation resulted diverge in an average 492.98%, highly over estimating the calculated value. Whereas, Seed, Woodward and Lundgren correlation resulted in an average 733.65% extremely over estimating the calculated value of swelling potential. But the developed correlation equation is deviated by 34.82% from the actual swelling potential. In conclusion, someone may use this suggested equation rather than existing equation for the estimation of swelling potential of the study area alternatively.

Table6.4 Comparison between Calculated Swelling Potential with Different Researchers Predicted Models

Test Pit	Depth (m)	Actual Values			Developed Correlation		Proposed Sp Values By Researchers (%)					
							Anderson et al		Seed, Woodward and Lundgren		Holtz, Seed and Chen	
		Sp (%)	$\gamma_d$ (kN/m <sup>3</sup> )	IP (%)	Calculated Sp (%)	Deviation from actual (%)	Calculated Sp (%)	Deviation from actual (%)	Calculated Sp (%)	Deviation from actual (%)	Calculated Sp (%)	Deviation from actual (%)
TP1	1.20	6.93	12.93	60.06	7.49	8.10	10.69	54.33	47.23	581.53	39.24	466.23
	2.30	9.75	12.90	59.83	8.29	-15.02	10.64	9.13	46.79	379.90	38.49	294.77
TP2	0.90	11.35	14.34	56.16	7.02	-38.14	9.80	-13.68	40.09	253.22	28.30	149.34
TP3	1.00	1.25	12.49	28.67	0.59	-52.83	3.47	177.86	7.77	521.60	2.83	126.40
TP4	1.20	2.91	12.95	46.04	2.96	1.76	7.47	156.69	24.69	748.45	12.12	316.49
	2.50	1.52	13.43	58.30	7.82	414.49	10.29	576.95	43.92	2789.47	33.86	2127.63
TP5	1.50	3.66	12.09	55.82	7.87	114.98	9.72	165.53	39.5	979.23	27.50	651.37
	2.50	1.09	12.16	53.54	4.70	331.56	9.19	743.47	35.68	3173.39	22.72	1984.40
TP6	1.50	3.45	12.10	46.60	2.55	-26.03	7.60	120.22	25.43	637.10	12.70	268.12
	3.00	2.99	15.48	52.16	4.26	42.63	8.88	196.86	33.48	1019.73	20.24	576.92
TP7	1.50	11.74	13.99	56.74	11.87	1.10	9.93	-15.42	41.11	250.17	29.71	153.07
	2.70	7.34	15.20	54.59	8.48	15.47	9.43	28.54	37.41	409.67	24.81	238.01
TP8	1.30	11.66	14.16	57.11	11.50	-1.40	10.02	-14.11	41.77	258.23	30.64	162.78
TP9	1.40	8.53	11.26	47.21	6.36	-25.50	7.74	-9.28	26.25	207.74	13.37	56.74
TP10	1.50	11.50	12.13	68.00	7.96	-30.81	12.52	8.86	63.94	456.00	76.33	563.74
	3.00	10.10	16.22	63.70	8.12	-19.65	11.53	14.16	54.52	439.80	53.23	427.03
TP11	1.50	10.76	14.48	49.20	10.73	-0.30	8.20	-23.83	29.03	169.80	15.79	46.75
	3.00	6.90	13.72	42.76	5.48	-20.57	6.71	-2.70	20.61	198.70	9.23	33.77
TP12	1.50	10.75	13.72	60.17	9.82	-8.67	10.72	-0.29	47.44	341.30	39.60	268.37
TP13	1.70	6.24	10.83	66.15	6.57	5.24	12.10	93.84	59.78	858.01	65.37	947.60
Average		7.02	13.33	54.14	7.02	<b>34.82</b>	9.33	<b>113.36</b>	38.32	<b>733.65</b>	29.80	<b>492.98</b>

Where: - Sp – Swelling Potential (%)

w – Natural moisture content (%)

IP – Plastic Index (%)

% Clay – Percentage of clay content in the soil sample (%)

LL – Liquid limit (%)

$\gamma_d$  – Dry density (KN/m<sup>3</sup>)

PL – Plastic limit (%)

LI – Liquid index (%)

SE – Standard error

MPE – Mean percent error (%)

R<sup>2</sup> and Adj. R<sup>2</sup> – Correlation coefficients (%)

P-Value – Overall significance of the regression

n – Number of correlated samples

EQ – Equation

K –  $3.6 \times 10^{-5}$  and a constant

Ps – Swelling Pressure

## 7. Discussion

### 7.1 Discussion of Laboratory Test results

Tests like natural moisture content, particle size distribution, Atterberg limits (liquid limit, plastic limits and plasticity index) and swelling pressure tests are conducted for laboratory analysis. From Table 4.8 we can observe the following points:

- Samples TP-7 at 1.5m depth and TP-13 at 1.7m test results of swelling pressure & swelling potential are (378.12kPa & 11.74%) and (183.89kPa & 6.26%) respectively. The reason is that in the case of the first sample the natural moisture content (25.03%) is low and its dry density (15.48kN/m<sup>3</sup>) is high and the second sample natural moisture content (43.56%) is high and dry density (10.83kN/m<sup>3</sup>) is low. This indicates that the second sample has already swelled in situ more than the first sample.
- It is known that not only the moisture content and density of a soil govern the swelling characteristics, but also consistency or clay type. For example, samples TP5 at 2.5m depth and TP10 at 3.0m depth their moisture contents and dry densities are (39.33% and 12.09kN/m<sup>3</sup>) and (39.92% and 12.1309kN/m<sup>3</sup>) respectively, which are almost similar. But their swelling pressure and potentials are quite different. The Swelling pressure and potential of first sample TP5 is (37.63kPa and 1.09%) and that of the second sample TP10 is (443.74kPa and 10.10%). The reason for this is that plasticity index (IP) of TP5 is 53.3% and that of TP10 is 63.70%.
- On the other hand, both the above two cases are happen together. TP8 at 1.30m and TP10 at 1.50m depths are good examples; their Swelling pressure (354.63kPa & 359.91kPa) and Swelling potential (11.66% & 11.50%) are relatively the same. But, the moisture content, dry density and consistency of these samples are ( $w = 25.7\%$ ,  $\gamma_d = 15.2\text{kN/m}^3$  and  $IP = 57.11\%$ ) and ( $w = 41.34\%$ ,  $\gamma_d = 11.26\text{kN/m}^3$  and  $IP = 68.00\%$ ) respectively.
- Table 5.2 shows the laboratory results of the Sendafa expansive soils fall under high to very high degree of expansion.

## 7.2 Discussion of Correlation and Regression

In expansive soils the swell pressure and swell potential are important parameters to understand the severity of problem posed by expansive soil.

The swelling potential of the research area is correlated with the index property parameters of the laboratory results one by one and summarized in (Table6.1); as a result nine equations are developed (EQ.1 to EQ.9) by single linear regression method. And also after so many regression trials using multiple linear regression method, additional equations were developed (Table6.2). Out of these equations swelling potential with plasticity index and dry density in combination is selected as best fit equation. To select the best fit linear regression equations, the preferred criteria focused were the correlation coefficients ( $R^2$  and  $Adj.R^2$ ), the P-Value, the Standard Error (SE) and the Mean Percentage Error (MPE).

## 8. Conclusions and Recommendations

### 8.1 Conclusions

Based on the test results to predict swelling potential by single and multiple linear regressions, the following conclusions were drawn.

- The dominant soil color in the study area is gray to black and the index properties investigated are; clay fraction ranges from (35.37-74.33)%, liquid limit ranges from (62.67-108)%, plasticity index ranges from (28.67-68)%, free swell values ranging from (65.5-186)% and specific gravity of solids ranging from (2.64-2.79)%.
- The swelling pressure of the study area ranges from (37.63 - 443.74) kPa.
- From the Single Linear Regression Analysis above, plasticity index has good correlation with swelling potential among other single index parameters. Similarly, different researchers' models for different countries show that plastic index is a single index parameter for correlation of swelling potential.
- In prediction of swelling potential by Multiple Linear Regression Analysis, the relationship between swelling potential with dry density and plastic index is a relatively improved among the equations developed to calculate swelling potential from multiple soil index tests.

### 8.2 Recommendations

- The accuracy of newly developed equations may be further modified or improved by increasing other additional soil samples and by decreasing expected errors during sampling and testing time.
- There is 34.26% precision variation in between actual laboratory and predicted Sp values. So that, it is recommended to use directly the developed equations for preliminary design and small projects to predict the swelling potential of the study area.
- Sendafa is one of the fast growing towns and commercial centers in the Oromia Special Zone. It has also a great potential for investment expansion as a result of its location near to the capital and has wide, flat and free landscape. Further detailed engineering soil investigation is essential.

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## **10. Appendices**

### Appendix A: - Laboratory Test Analyses

1) Natural Moisture Content (Section 4.2.2.1)

1.1 Location: Beke Kebele 02 (TP1)

Determination Number	1	2	1	2
Depth	1.2m		2.3m	
Container Number	A28	G5	21A	B6
Mass of container, gm	15.6	15.5	15.5	15.6
Mass of container +wet soil, gm	37.8	38.6	38.4	40.7
Mass of container +dry soil, gm	32	32.2	31.8	33.6
Mass of water, gm	5.8	6.4	6.6	7.1
Mass of dry soil, gm	16.4	16.7	16.3	18
Water content, %	35.37	38.32	40.49	39.44
Average water content, %	36.84		39.97	

1.2 Location: St. Merry (TP2)

Determination No.	1	2
Depth	0.90m	
Container No.	4P	1L4
Mass of container, gm	15.7	15.7
Mass of container +wet soil, gm	55.2	59.3
Mass of container +dry soil, gm	45.4	48.5
Mass of water, gm	9.8	10.8
Mass of dry soil, gm	29.7	32.8
Water content, %	33.00	32.93
Average water content, %	32.96	

1.3 Location: Beke Gote 03 (TP3)

Determination No.	1	2
Depth	1.0m	
Container No.	A302	1L3
Mass of container, gm	15.5	15.7
Mass of container +wet soil, gm	55.9	54.7
Mass of container +dry soil, gm	47	46.4
Mass of water, gm	8.9	8.3
Mass of dry soil, gm	31.5	30.7
Water content, %	28.25	27.04
Average water content, %	27.64	

1.4 Location: Sendafa & Beke Border (TP4)

Determination No.	1	2	1	2
Depth	1.2m		2.5m	
Container No.	D31	12	G3	21
Mass of container, gm	15.5	15.5	15.80	21.20
Mass of container +wet soil, gm	48.5	53.3	70.30	72.00
Mass of container +dry soil, gm	39.9	42.9	55.50	58.20
Mass of water, gm	8.6	10.4	14.80	13.80
Mass of dry soil, gm	24.4	27.4	39.70	37.00
Water content, %	35.25	37.96	37.28	37.30
Average water content, %	38.02		37.29	

1.5 Location: Kebt Tera (TP5)

Determination No.	1	2	1	2
Depth	1.5m		2.5m	
Container No.	H20	M02	1L3	2P3
Mass of container, gm	15.6	15.7	15.8	15.6
Mass of container +wet soil, gm	65.60	65.50	61.8	61
Mass of container +dry soil, gm	53.00	52.80	48.9	48.1
Mass of water, gm	12.60	12.70	12.9	12.9
Mass of dry soil, gm	37.40	37.10	33.1	32.5
Water content, %	33.69	34.23	38.97	39.69
Average water content, %	33.96		39.33	

1.6 Location: High School (TP6)

Determination No.	1	2	1	2
Depth	1.5m		3.0m	
Container No.	M10	TH1	MF	BL
Mass of container, gm	11	16	15.6	15.7
Mass of container +wet soil, gm	46.80	47.50	68.50	65.70
Mass of container +dry soil, gm	37.20	38.80	54.70	52.90
Mass of water, gm	9.60	8.70	13.80	12.80
Mass of dry soil, gm	26.20	22.80	39.10	37.20
Water content, %	36.64	38.16	35.29	34.41
Average water content, %	37.40		34.85	

1.7 Location: High School (TP7)

Determination No.	1	2	1	2
Depth	1.50m		2.70m	
Container No.	33	75	B11	TP#1
Mass of container, gm	15.75	15.7	16	22.3
Mass of container +wet soil, gm	48.1	48.55	51.3	52.9
Mass of container +dry soil, gm	41.6	42	43.4	46.0
Mass of water, gm	6.5	6.55	7.9	6.9
Mass of dry soil, gm	25.85	26.3	27.4	23.7
Water content, %	25.15	24.90	28.83	29.11
Average water content, %	25.03		28.97	

1.8 Location: Zenbaba Grocery (TP8)

Determination No.	1	2
Depth	1.30m	
Container No.	MT7	MT8
Mass of container, gm	16.8	15.5
Mass of container +wet soil, gm	54	54.6
Mass of container +dry soil, gm	46.4	46.6
Mass of water, gm	7.6	8
Mass of dry soil, gm	29.6	31.1
Water content, %	25.68	25.72
Average water content, %	25.70	

1.9 Location: Municipality (TP9)

Determination No.	1	2
Depth	1.40m	
Container No.	40	A
Mass of container, gm	16	15.5
Mass of container +wet soil, gm	53.6	53.5
Mass of container +dry soil, gm	44.7	44.5
Mass of water, gm	8.9	9
Mass of dry soil, gm	28.7	29
Water content, %	31.01	31.03
Average water content, %	31.02	

1.10 Location: Dabe 1 (TP10)

Determination No.	1	2	1	2
Depth	1.5m		3.0m	
Container No.	MT8	AL3	30	60
Mass of container, gm	15.45	15.7	15.6	15.5
Mass of container +wet soil, gm	44.5	44.8	44	43.000
Mass of container +dry soil, gm	36.3	36.0	35.75	35.300
Mass of water, gm	8.2	8.8	8.25	7.7
Mass of dry soil, gm	20.85	20.3	20.15	19.8
Water content, %	39.33	43.35	40.94	38.89
Average water content, %	41.34		39.92	

1.11 Location: Dire Mazoria (TP11)

Determination No.	1	2	1	2
Depth	1.5m		3.0m	
Container No.	A49	B4	MT9	FL105
Mass of container, gm	15.9	16	15.8	15.2
Mass of container +wet soil, gm	50.65	50.5	57.6	57.400
Mass of container +dry soil, gm	43.1	42.9	49	48.700
Mass of water, gm	7.55	7.6	8.6	8.7
Mass of dry soil, gm	27.2	26.9	33.2	33.5
Water content, %	27.76	28.25	25.90	25.97
Average water content, %	28.01		25.94	

1.12 Location: Dabe 2 (TP12)

Determination No.	1	2
Depth	1.50m	
Container No.	MT2	B
Mass of container, gm	15.9	15.5
Mass of container +wet soil, gm	47.8	46.95
Mass of container +dry soil, gm	39.5	38.9
Mass of water, gm	8.3	8.05
Mass of dry soil, gm	23.6	23.4
Water content, %	35.17	34.40
Average water content, %	34.79	

1.13 Location: Dire Caf  (TP13)

Determination No.	1	2
Depth	1.70m	
Container No.	A-1	MT8
Mass of container, gm	15.4	15.5
Mass of container +wet soil, gm	46.7	44.6
Mass of container +dry soil, gm	37.5	35.5
Mass of water, gm	9.2	9.1
Mass of dry soil, gm	22.1	20
Water content, %	41.63	45.50
Average water content, %	43.56	

2) Specific gravity (Section 4.2.2.2)

2.1 Location: Beke Kebele 02 (TP1)

Determination Number	1	2	1	2
Depth	1.2m		2.3m	
Weight of dry, clean pycnometer, wp (g)	44.2	47.5	63.5	47.5
Weight of pycnometer + water, wpw (g)	143.75	147.30	163.00	147.30
Observed temperature of water, Ti (oc)	18.7	19.5	20.8	21.6
Weight of pycnometer + soil + water, Wpws (g)	159.6	163.25	179.1	163.3
Temperature, Tx(oc)	18.6	19.6	20.7	21.5
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	143.75	147.30	163.00	147.30
Weight of dry soil , ws (gm)	25	25	25	25
Conversion factor , K	1.00028	1.0001	0.99986	0.9997
Specific gravity of soil at 20°C.	2.73	2.76	2.81	2.78
Average specific gravity of the soil	2.75		2.79	

2.2 Location: St. Merry (TP2)

Determination Number	1	2
Depth	0.90m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3
Weight of pycnometer + water, wpw (g)	144.9	144.9
Observed temperature of water, Ti (oc)	22	22
Weight of pycnometer + soil + water, Wpws (g)	164.5	160.6
Temperature, Tx(oc)	24.4	23.8
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	144.94	144.95
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.999	0.9991
Specific gravity of soil at 20°C.	2.76	2.73
Average specific gravity of the soil	2.75	

2.3 Location: Got 3 (TP3)

Determination Number	1	2
Depth	1.0m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3
Weight of pycnometer + water, wpw (g)	144.9	144.9
Observed temperature of water, Ti (oc)	20	20
Weight of pycnometer + soil + water, Wpws (g)	160.3	160.4
Temperature, Tx(oc)	23.5	23.5
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	144.90	144.90
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9992	0.9992
Specific gravity of soil at 20°C.	2.62	2.65
Average specific gravity of the soil	2.64	

2.4 Location: Beke and Sendafa Border (TP4)

Determination Number	1	2	1	2
Depth	1.2m		2.5m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3	45.3	45.3
Weight of pycnometer + water, wpw (g)	145.3	145.2	145.2	145.2
Observed temperature of water, Ti (oc)	19	19.5	20.5	19.5
Weight of pycnometer + soil + water, Wpws (g)	161.1	161.2	161.2	161.1
Temperature, Tx(oc)	24	23	24	23
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	145.19	145.12	145.12	145.12
Weight of dry soil , ws (gm)	25	25	25	25
Conversion factor , K	0.9991	0.9993	0.9991	0.9993
Specific gravity of soil at 20°C.	2.75	2.80	2.80	2.77
Average specific gravity of the soil	2.77		2.78	

2.5 Location: Kebt Tera (TP5)

Determination Number	1	2	1	2
Depth	1.5m		2.5m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3	45.3	45.3
Weight of pycnometer + water, wpw (g)	145.1	145.2	145	145
Observed temperature of water, Ti (oc)	19.5	20.0	20.0	20.0
Weight of pycnometer + soil + water, Wpws (g)	160.9	160.9	160.8	160.8
Temperature, Tx(oc)	23	25.5	24	23.7
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	145.02	145.07	144.91	144.93
Weight of dry soil , ws (gm)	25	26	25	25
Conversion factor , K	0.9993	0.99875	0.9991	0.9992
Specific gravity of soil at 20°C.	2.74	2.72	2.74	2.73
Average specific gravity of the soil	2.73		2.74	

2.6 Location: High School (TP6)

Determination Number	1	2	1	2
Depth	1.5m		3.0m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3	45.3	45.3
Weight of pycnometer + water, wpw (g)	145.3	145.2	145.0	145.0
Observed temperature of water, Ti (oc)	19.6	19.3	19.0	19.0
Weight of pycnometer + soil + water, Wpws (g)	160.7	160.8	160.6	160.75
Temperature, Tx(oc)	23.0	23.0	22.5	22.3
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	145.25	145.18	144.93	144.93
Weight of dry soil , ws (gm)	25	25	25	25
Conversion factor , K	0.9993	0.9993	0.99945	0.9995
Specific gravity of soil at 20°C.	2.62	2.66	2.68	2.72
Average specific gravity of the soil	2.64		2.70	

2.7 Location: Amanuel Church (TP7)

Determination Number	1	2	1	2
Depth	1.5m		2.7m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3	45.3	45.3
Weight of pycnometer + water, wpw (g)	145.1	145.2	145	145
Observed temperature of water, Ti (oc)	19.0	19.5	19	19.5
Weight of pycnometer + soil + water, Wpws (g)	160.8	160.9	160.8	160.8
Temperature, Tx(oc)	23.5	22.5	22.5	22.5
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	145.00	145.14	144.93	144.94
Weight of dry soil , ws (gm)	25	25	25	25
Conversion factor , K	0.9992	0.9995	0.99945	0.9995
Specific gravity of soil at 20°C.	2.71	2.71	2.74	2.74
Average specific gravity of the soil	2.71		2.74	

2.8 Location: Zenbaba Grocery (TP8)

Determination Number	1	2
Depth	1.3m	
Weight of dry, clean pycnometer, wp (g)	47.5	63.5
Weight of pycnometer + water, wpw (g)	147.3	163.1
Observed temperature of water, Ti (oc)	20.1	19.9
Weight of pycnometer + soil + water, Wpws (g)	163.25	178.95
Temperature, Tx(oc)	20.1	20
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	147.25	163.05
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	1.0000	1.0000
Specific gravity of soil at 20°C.	2.78	2.75
Average specific gravity of the soil	2.76	

2.9 Location: Municipality (TP9)

Determination Number	1	2
Depth	1.4m	
Weight of dry, clean pycnometer, wp (g)	45.3	45.3
Weight of pycnometer + water, wpw (g)	145	145
Observed temperature of water, Ti (oc)	19.5	19.4
Weight of pycnometer + soil + water, Wpws (g)	160.75	160.8
Temperature, Tx(oc)	21.6	22.5
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	144.95	144.94
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9997	0.9995
Specific gravity of soil at 20°C.	2.72	2.74
Average specific gravity of the soil	2.73	

2.10 Location: Dabe 1 (TP10)

Determination Number	1	2	1	2
Depth	1.5m		3.0m	
Weight of dry, clean pycnometer, wp (g)	47.5	44.2	63.5	63.5
Weight of pycnometer + water, wpw (g)	147	143.7	162.9	162.9
Observed temperature of water, Ti (oc)	18.5	18.9	19.7	21
Weight of pycnometer + soil + water, Wpws (g)	162.55	159.2	178.5	178.85
Temperature, Tx(oc)	19.7	19	19.9	21.5
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	146.98	143.70	162.89	162.89
Weight of dry soil , ws (gm)	25	25	25	25
Conversion factor , K	1.0001	1.0002	1.0000	0.9997
Specific gravity of soil at 20°C.	2.65	2.63	2.66	2.76
Average specific gravity of the soil	2.64		2.71	

2.11 Location: Dire Mazoria (TP11)

Determination Number	1	2	1	2
Depth	1.5m		3.0m	
Weight of dry, clean pycnometer, wp (g)	47.5	44.2	63.45	47.5
Weight of pycnometer + water, wpw (g)	147.3	143.7	162.9	147.2
Observed temperature of water, Ti (oc)	21.9	22.1	20.4	20.1
Weight of pycnometer + soil + water, Wpws (g)	163.2	159.8	179	163.1
Temperature, Tx(oc)	22.1	22.3	20.6	20.4
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	147.30	143.69	162.87	147.17
Weight of dry soil , ws (gm)	25	25	25	25
Conversion factor , K	0.9996	0.9995	0.9999	0.9999
Specific gravity of soil at 20°C.	2.75	2.81	2.82	2.76
Average specific gravity of the soil	2.78		2.79	

2.12 Location: Dabe 2 (TP12)

Determination Number	1	2
Depth	1.5m	
Weight of dry, clean pycnometer, wp (g)	44.2	44.2
Weight of pycnometer + water, wpw (g)	143.75	143.8
Observed temperature of water, Ti (oc)	19.9	21.5
Weight of pycnometer + soil + water, Wpws (g)	159.8	159.6
Temperature, Tx(oc)	20	21.5
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	143.75	143.80
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	1.0000	0.9997
Specific gravity of soil at 20°C.	2.79	2.72
Average specific gravity of the soil	2.75	

2.13 Location: Dire Cafe (TP13)

Determination Number	1	2
Depth	1.7m	
Weight of dry, clean pycnometer, wp (g)	63.5	47.5
Weight of pycnometer + water, wpw (g)	162.9	147.3
Observed temperature of water, Ti (oc)	21.2	21.5
Weight of pycnometer + soil + water, Wpws (g)	178.75	163.05
Temperature, Tx(oc)	21	21.3
Weight of pycnometer + water at Tx , Wpw(atTx) (g)	162.90	147.28
Weight of dry soil , ws (gm)	25	25
Conversion factor , K	0.9998	0.9999
Specific gravity of soil at 20°C.	2.73	2.71
Average specific gravity of the soil	2.72	

3) Atterberg's limit (Section 4.2.2.3)

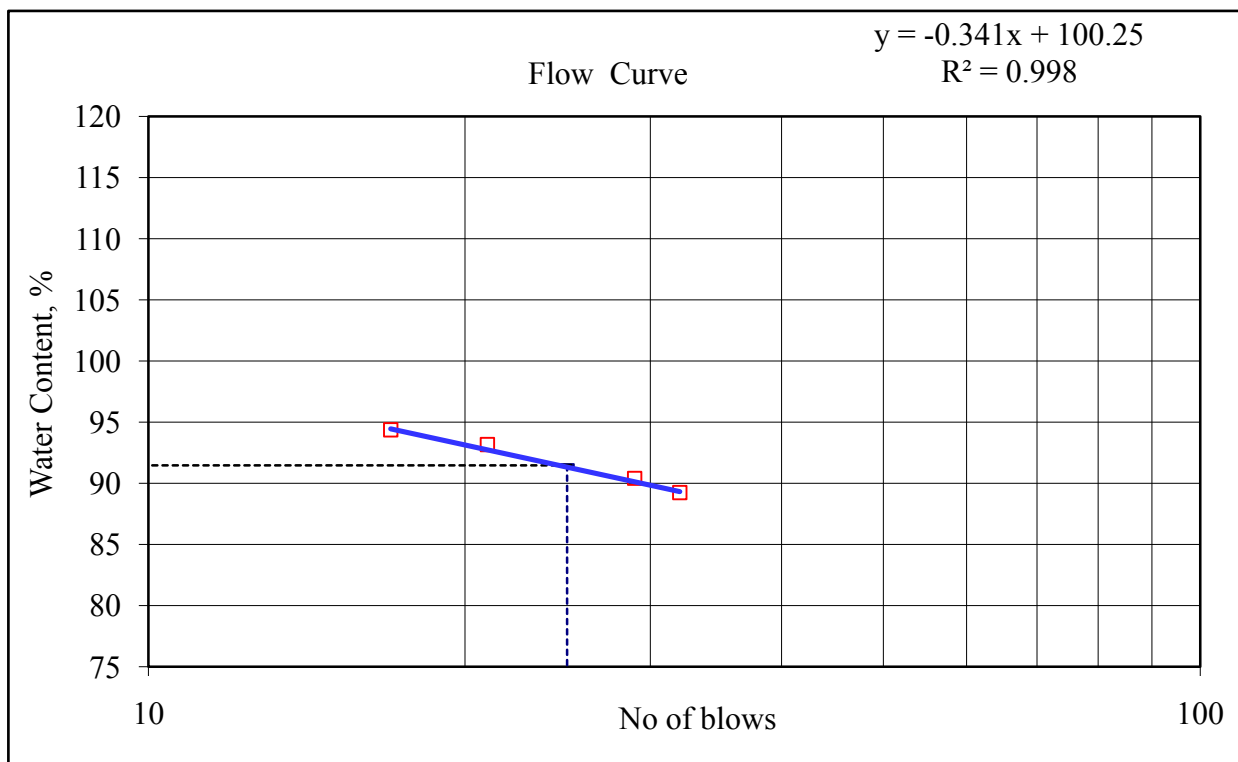
3.1 Location: Beke Kebele 02 (TP1) @ 1.2m

Trial Number	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container Number	TH2	MT6	MT4	MT5	A48	P-1
Mass of container, g	15.50	15.90	15.60	16.00	15.90	15.95
Mass of container + Wet soil, g	42.75	42.75	42.45	43.60	23.20	23.30
Mass of container + Dry soil, g	29.90	30.00	29.50	30.20	21.50	21.50
Mass of water, g	12.85	12.75	12.95	13.40	1.70	1.80
Mass of dry soil, g	14.40	14.10	13.90	14.20	5.60	5.55
Water content, %	89.24	90.43	93.17	94.37	30.36	32.43
Number of blows	32	29	21	17	-----	-----

Liquid Limit, % = 91.68

Plastic Limit, % = 31.39

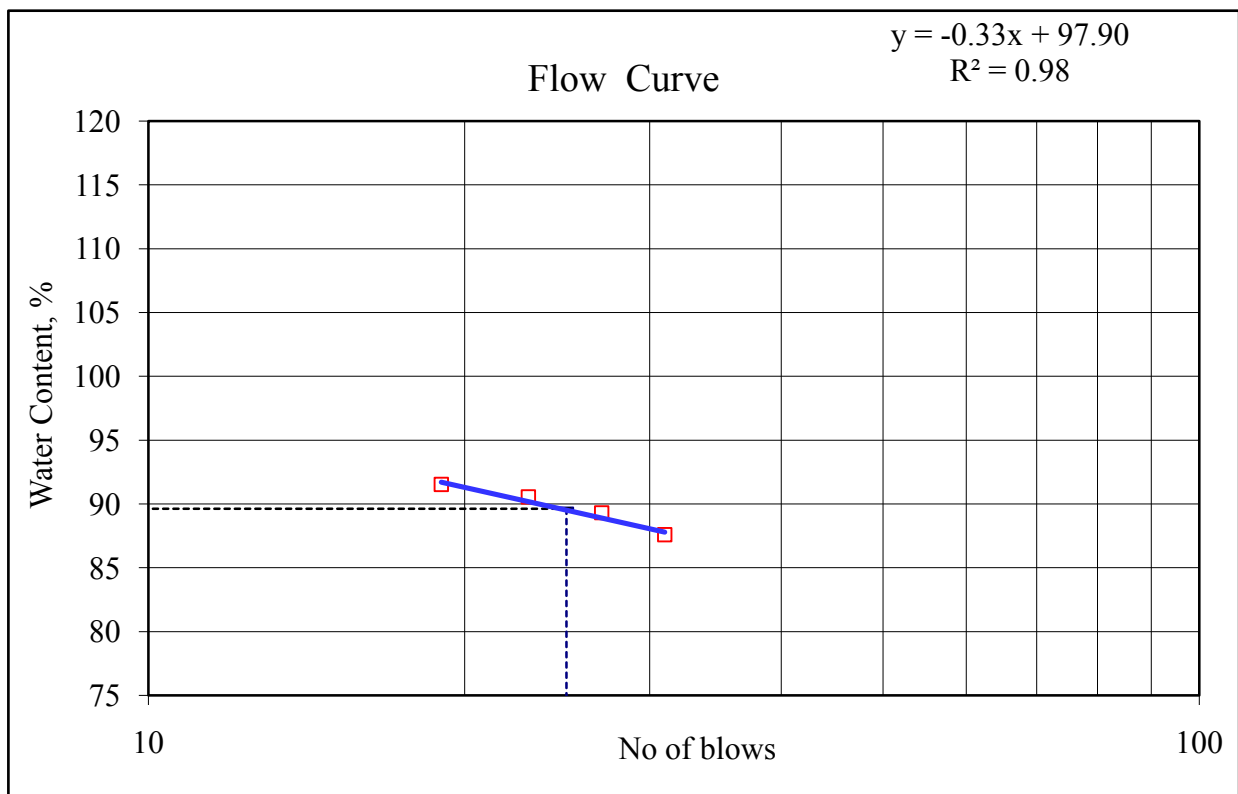
PI, % = 60.06



3.2 Location: Beke Kebele 02 (TP1) @ 2.3m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A49	28	M1	GA	P-2	B11
Mass of container, g	15.90	15.70	15.70	15.60	16.40	16.10
Mass of container + Wet soil, g	43.10	44.10	43.90	45.00	22.50	22.20
Mass of container + Dry soil, g	30.40	30.70	30.50	30.95	21.10	20.80
Mass of water, g	12.70	13.40	13.40	14.05	1.40	1.40
Mass of dry soil, g	14.50	15.00	14.80	15.35	4.70	4.70
Water content, %	87.59	89.33	90.54	91.53	29.79	29.79
No of blows	31	27	23	19	-----	-----

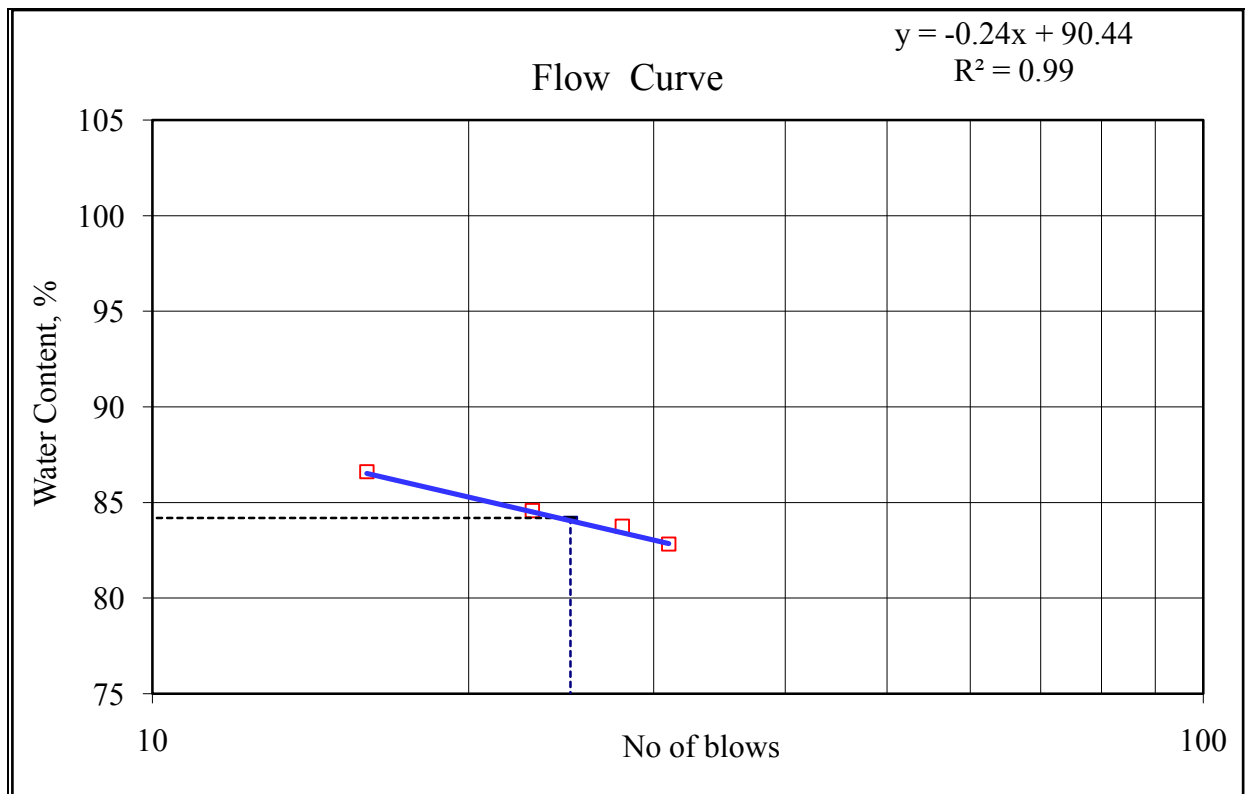
Liquid Limit, % = 89.65                      Plastic Limit, % = 29.79                      PI, % = 59.83



3.3 Location: St. Merry (TP2) @ 0.90m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	60	IL6	125	B4	F101	Z
Mass of container, g	15.50	15.80	15.80	16.50	15.70	15.80
Mass of container + Wet soil, g	46.40	45.20	45.70	45.80	22.35	22.40
Mass of container + Dry soil, g	32.40	31.80	32.00	32.20	20.90	20.95
Mass of water, g	14.00	13.40	13.70	13.60	1.45	1.45
Mass of dry soil, g	16.90	16.00	16.20	15.70	5.20	5.15
Water content, %	82.84	83.75	84.57	86.62	27.88	28.16
No of blows	31	28	23	16	-----	-----

Liquid Limit, % = 84.44                      Plastic Limit, % = 28.02                      PI, % = 56.16



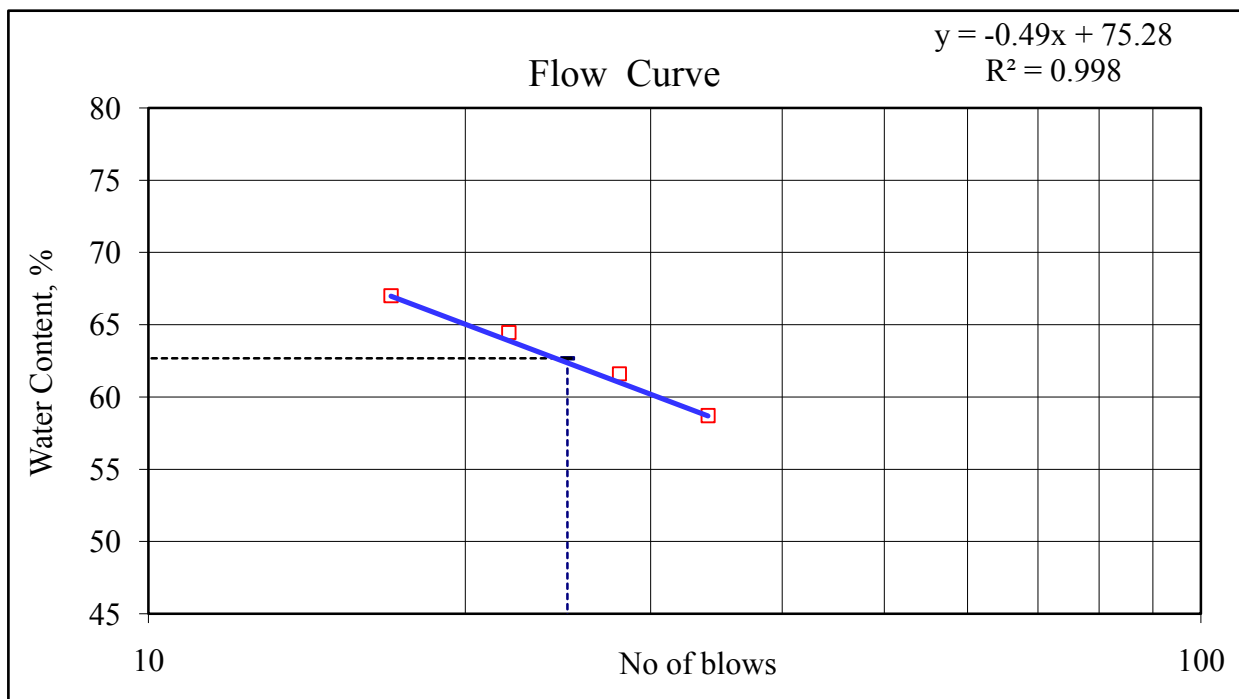
3.4 Location: Got 3 (TP3) @ 1.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	H5	G3	Gp	A109	117	3M
Mass of container, g	15.50	13.90	15.60	15.70	10.90	10.50
Mass of container + Wet soil, g	30.10	29.90	28.10	31.40	17.20	17.60
Mass of container + Dry soil, g	24.70	23.80	23.20	25.10	16.05	15.90
Mass of water, g	5.40	6.10	4.90	6.30	1.15	1.70
Mass of dry soil, g	9.20	9.90	7.60	9.40	5.15	5.40
Water content, %	58.70	61.62	64.47	67.02	22.33	31.48
No of blows	34	28	22	17	-----	-----

Liquid Limit, % = 63.03

Plastic Limit, % = 34.00

PI, % = 28.67



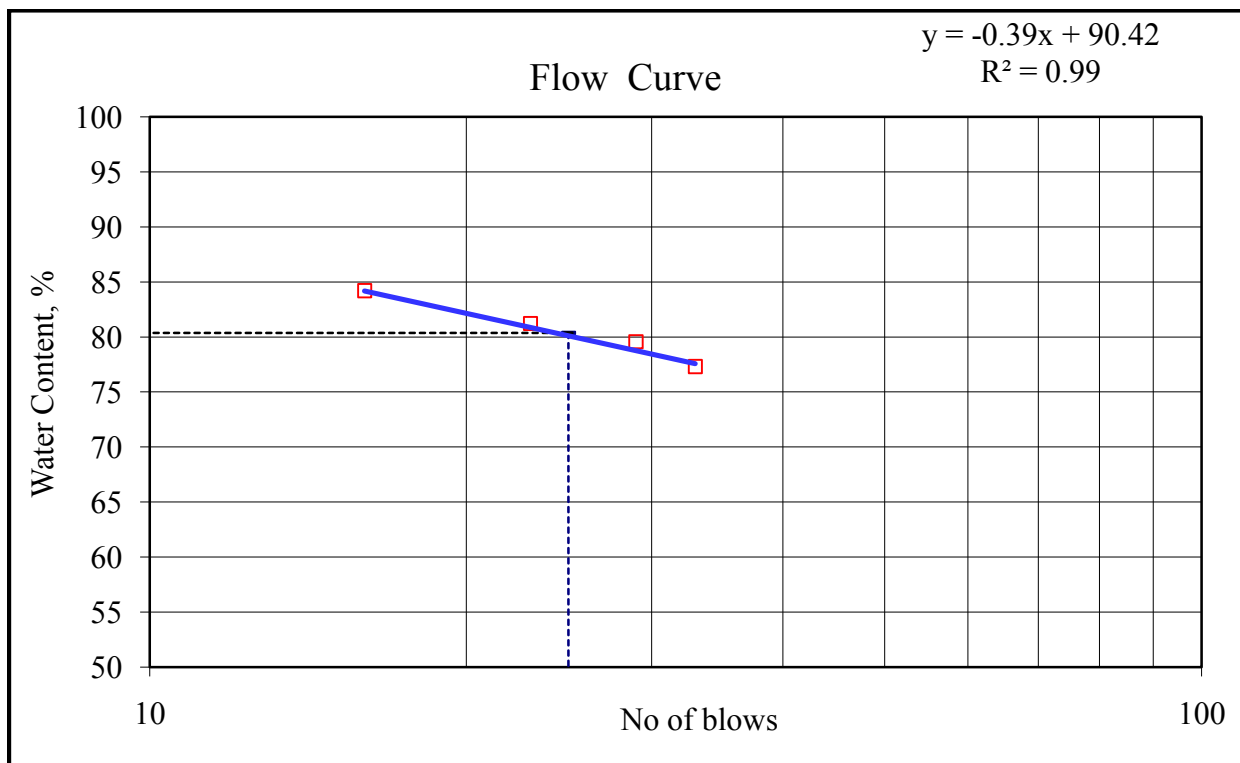
3.5 Location: Beke and Sendafa Border (TP4) @ 1.2m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	8%	GM-15	50	MT4	B11	28
Mass of container, g	15.70	15.40	15.70	15.70	15.90	15.65
Mass of container + Wet soil, g	36.80	33.00	33.10	36.70	22.80	22.65
Mass of container + Dry soil, g	27.60	25.20	25.30	27.10	21.00	20.90
Mass of water, g	9.20	7.80	7.80	9.60	1.80	1.75
Mass of dry soil, g	11.90	9.80	9.60	11.40	5.10	5.25
Water content, %	77.31	79.59	81.25	84.21	35.29	33.33
No of blows	33	29	23	16	-----	-----

Liquid Limit, % = 80.70

Plastic Limit, % = 34.31

PI, % = 46.04



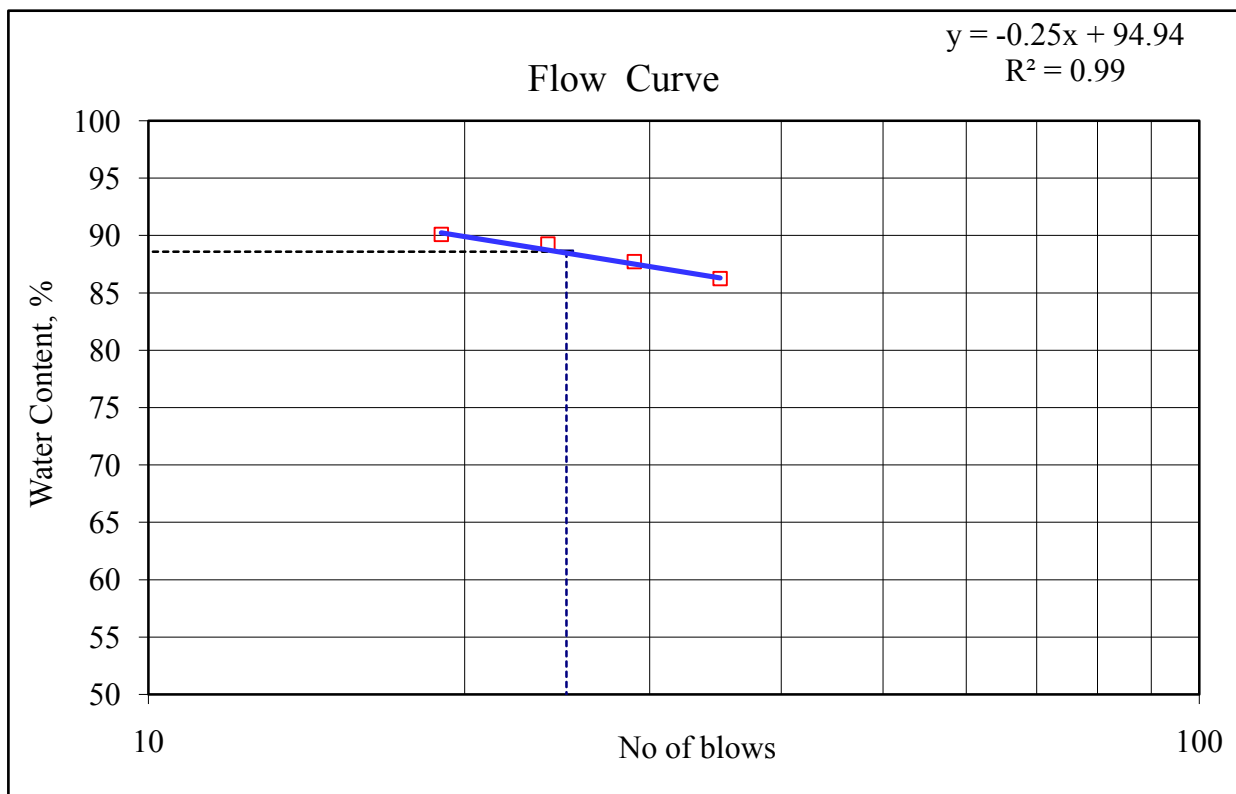
3.6 Location: Beke and Sendafa Border (TP4) @ 2.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	P-2	60	Z	B4	M3	AL3
Mass of container, g	16.30	15.50	15.80	16.00	15.90	15.60
Mass of container + Wet soil, g	46.10	46.10	44.00	46.70	23.00	22.70
Mass of container + Dry soil, g	32.30	31.80	30.70	32.15	21.30	21.10
Mass of water, g	13.80	14.30	13.30	14.55	1.70	1.60
Mass of dry soil, g	16.00	16.30	14.90	16.15	5.40	5.50
Water content, %	86.25	87.73	89.26	90.09	31.48	29.09
No of blows	35	29	24	19	-----	27

Liquid Limit, % = 88.69

Plastic Limit, = 30.29

PI, %= 58.30



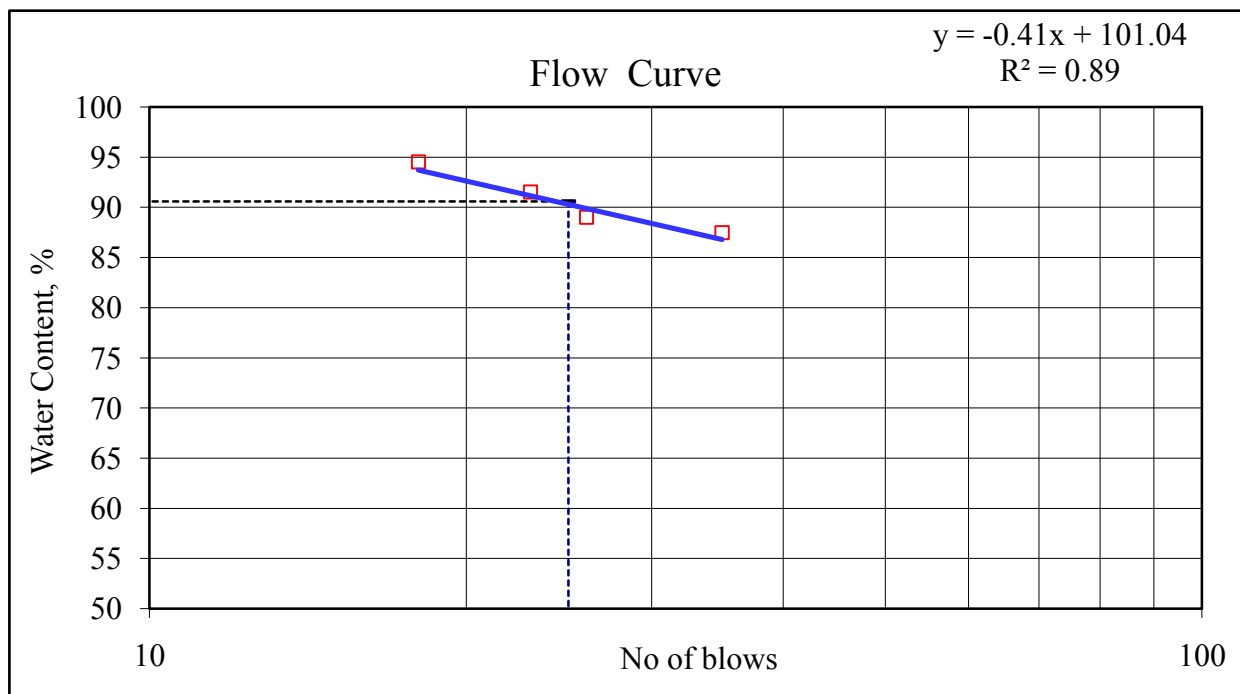
3.7 Location: Keft Tera (TP5) @ 1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	B25	F101	TH1	28	TH1	MT4
Mass of container, g	15.60	15.50	15.90	15.60	15.9	15.60
Mass of container + Wet soil, g	44.10	44.80	43.10	44.20	23.3	23.90
Mass of container + Dry soil, g	30.80	31.00	30.10	30.30	21.4	21.75
Mass of water, g	13.30	13.80	13.00	13.90	1.90	2.15
Mass of dry soil, g	15.20	15.50	14.20	14.70	5.50	6.15
Water content, %	87.50	89.03	91.55	94.56	34.55	34.96
No of blows	35	26	23	18	-----	-----

Liquid Limit, % = 90.79

Plastic Limit, % = 34.75

PI, % = 55.2



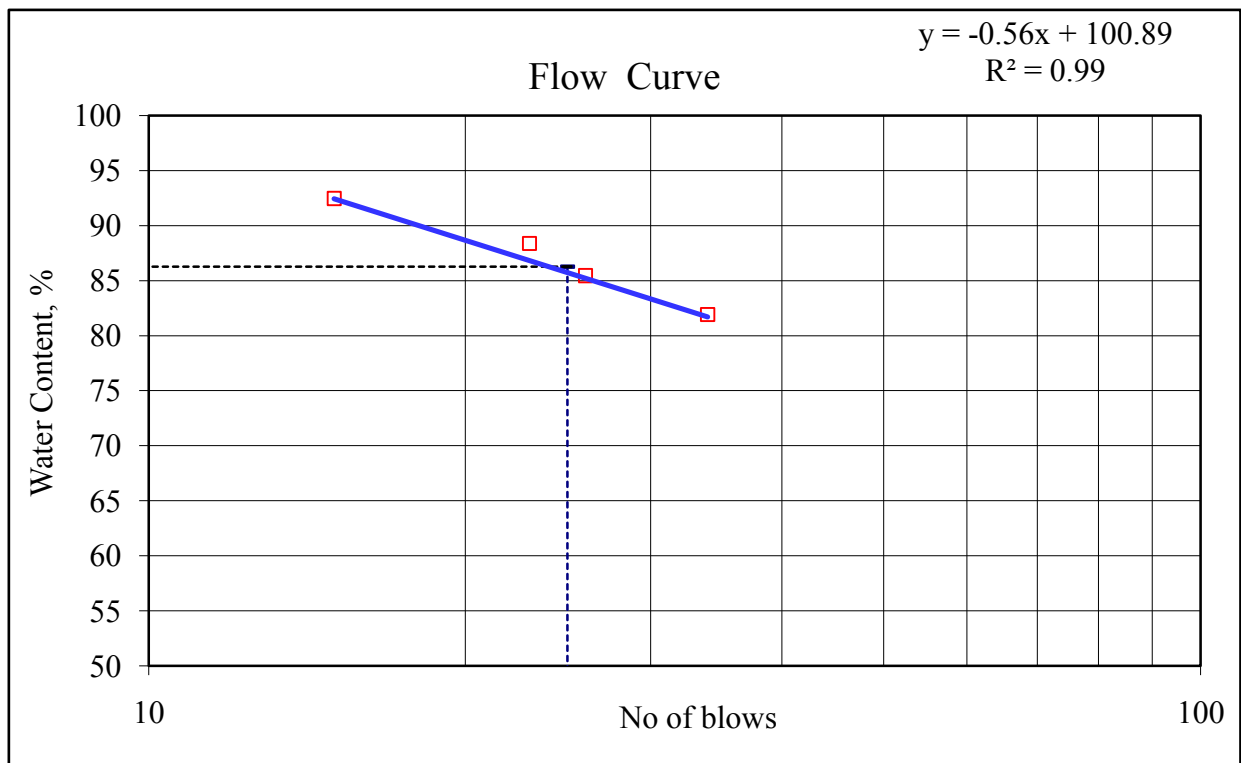
3.8 Location: Keft Tera (TP5) @ 2.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A48	AM	4	P-1	IL6	A49
Mass of container, g	15.80	15.60	15.80	15.60	15.80	15.90
Mass of container + Wet soil, g	42.00	41.10	41.80	43.70	23.00	23.10
Mass of container + Dry soil, g	30.20	29.35	29.60	30.20	21.20	21.35
Mass of water, g	11.80	11.75	12.20	13.50	1.80	1.75
Mass of dry soil, g	14.40	13.75	13.80	14.60	5.40	5.45
Water content, %	81.94	85.45	88.41	92.47	33.33	32.11
No of blows	34	26	23	15	-----	-----

Liquid Limit, % = 86.89

Plastic Limit, % = 32.72

PI, % = 53.54



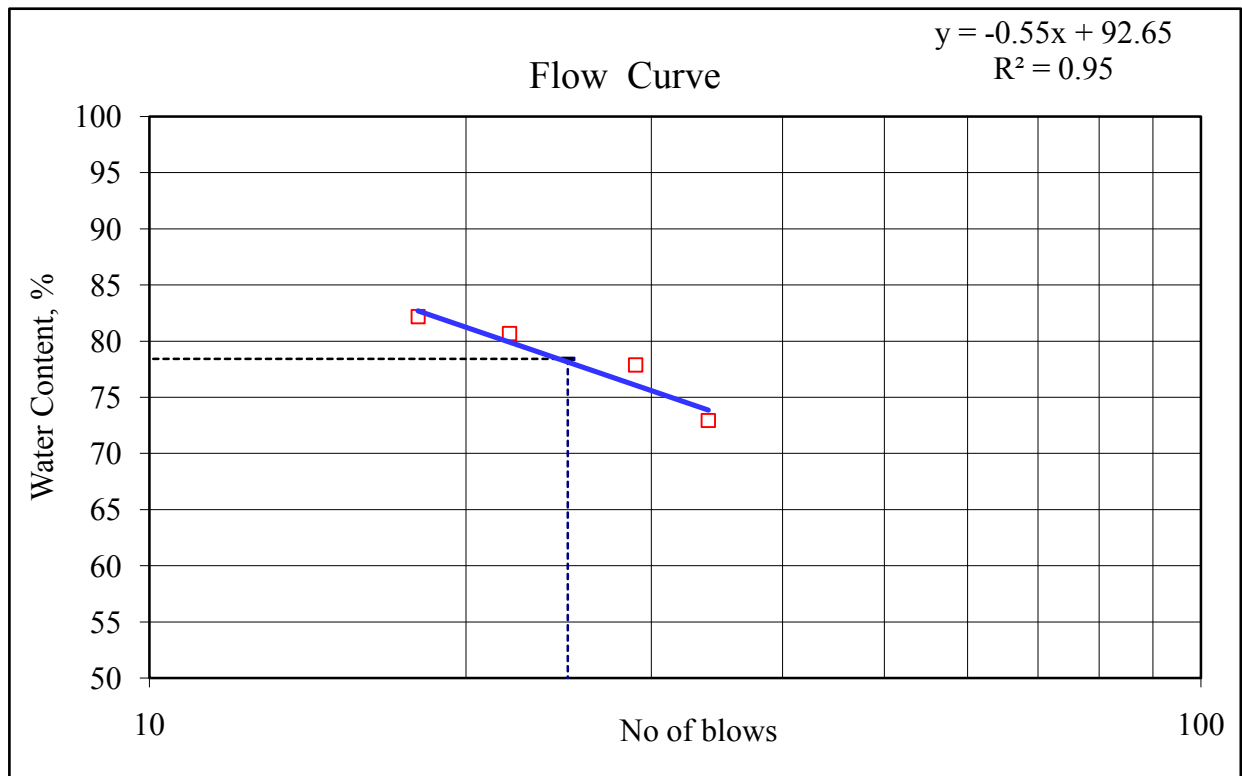
3.9 Location: High School (TP6) @ 1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	12%	P-2	B-11	PT#1	PL-2	F101
Mass of container, g	15.90	15.90	16.00	22.40	13.90	15.50
Mass of container + Wet soil, g	37.00	36.00	37.50	45.90	21.10	24.10
Mass of container + Dry soil, g	28.10	27.20	27.90	35.30	19.30	22.10
Mass of water, g	8.90	8.80	9.60	10.60	1.80	2.00
Mass of dry soil, g	12.20	11.30	11.90	12.90	5.40	6.60
Water content, %	72.95	77.88	80.67	82.17	33.33	30.30
No of blows	34	29	22	18	-----	-----

Liquid Limit, % = 78.90

Plastic Limit, % = 31.2

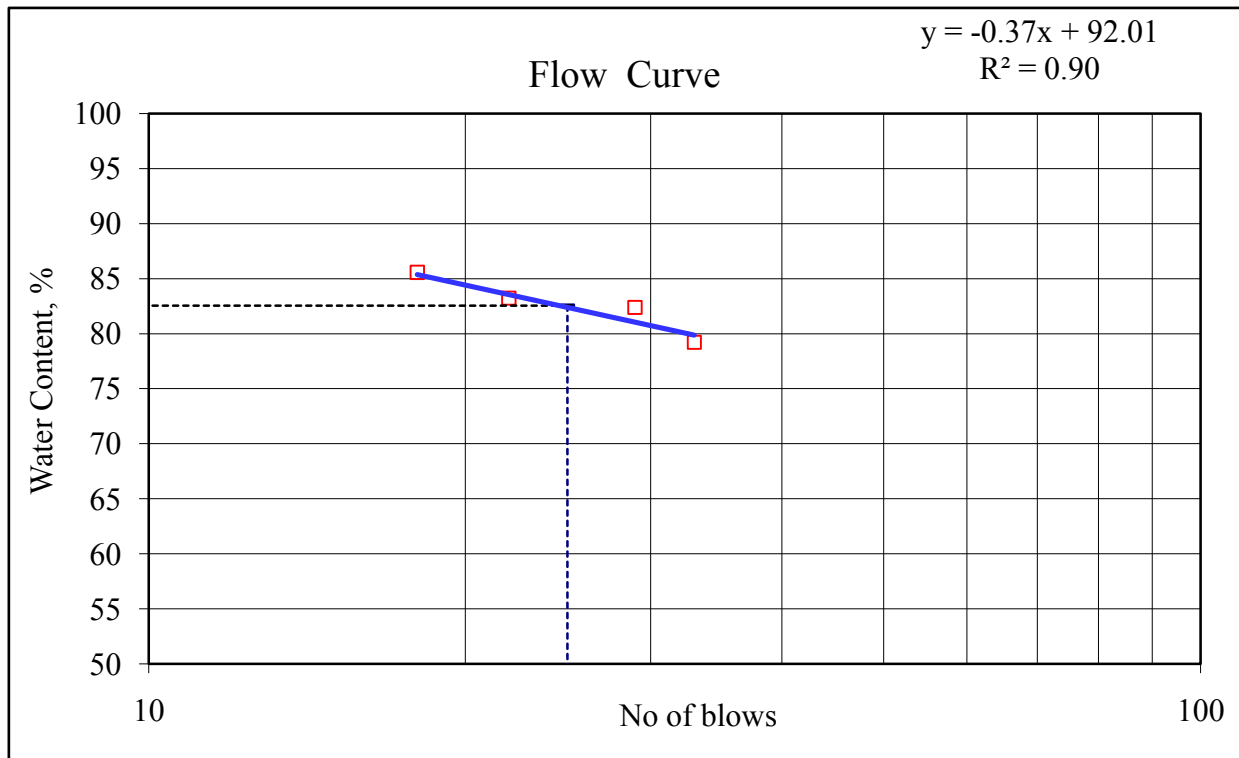
PI, % = 46.60



3.10 Location: High School (TP6) @ 3.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	9T	IL6	S4	D2	B11	MT1
Mass of container, g	15.60	15.80	15.75	15.70	16.00	15.50
Mass of container + Wet soil, g	34.60	32.40	34.90	35.00	22.70	22.10
Mass of container + Dry soil, g	26.20	24.90	26.20	26.10	21.10	20.60
Mass of water, g	8.40	7.50	8.70	8.90	1.60	1.50
Mass of dry soil, g	10.60	9.10	10.45	10.40	5.10	5.10
Water content, %	79.25	82.42	83.25	85.58	31.37	29.41
No of blows	33	29	22	18	-----	-----

Liquid Limit, % = 82.76      Plastic Limit, % = 30.39      PI, % = 52.16



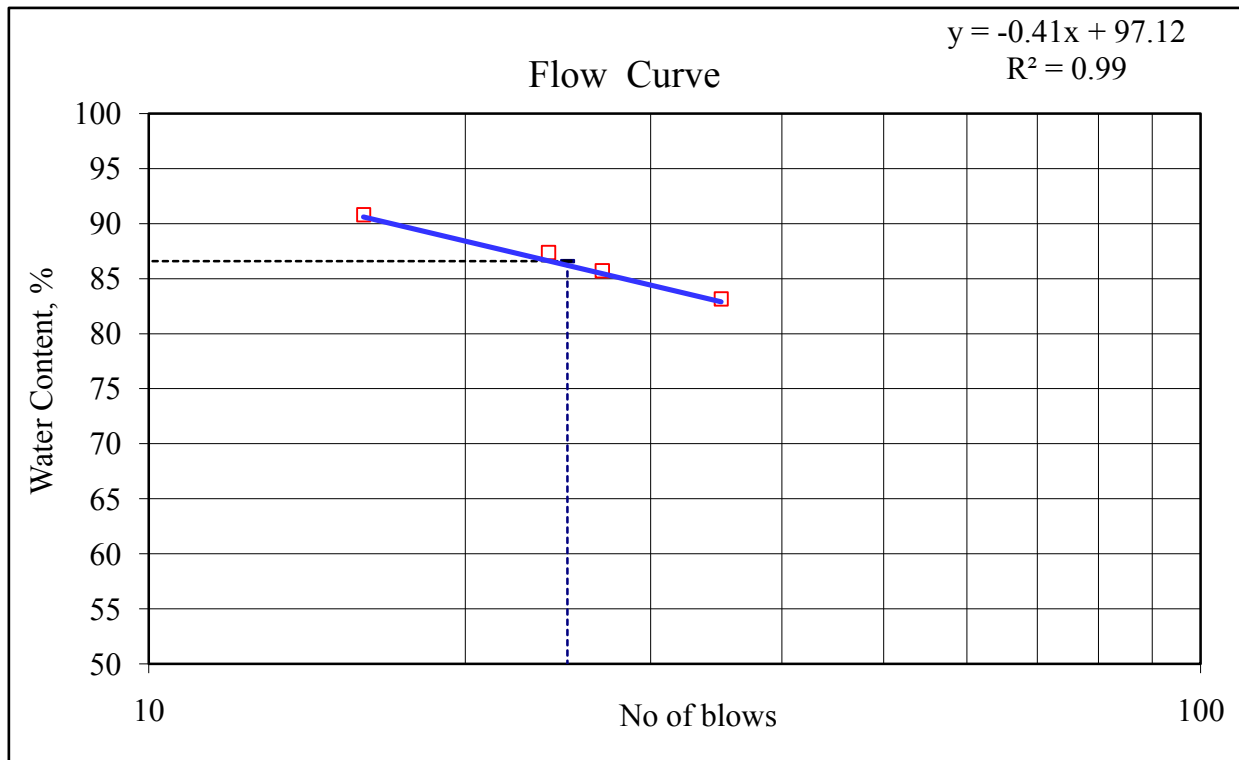
3.11 Location: Amanuel Church (TP7) @1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	TM2	Z1	G8	SG2	MT5	MT6
Mass of container, g	15.50	15.50	15.90	15.70	16.00	15.90
Mass of container + Wet soil, g	42.70	41.50	42.60	42.70	24.00	24.00
Mass of container + Dry soil, g	30.35	29.50	30.15	29.85	22.10	22.20
Mass of water, g	12.35	12.00	12.45	12.85	1.90	1.80
Mass of dry soil, g	14.85	14.00	14.25	14.15	6.10	6.30
Water content, %	83.16	85.71	87.37	90.81	31.15	28.57
No of blows	35	27	24	16	-----	-----

Liquid Limit, % = 86.87

Plastic Limit, % = 29.86

PI, % = 56.74



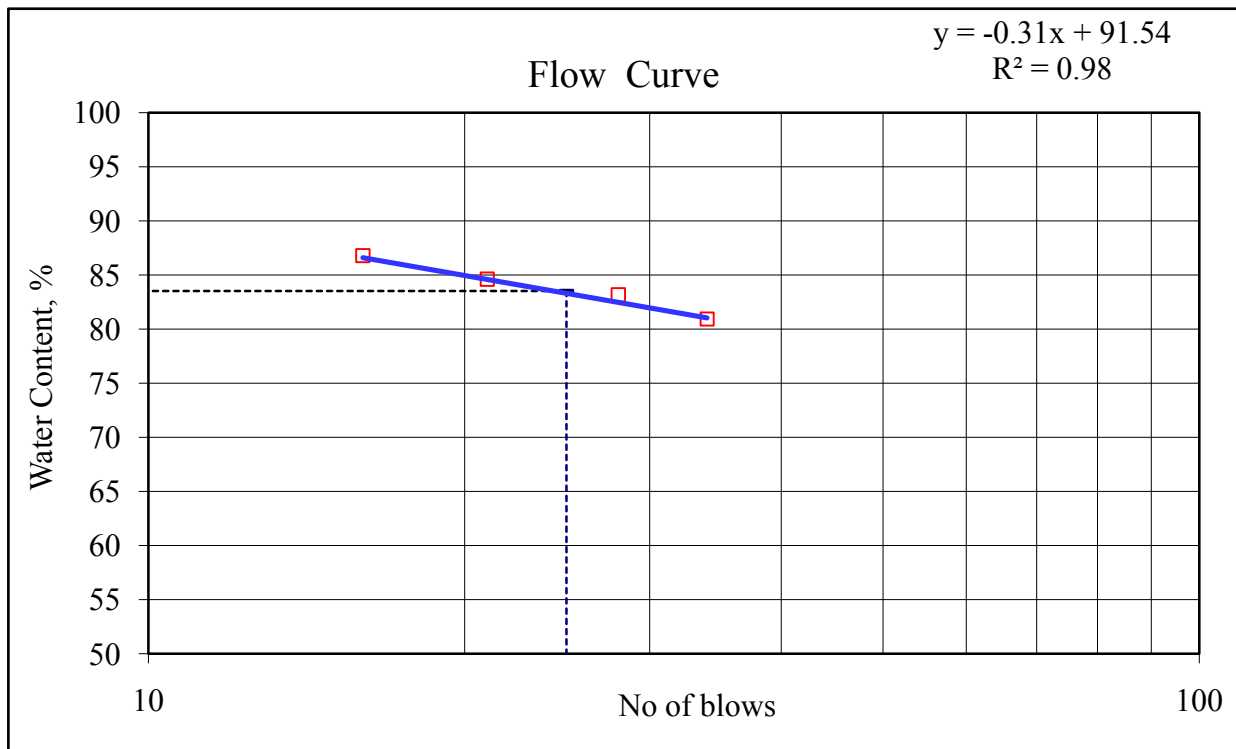
3.12 Location: Amanuel Church (TP7) @ 2.7m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	G84	H6	35	IL6	TH2	M1
Mass of container, g	15.60	15.60	23.00	15.70	15.45	15.60
Mass of container + Wet soil, g	42.20	43.00	51.80	42.60	23.50	23.60
Mass of container + Dry soil, g	30.30	30.56	38.60	30.10	21.70	21.80
Mass of water, g	11.90	12.44	13.20	12.50	1.80	1.80
Mass of dry soil, g	14.70	14.96	15.60	14.40	6.25	6.20
Water content, %	80.95	83.16	84.62	86.81	28.80	29.03
No of blows	34	28	21	16	-----	-----

Liquid Limit, % = 83.79

Plastic Limit, % = 28.92

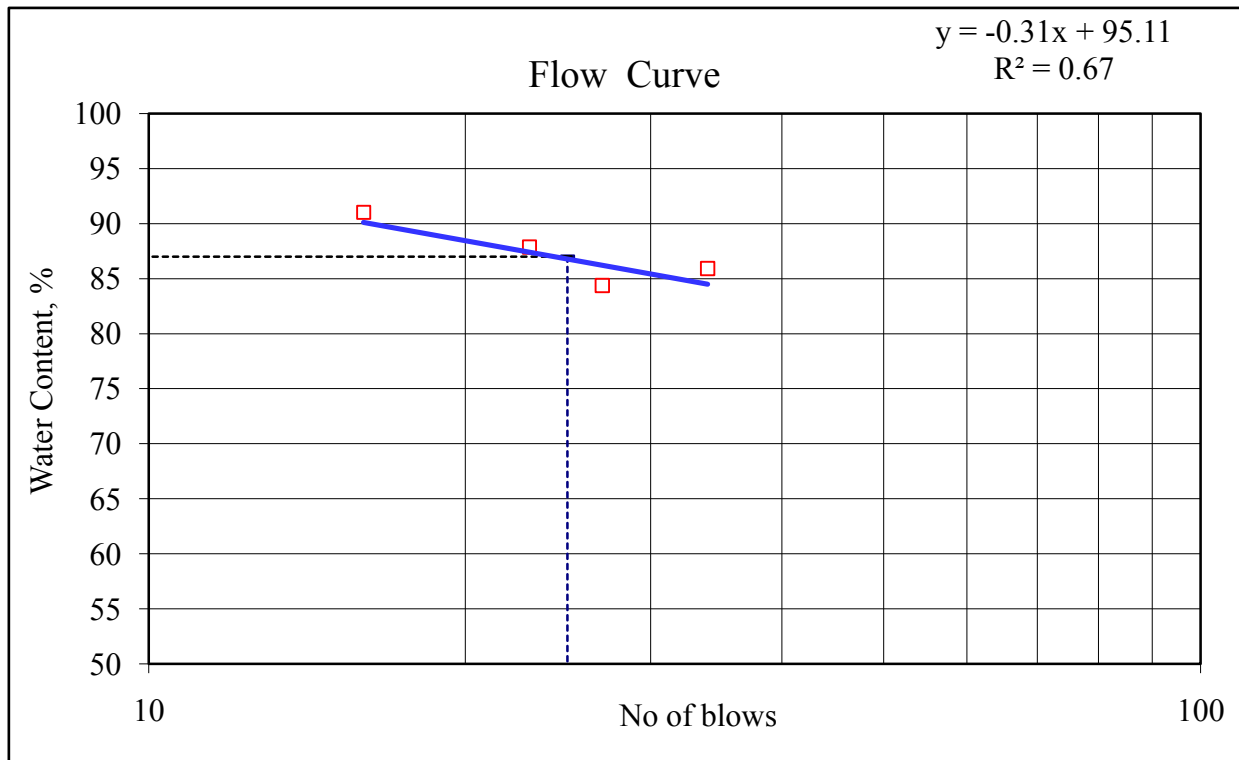
PI, % = 54.59



3.13 Location: Zenbaba Grocery (TP8) @1.3m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	FL105	62	H10	B16	GA	28
Mass of container, g	15.20	15.50	15.75	16.05	15.70	15.70
Mass of container + Wet soil, g	33.70	33.20	35.10	34.20	22.05	21.95
Mass of container + Dry soil, g	25.15	25.10	26.05	25.55	20.60	20.50
Mass of water, g	8.55	8.10	9.05	8.65	1.45	1.45
Mass of dry soil, g	9.95	9.60	10.30	9.50	4.90	4.80
Water content, %	85.93	84.38	87.86	91.05	29.59	30.21
No of blows	34	27	23	16	-----	-----

Liquid Limit, % = 87.36      Plastic Limit, % = 29.90      PI, % = 57.11



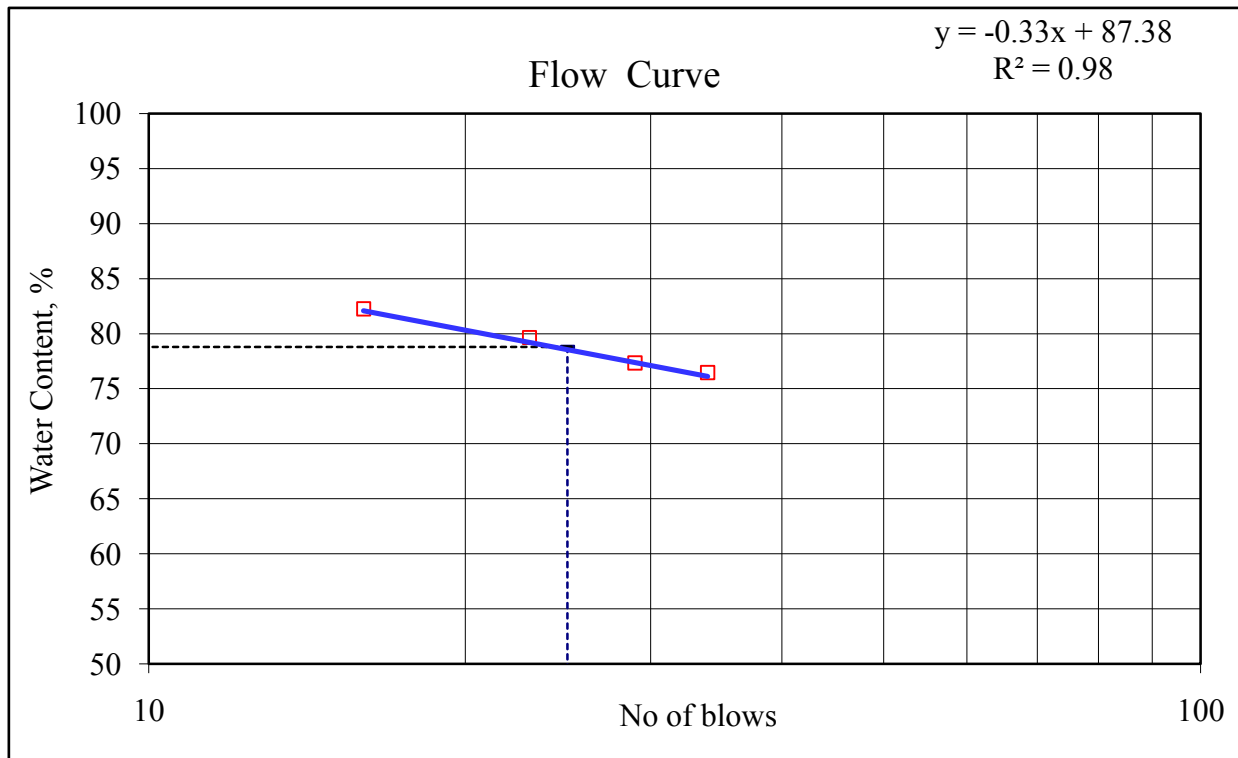
3.14 Location: Municipality (TP9) @1.4m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	TP#1	TH1	A27	24	28	P-2
Mass of container, g	22.40	15.90	21.90	15.70	15.50	15.80
Mass of container + Wet soil, g	46.40	38.60	49.75	38.30	22.00	23.50
Mass of container + Dry soil, g	36.00	28.70	37.40	28.10	20.40	21.70
Mass of water, g	10.40	9.90	12.35	10.20	1.60	1.80
Mass of dry soil, g	13.60	12.80	15.50	12.40	4.90	5.90
Water content, %	76.47	77.34	79.68	82.26	32.65	30.51
No of blows	34	29	23	16	-----	-----

Liquid Limit, % = 79.13

Plastic Limit, % = 31.58

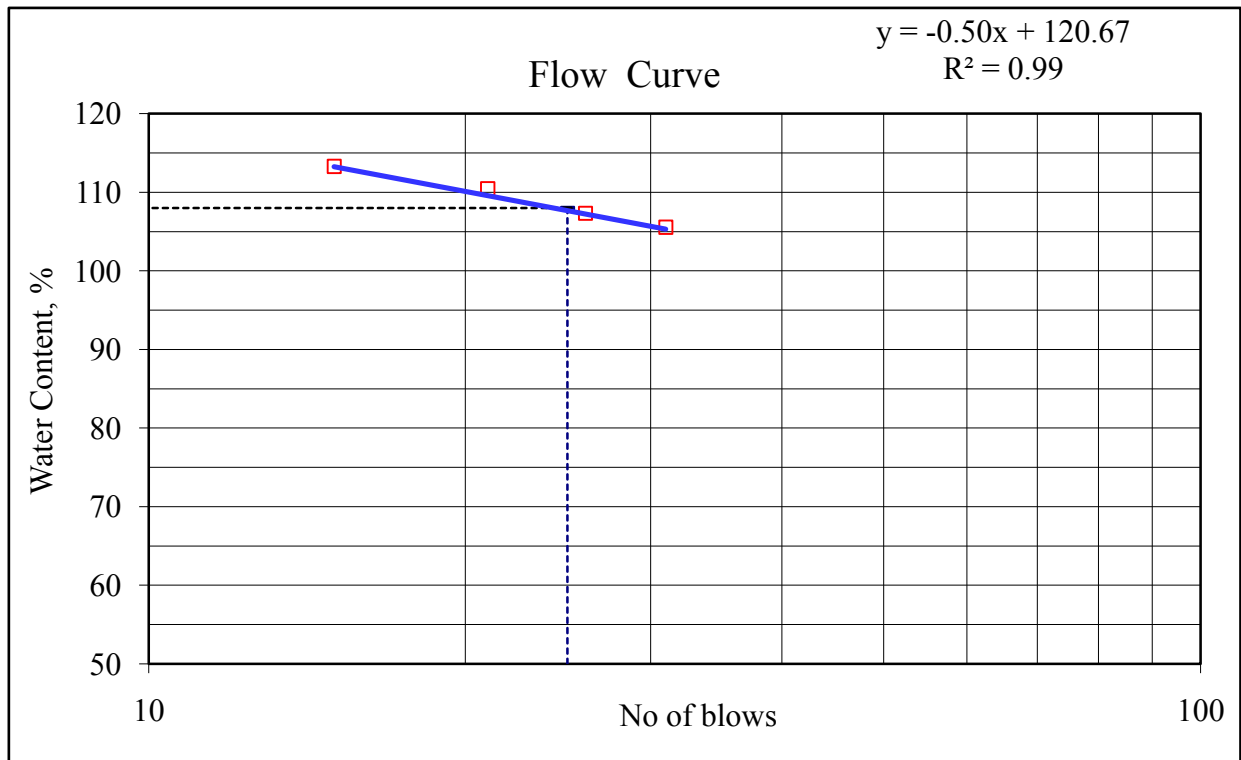
PI, % = 47.21



3.15 Location: Dabe 1 (TP10) @1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	IL6	MT2	MT6	M3	40	93
Mass of container, g	15.70	15.85	16.00	15.90	16.00	15.90
Mass of container + Wet soil, g	41.60	39.80	40.20	40.00	22.70	22.50
Mass of container + Dry soil, g	28.30	27.40	27.50	27.20	20.80	20.60
Mass of water, g	13.30	12.40	12.70	12.80	1.90	1.90
Mass of dry soil, g	12.60	11.55	11.50	11.30	4.80	4.70
Water content, %	105.56	107.36	110.43	113.27	39.58	40.43
No of blows	31	26	21	15	-----	-----

Liquid Limit, % = 108.17      Plastic Limit, % = 40.00      PI, % = 68.00



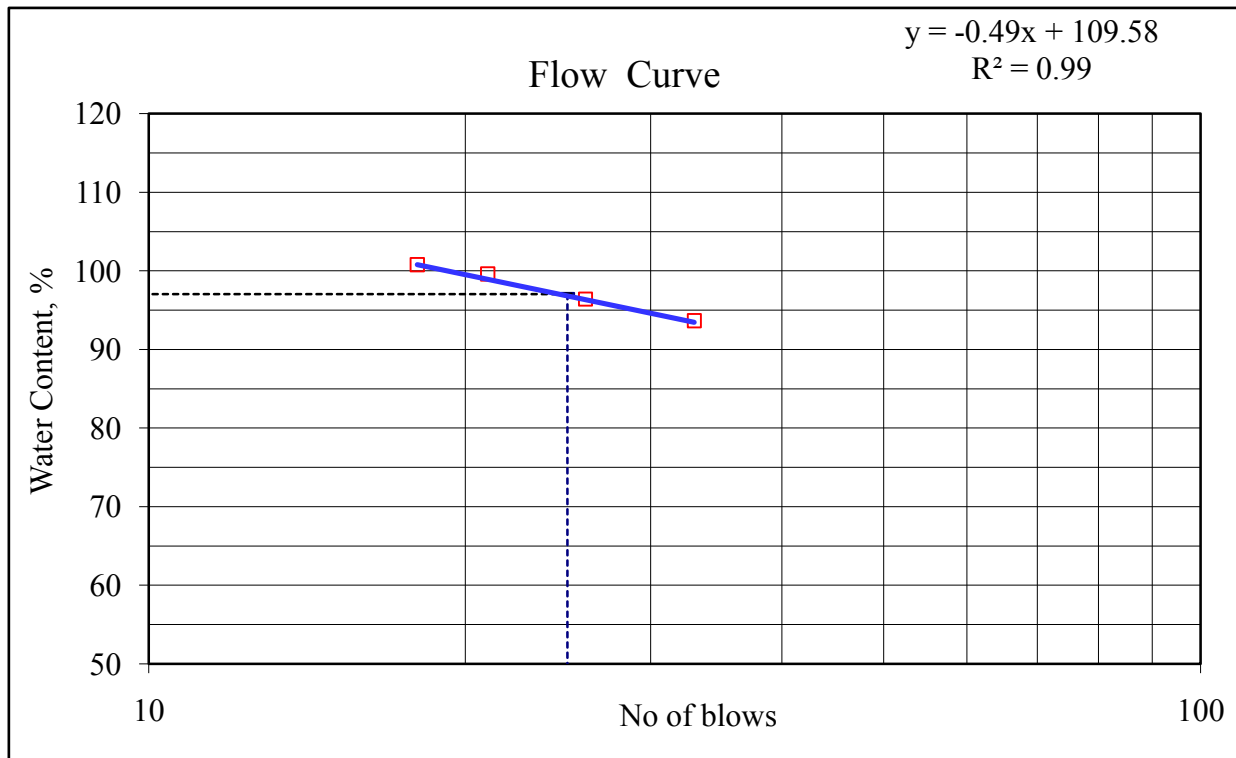
3.16 Location: Dabe 1 (TP10) @ 3.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	A49	MT5	B4	M3	MT6	B11
Mass of container, g	15.90	16.05	16.95	15.90	15.90	16.05
Mass of container + Wet soil, g	40.30	40.90	41.00	41.40	23.35	23.20
Mass of container + Dry soil, g	28.50	28.70	29.00	28.60	21.50	21.40
Mass of water, g	11.80	12.20	12.00	12.80	1.85	1.80
Mass of dry soil, g	12.60	12.65	12.05	12.70	5.60	5.35
Water content, %	93.65	96.44	99.59	100.79	33.04	33.64
No of blows	33	26	21	18	-----	-----

Liquid Limit, % = 97.33

Plastic Limit, % = 33.34

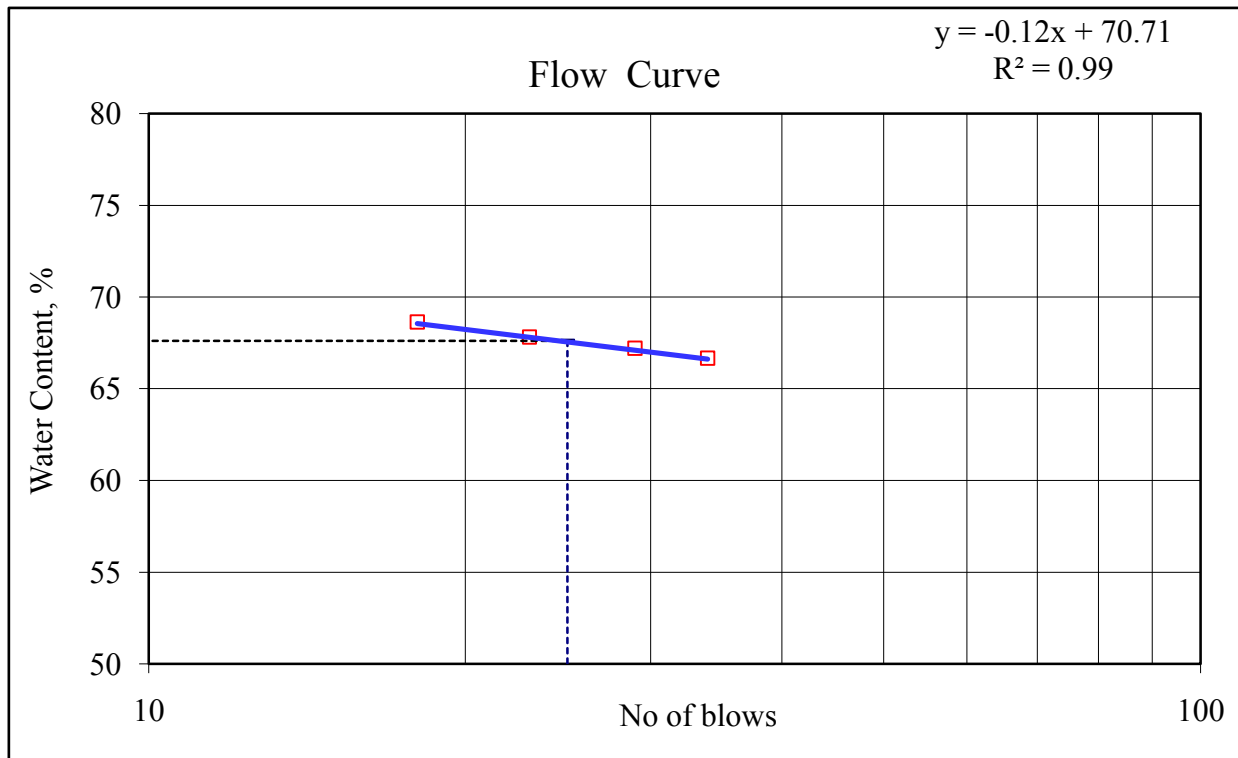
PI, % = 63.70



3.17 Location: Dire Mazoria (TP11) @1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	4	TH1	MT7	Z1	MG	B25
Mass of container, g	15.80	15.90	16.80	15.50	15.35	15.70
Mass of container + Wet soil, g	46.30	47.00	43.65	48.30	22.30	22.90
Mass of container + Dry soil, g	34.10	34.50	32.80	34.95	21.30	21.70
Mass of water, g	12.20	12.50	10.85	13.35	1.00	1.20
Mass of dry soil, g	18.30	18.60	16.00	19.45	5.95	6.00
Water content, %	66.67	67.20	67.81	68.64	16.81	20.00
No of blows	34	29	23	18	-----	-----

Liquid Limit, % = 67.71      Plastic Limit, % = 18.40      PI, % = 49.20



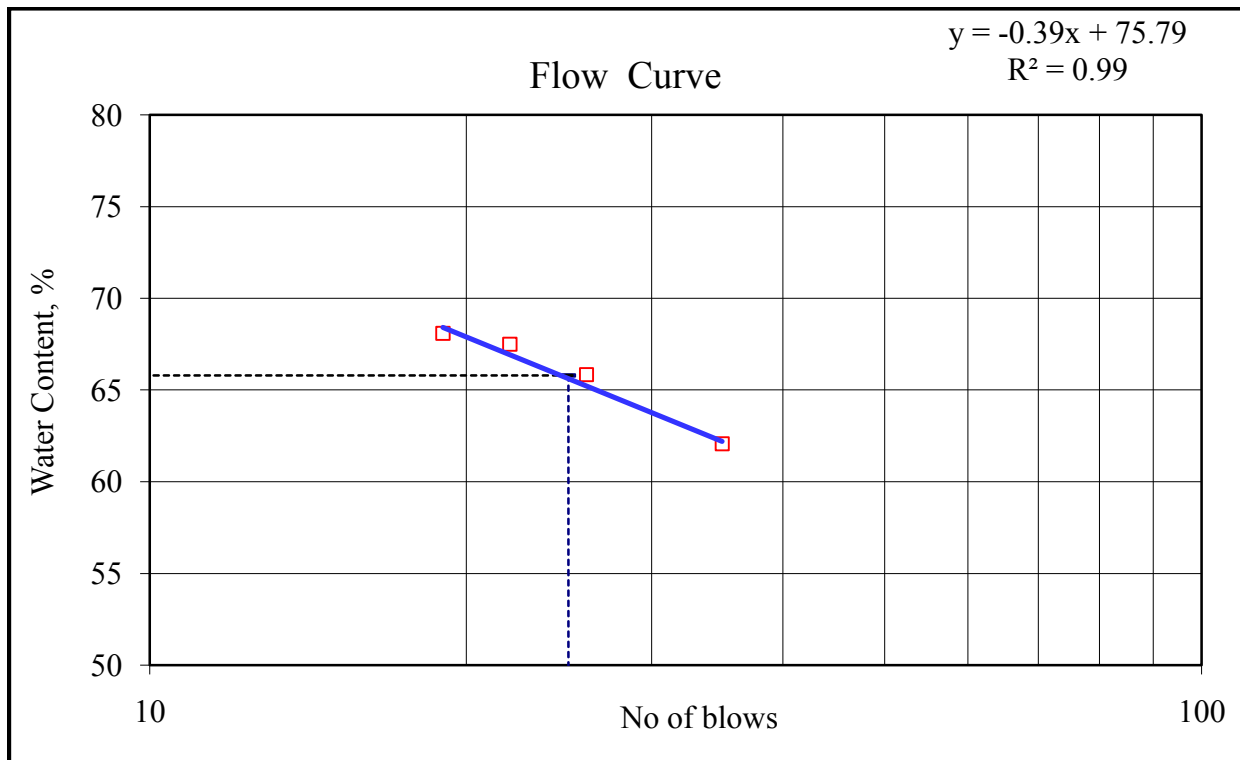
3.18 Location: Dire Mazoria (TP11) @ 3.0m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	F101	AM	Z	Z1	40	93
Mass of container, g	15.70	15.60	15.80	15.60	15.75	15.80
Mass of container + Wet soil, g	39.85	39.40	39.00	40.90	23.20	23.30
Mass of container + Dry soil, g	30.60	29.95	29.65	30.65	21.80	21.90
Mass of water, g	9.25	9.45	9.35	10.25	1.40	1.40
Mass of dry soil, g	14.90	14.35	13.85	15.05	6.05	6.10
Water content, %	62.08	65.85	67.51	68.11	23.14	22.95
No of blows	35	26	22	19	-----	-----

Liquid Limit, % = 66.04

Plastic Limit, % = 23.05

PI, % = 42.76



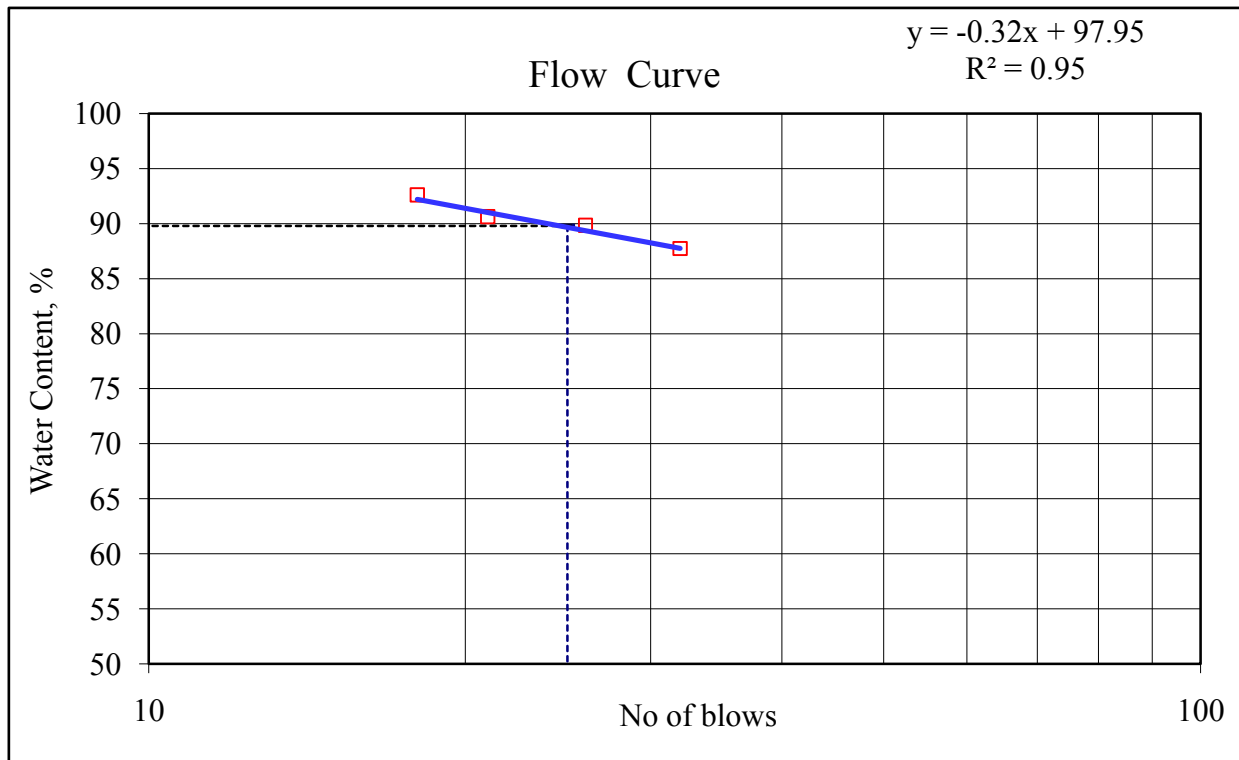
3.19 Location: Dabe 2 (TP12) @1.5m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	AM	Z	MT8	AL3	S4	12%
Mass of container, g	15.60	15.80	15.50	15.60	15.80	15.80
Mass of container + Wet soil, g	41.70	42.00	39.90	41.70	22.80	22.80
Mass of container + Dry soil, g	29.50	29.60	28.30	29.15	21.20	21.20
Mass of water, g	12.20	12.40	11.60	12.55	1.60	1.60
Mass of dry soil, g	13.90	13.80	12.80	13.55	5.40	5.40
Water content, %	87.77	89.86	90.63	92.62	29.63	29.63
No of blows	32	26	21	18	-----	-----

Liquid Limit, % = 89.95

Plastic Limit, % = 29.63

PI, % = 60.17



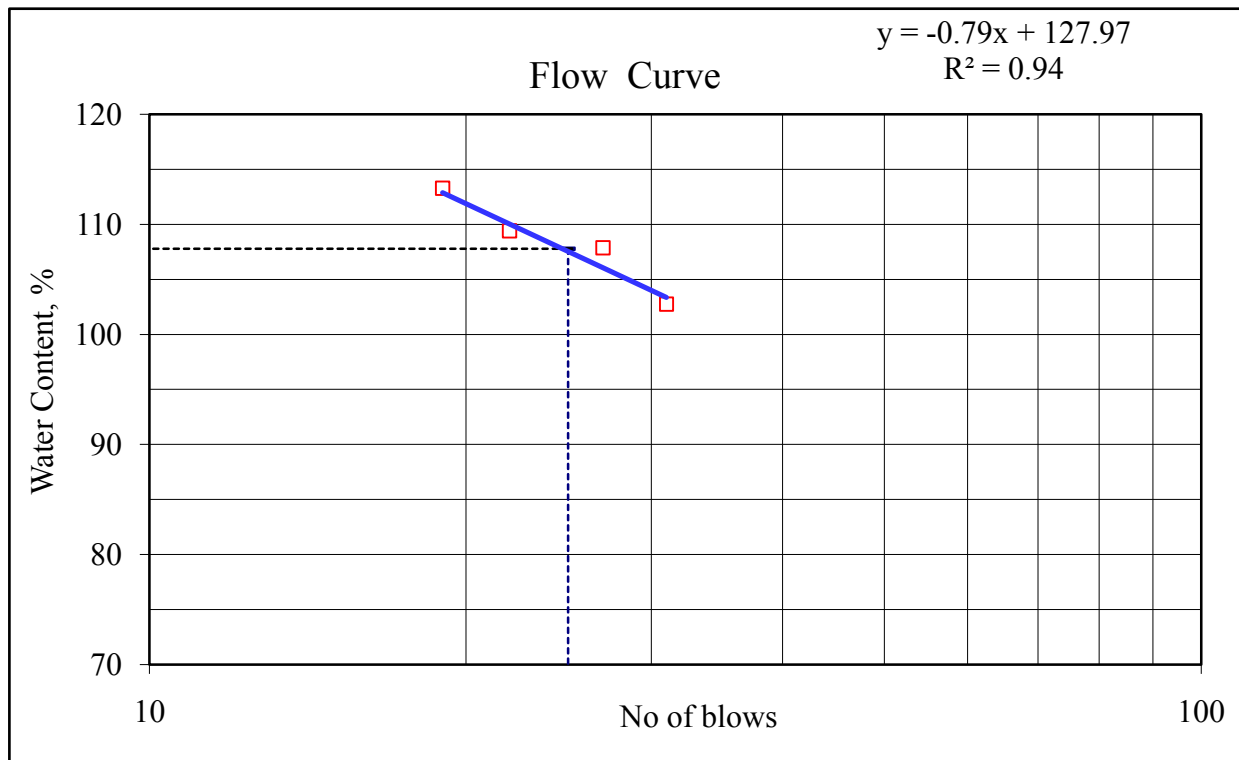
3.20 Location: Dire Caf  (TP13) @1.7m

Trial No	Liquid Limit				Plastic Limit	
	1	2	3	4	1	2
Container No	PL-1	P-2	F101	MT5	2Z2	G8
Mass of container, g	15.90	16.40	15.70	16.00	15.20	15.30
Mass of container + Wet soil, g	38.00	40.20	40.20	40.10	21.80	21.80
Mass of container + Dry soil, g	26.80	27.85	27.40	27.30	19.90	19.85
Mass of water, g	11.20	12.35	12.80	12.80	1.90	1.95
Mass of dry soil, g	10.90	11.45	11.70	11.30	4.70	4.55
Water content, %	102.75	107.86	109.40	113.27	40.43	42.86
No of blows	31	27	22	19	-----	-----

Liquid Limit, % = 108.22

Plastic Limit, % = 41.64

PI, % = 66.15



4) Grain size analysis (Section 4.2.2.4)

4.1 Location: Beke Kebele 02 (TP1) @ 1.2m

Total mass of sample, gm                      1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.0
2"	50.0						100.0
1.5"	37.5						100.0
1"	25.0						100.0
3/4"	19.0						100.0
1/2"	12.5						100.0
3/8"	9.5						100.0
No 4	4.75	1262.9	1268.3	5.40	0.36	0.36	99.64
No 8	2.36	990.3	1005.6	15.30	1.02	1.38	98.62
No 10	2	944.2	950.0	5.80	0.39	1.77	98.23
No 16	1.18	894.4	913.5	19.10	1.27	3.04	96.96
No 30	0.6	833.6	851.1	17.50	1.17	4.21	95.79
No 40	0.425	786.2	791.9	5.70	0.38	4.59	95.41
No 50	0.3	750.1	754.3	4.20	0.28	4.87	95.13
No 100	0.15	782.3	788.1	5.80	0.39	5.25	94.75
No 200	0.075	764.5	767.7	3.20	0.21	5.47	94.53
pan	-----	735.8	735.8	1418.0	94.53	100	0

Gravel	sand	silt	clay
1.77%	3.70%	38.14%	56.39%

Developing Correlation between Index Properties and Swelling Potential of Expansive Soil of Sendafa Town, Ethiopia

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Hydrometer Analysis

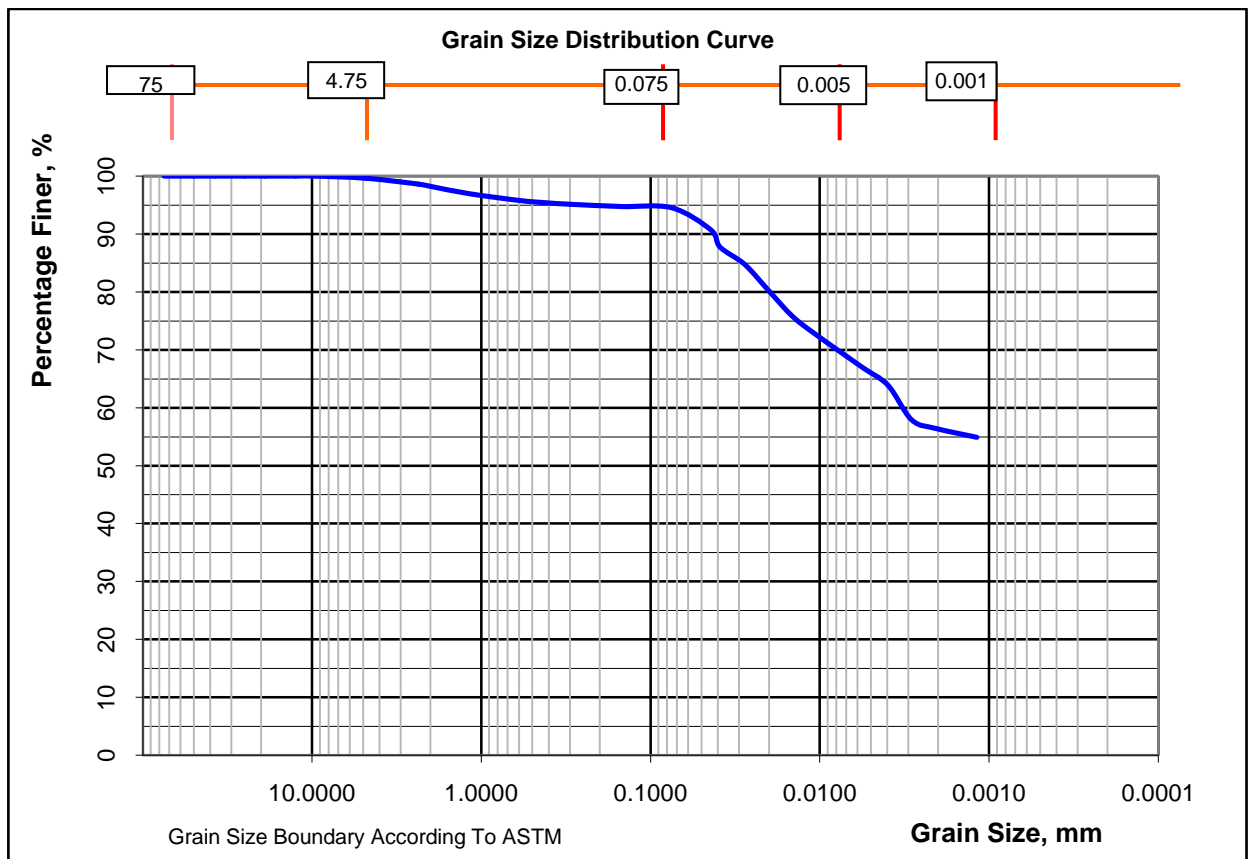
Specific Gravity

2.73

Temperature, °C

20.37

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Percent Finer (%)	Percent Finer Combined (%)
0.75	1.0330	-0.0026	1.0304	8.26	0.013286	0.0441	95.94	90.70
1	1.0320	-0.0026	1.0294	8.52	0.013286	0.0388	92.79	87.72
2	1.0310	-0.0026	1.0284	8.79	0.013286	0.0278	89.63	84.73
4	1.0295	-0.0026	1.0269	9.18	0.013286	0.0201	84.90	80.26
8	1.0280	-0.0026	1.0254	9.58	0.013286	0.0145	80.16	75.78
15	1.0270	-0.0026	1.0244	9.85	0.013286	0.0108	77.01	72.80
30	1.0260	-0.0026	1.0234	10.11	0.013286	0.0077	73.85	69.81
60	1.0250	-0.0026	1.0224	10.37	0.013286	0.0055	70.70	66.83
120	1.0240	-0.0026	1.0214	10.64	0.013286	0.0040	67.54	63.85
240	1.0220	-0.0026	1.0194	11.17	0.013286	0.0029	61.23	57.88
480	1.0215	-0.0026	1.0189	11.30	0.013286	0.0020	59.65	56.39
1440	1.0210	-0.0026	1.0184	11.43	0.013286	0.0012	58.07	54.90



4.2 Location: Beke Kebele 02 (TP1) @ 2.3m

Total mass of sample gm, 1500

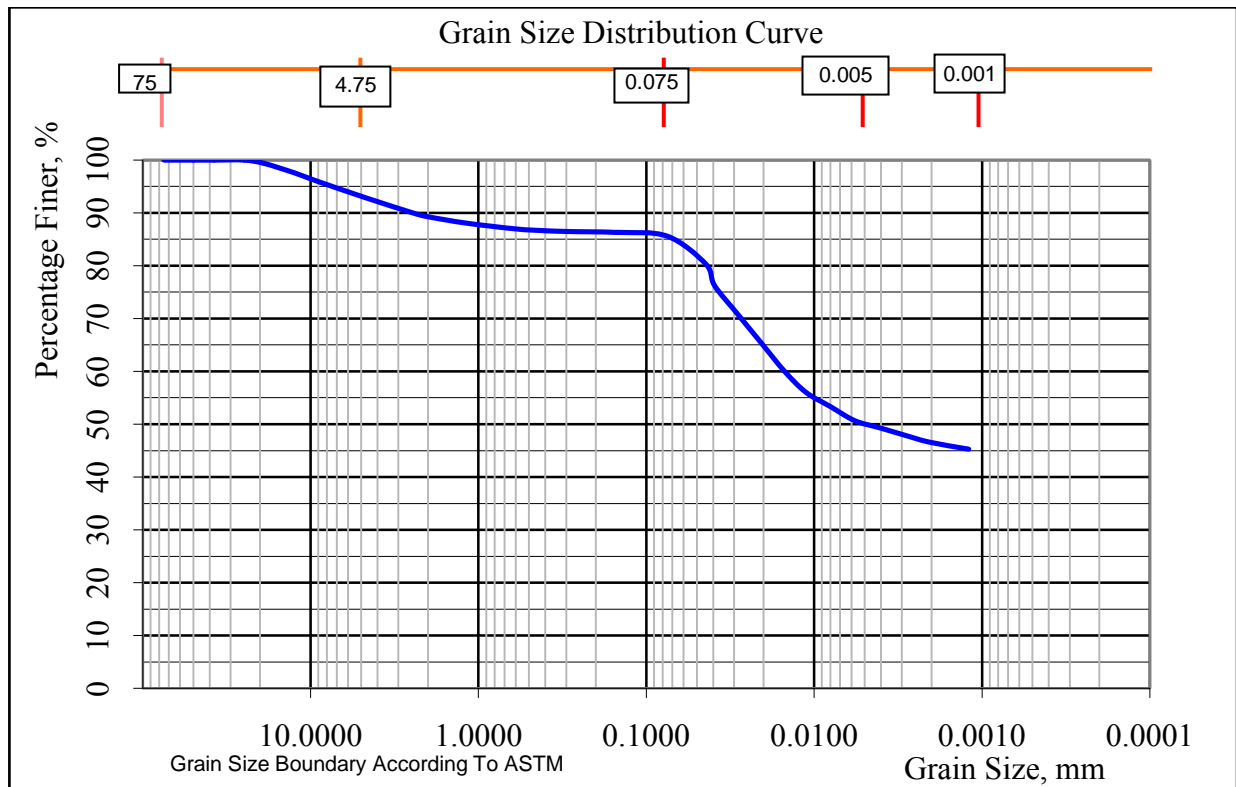
Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil(g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.0
2"	50.0						100.0
1.5"	37.5						100.0
1"	25.0						100.0
3/4"	19.0	1178.40	1188.30	9.90	0.66	0.66	99.34
1/2"	12.5	1216.80	1244.00	27.20	1.81	2.47	97.53
3.8"	9.5	1164.50	1184.90	20.40	1.36	3.83	96.17
No 4	4.75	1262.90	1311.70	48.80	3.25	7.09	92.91
No 8	2.36	990.30	1036.80	46.50	3.10	10.19	89.81
No 10	2	944.20	953.10	8.90	0.59	10.78	89.22
No 16	1.18	894.40	912.40	18.00	1.20	11.98	88.02
No 30	0.6	833.60	849.70	16.10	1.07	13.05	86.95
No 40	0.425	786.20	790.50	4.30	0.29	13.34	86.66
No 50	0.3	750.10	753.10	3.00	0.20	13.54	86.46
No 100	0.15	782.30	785.10	2.80	0.19	13.73	86.27
No 200	0.075	764.50	775.30	10.80	0.72	14.45	85.55
Pan	-----	735.80	735.9	1283.3	85.55	100	0

Gravel	sand	silt	clay
10.78	3.67	39.10	46.45

Hydrometer Analysis

Specific Gravity of soil = 2.76      Temperature, °C = 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0027	1.0298	8.42	0.013214	0.0443	93.46	80.27
1	1.0310	-0.0027	1.0283	8.81	0.013214	0.0392	88.76	76.23
2	1.0290	-0.0027	1.0263	9.34	0.013214	0.0286	82.49	70.84
4	1.0270	-0.0027	1.0243	9.87	0.013214	0.0208	76.21	65.46
8	1.0250	-0.0027	1.0223	10.40	0.013214	0.0151	69.94	60.07
15	1.0235	-0.0027	1.0208	10.80	0.013214	0.0112	65.24	56.03
30	1.0225	-0.0027	1.0198	11.06	0.013214	0.0080	62.10	53.34
60	1.0215	-0.0027	1.0188	11.33	0.013214	0.0057	58.96	50.64
120	1.0210	-0.0027	1.0183	11.46	0.013214	0.0041	57.40	49.30
240	1.0205	-0.0027	1.0178	11.59	0.013214	0.0029	55.83	47.95
480	1.0200	-0.0027	1.0173	11.72	0.013214	0.0021	54.26	46.60
1440	1.0195	-0.0027	1.0168	11.86	0.013214	0.0012	52.69	45.25



4.3 Location: St. Merry (TP2) @ 0.90m

Total mass of sample gm, 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3/8"	9.5	1164.50	1170.50	6.00	0.40	0.40	99.60
No 4	4.75	1262.90	1278.00	15.10	1.01	1.41	98.59
No 8	2.36	990.30	1003.00	12.70	0.85	2.25	97.75
No 10	2	944.20	947.00	2.80	0.19	2.44	97.56
No 16	1.18	894.40	901.10	6.70	0.45	2.89	97.11
No 30	0.6	833.60	842.70	9.10	0.61	3.49	96.51
No 40	0.425	786.20	790.80	4.60	0.31	3.80	96.20
No 50	0.3	750.10	754.30	4.20	0.28	4.08	95.92
No 100	0.15	782.30	791.80	9.50	0.63	4.71	95.29
No 200	0.075	764.50	774.40	9.90	0.66	5.37	94.63
Pan	-----	735.80	735.9	1419.4	94.63	100	0

Gravel	sand	silt	clay
2.44	2.93	38.83	55.80

Developing Correlation between Index Properties and Swelling Potential of Expansive Soil of Sendafa Town, Ethiopia

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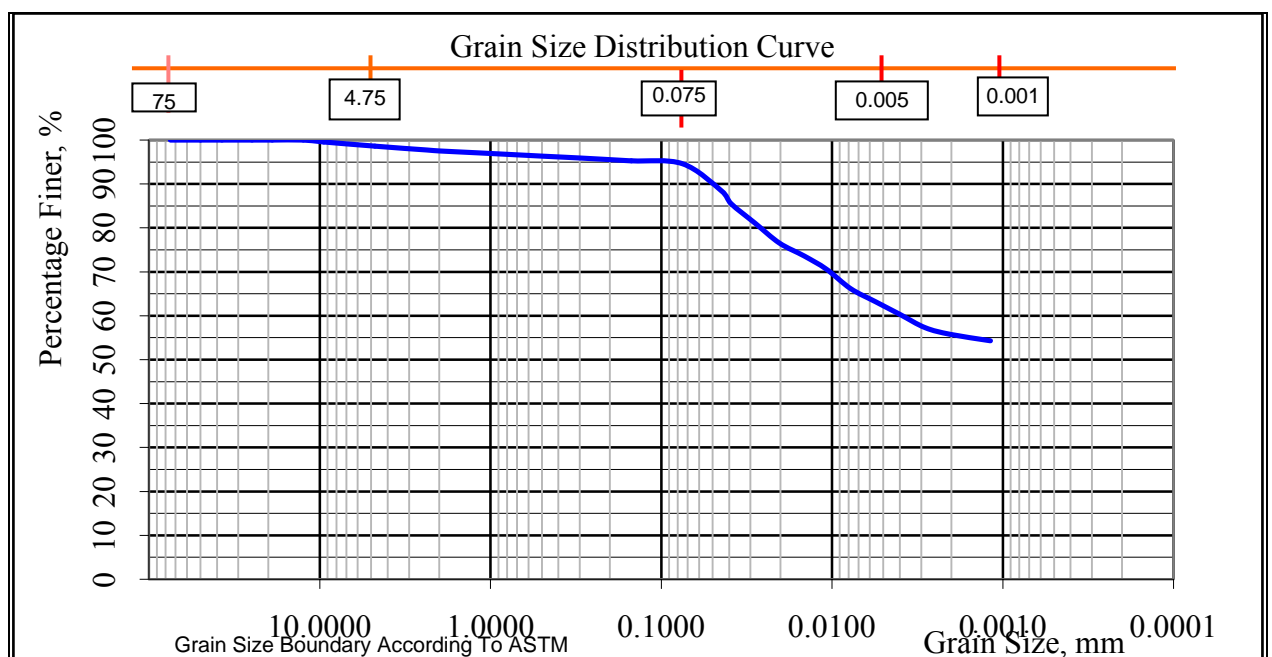
Hydrometer Analysis

Specific Gravity of soil =

2.76

Test Temperature, de 20

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0027	1.0298	8.42	0.01321	0.0443	93.46	88.44
1	1.0315	-0.0027	1.0288	8.68	0.01321	0.0389	90.33	85.47
2	1.0300	-0.0027	1.0273	9.08	0.01321	0.0282	85.62	81.02
4	1.0285	-0.0027	1.0258	9.48	0.01321	0.0203	80.92	76.57
8	1.0275	-0.0027	1.0248	9.74	0.01321	0.0146	77.78	73.60
15	1.0265	-0.0027	1.0238	10.00	0.01321	0.0108	74.65	70.63
30	1.0250	-0.0027	1.0223	10.40	0.01321	0.0078	69.94	66.18
60	1.0240	-0.0027	1.0213	10.67	0.01321	0.0056	66.80	63.21
120	1.0230	-0.0027	1.0203	10.93	0.01321	0.0040	63.67	60.25
240	1.0220	-0.0027	1.0193	11.19	0.01321	0.0029	60.53	57.28
480	1.0215	-0.0027	1.0188	11.33	0.01321	0.0020	58.96	55.80
1440	1.0210	-0.0027	1.0183	11.46	0.01321	0.0012	57.40	54.31



4.4 Location: Got 3 (TP3) @ 1.0m

Total mass of sample gm, 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75	1262.90	1265.30	2.40	0.16	0.16	99.84
No 8	2.36	990.30	995.20	4.90	0.33	0.49	99.51
No 10	2	944.20	946.20	2.00	0.13	0.62	99.38
No 16	1.18	894.40	900.80	6.40	0.43	1.05	98.95
No 30	0.6	833.60	840.40	6.80	0.45	1.50	98.50
No 40	0.425	786.20	789.30	3.10	0.21	1.71	98.29
No 50	0.3	750.10	754.00	3.90	0.26	1.97	98.03
No 100	0.15	782.30	801.00	18.70	1.25	3.21	96.79
No 200	0.075	764.50	786.50	22.00	1.47	4.68	95.32
Pan	-----	735.80	735.9	1429.8	95.32	100	0

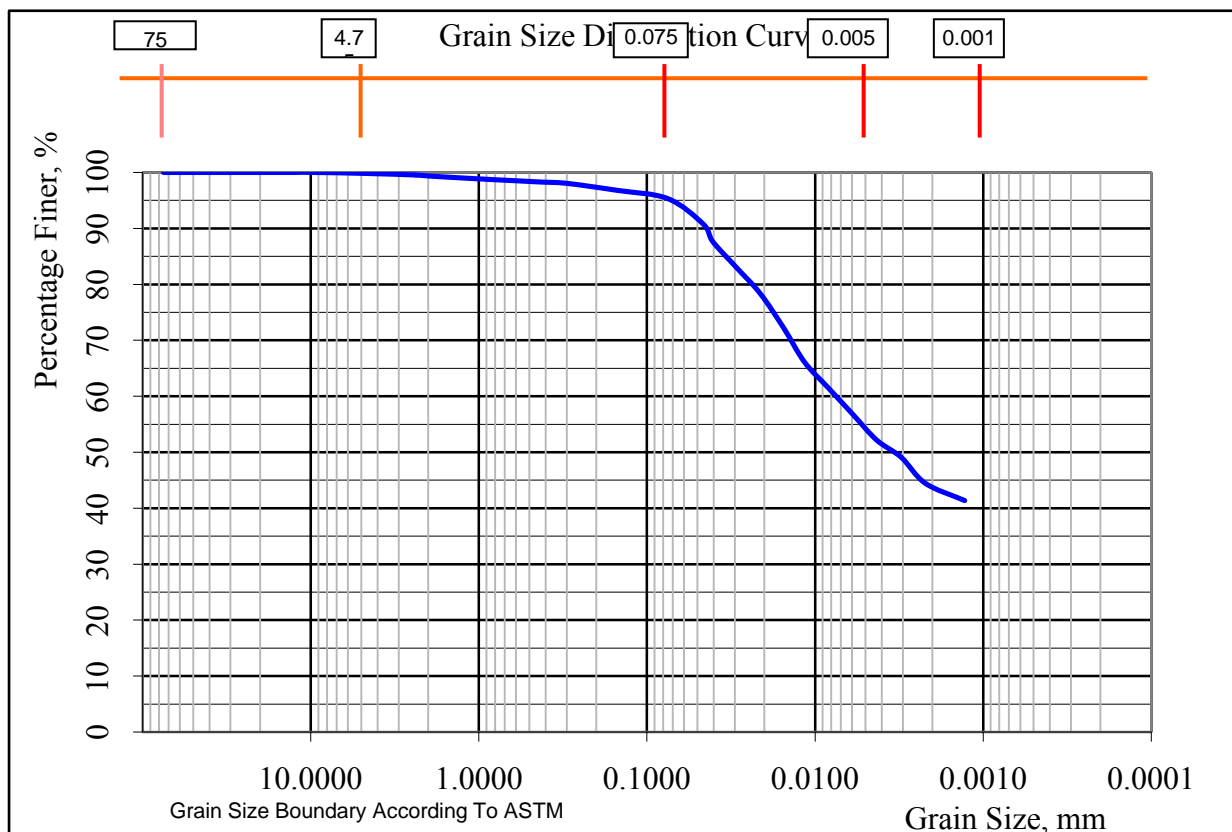
Gravel	sand	silt	clay
0.620	4.060	51.570	43.750

Hydrometer Analysis

Specific Gravity of soil =

2.62 Test Temperature, de 20.5

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0320	-0.0026	1.0294	8.52	0.01367	0.0461	95.19	90.74
1	1.0310	-0.0026	1.0284	8.79	0.01367	0.0405	91.95	87.65
2	1.0295	-0.0026	1.0269	9.18	0.01367	0.0293	87.10	83.02
4	1.0280	-0.0026	1.0254	9.58	0.01367	0.0212	82.24	78.39
8	1.0260	-0.0026	1.0234	10.11	0.01367	0.0154	75.76	72.22
15	1.0240	-0.0026	1.0214	10.64	0.01367	0.0115	69.29	66.05
30	1.0225	-0.0026	1.0199	11.04	0.01367	0.0083	64.43	61.42
60	1.0210	-0.0026	1.0184	11.43	0.01367	0.0060	59.58	56.79
120	1.0195	-0.0026	1.0169	11.83	0.01367	0.0043	54.72	52.16
240	1.0185	-0.0026	1.0159	12.09	0.01367	0.0031	51.48	49.07
480	1.0170	-0.0026	1.0144	12.49	0.01367	0.0022	46.62	44.44
1440	1.0160	-0.0026	1.0134	12.76	0.01367	0.0013	43.39	41.36



4.5 Location: Sendafa Beke Border (TP4) @ 1.2m

Total mass of sample gm, 1400

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75	1262.80	1263.40	0.60	0.04	0.04	99.96
No 8	2.36	990.00	990.90	0.90	0.06	0.11	99.89
No 10	2.0	955.80	956.40	0.60	0.04	0.15	99.85
No 16	1.18	894.40	897.50	3.10	0.22	0.37	99.63
No 30	0.600	830.80	838.70	7.90	0.56	0.94	99.06
No 40	0.425	789.60	793.80	4.20	0.30	1.24	98.76
No 50	0.300	750.10	753.70	3.60	0.26	1.49	98.51
No 100	0.150	777.50	784.90	7.40	0.53	2.02	97.98
No 200	0.075	764.10	769.60	5.50	0.39	2.41	97.59
Pan	-----	387.70	387.70	1366.2	97.59	100	0

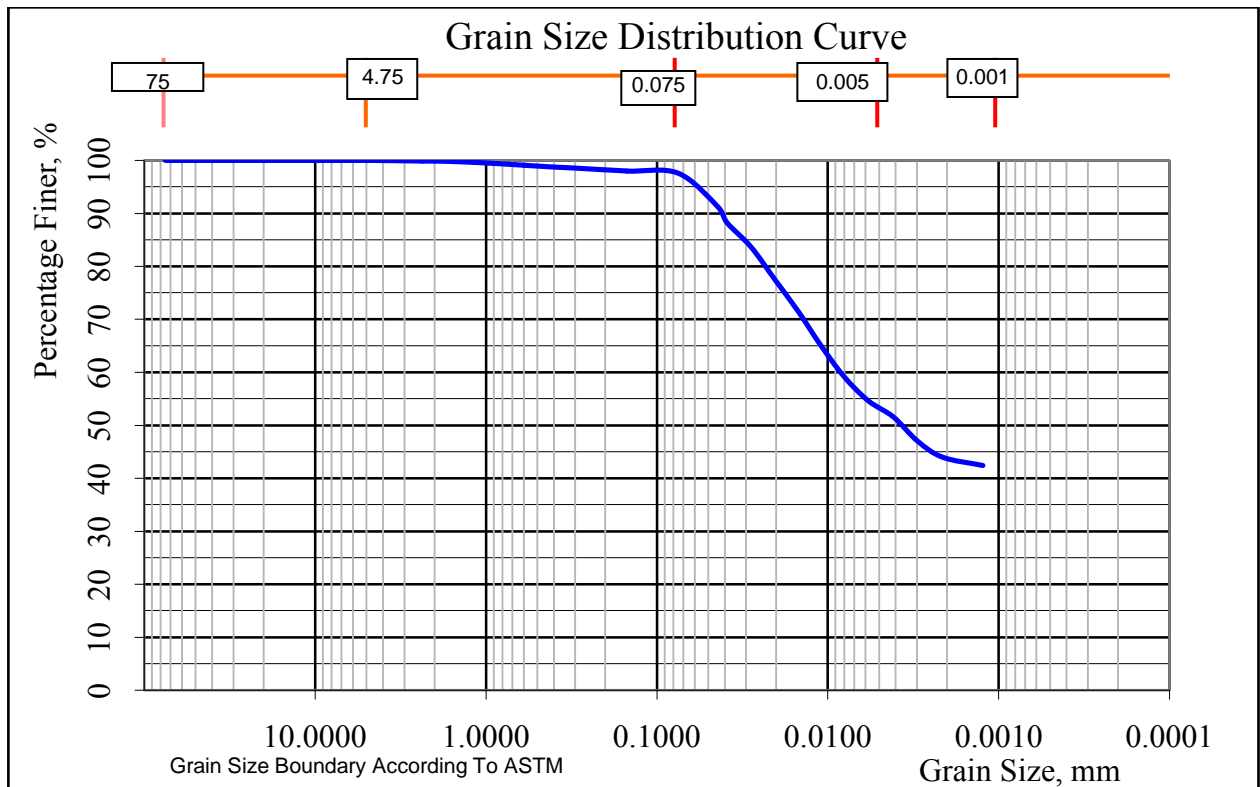
Gravel	sand	silt	clay
0.15	2.26	53.95	43.64

Hydrometer Analysis

Specific Gravity of soil =

2.77 Test Temperature, deg. 19.5

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0026	1.0299	8.39	0.01319	0.0441	93.51	91.25
1	1.0315	-0.0026	1.0289	8.66	0.01319	0.0388	90.38	88.20
2	1.0300	-0.0026	1.0274	9.05	0.01319	0.0281	85.69	83.62
4	1.0280	-0.0026	1.0254	9.58	0.01319	0.0204	79.44	77.52
8	1.0260	-0.0026	1.0234	10.11	0.01319	0.0148	73.18	71.42
15	1.0240	-0.0026	1.0214	10.64	0.01319	0.0111	66.93	65.31
30	1.0220	-0.0026	1.0194	11.17	0.01319	0.0080	60.67	59.21
60	1.0205	-0.0026	1.0179	11.57	0.01319	0.0058	55.98	54.63
120	1.0195	-0.0026	1.0169	11.83	0.01319	0.0041	52.85	51.58
240	1.0180	-0.0026	1.0154	12.23	0.01319	0.0030	48.16	47.00
480	1.0170	-0.0026	1.0144	12.49	0.01319	0.0021	45.04	43.95
1440	1.0165	-0.0026	1.0139	12.62	0.01319	0.0012	43.47	42.42



4.6 Location: Sendafa Beke Border (TP4) @ 2.5m

Total mass of sample gm, 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75						100.00
No 8	2.36	990.00	990.70	0.70	0.05	0.05	99.95
No 10	2	955.80	956.10	0.30	0.02	0.07	99.93
No 16	1.18	894.40	895.00	0.60	0.04	0.11	99.89
No 30	0.6	830.80	832.10	1.30	0.09	0.19	99.81
No 40	0.425	789.60	790.70	1.10	0.07	0.27	99.73
No 50	0.3	750.10	751.60	1.50	0.10	0.37	99.63
No 100	0.15	777.50	782.20	4.70	0.31	0.68	99.32
No 200	0.075	764.10	769.50	5.40	0.36	1.04	98.96
Pan	-----	387.70	387.7	1484.4	98.96	100	0

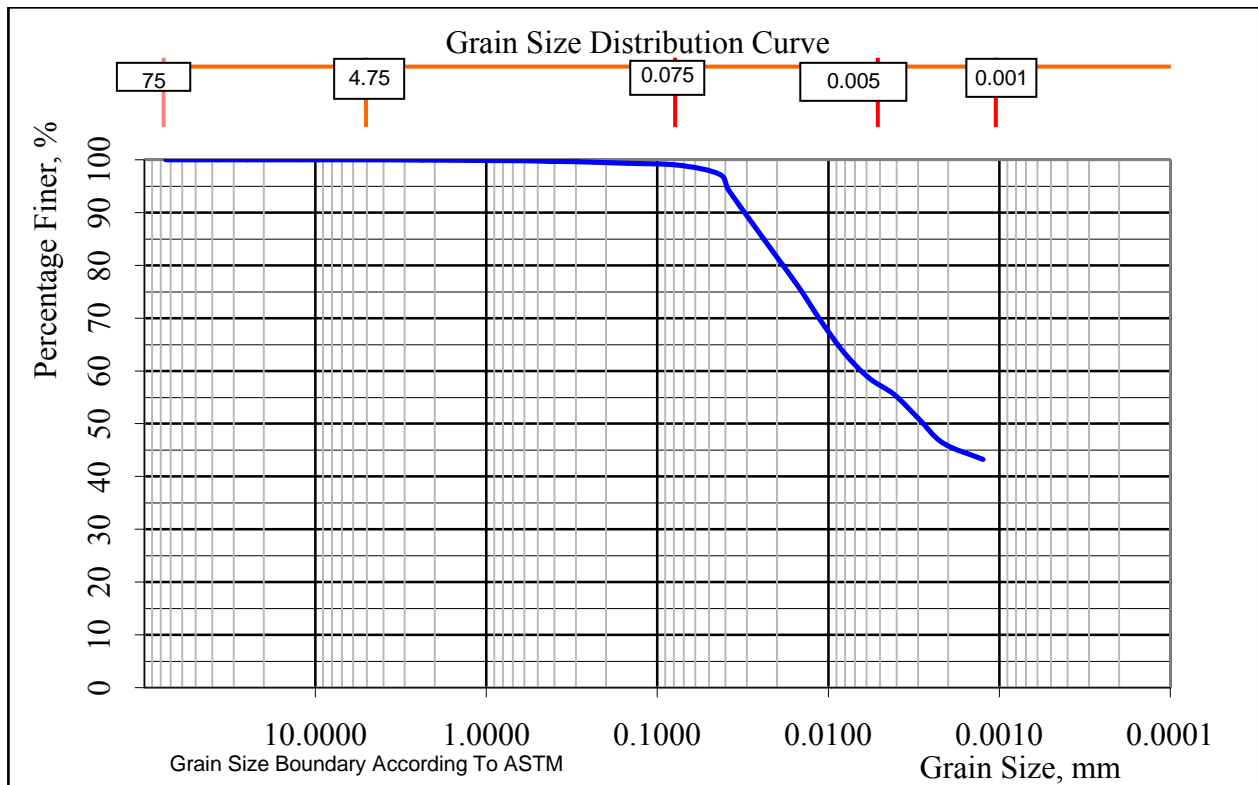
Gravel	sand	silt	clay
0.07	0.97	52.63	46.33

Hydrometer Analysis

Specific Gravity of soil =

2.78 Test Temperature, deg. 18.5

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0345	-0.003	1.0315	7.97	0.01332	0.0434	98.31	97.28
1	1.0335	-0.003	1.0305	8.23	0.01332	0.0382	95.19	94.20
2	1.0315	-0.003	1.0285	8.76	0.01332	0.0279	88.94	88.02
4	1.0295	-0.003	1.0265	9.29	0.01332	0.0203	82.70	81.84
8	1.0275	-0.003	1.0245	9.82	0.01332	0.0148	76.46	75.67
15	1.0255	-0.003	1.0225	10.35	0.01332	0.0111	70.22	69.49
30	1.0235	-0.003	1.0205	10.88	0.01332	0.0080	63.98	63.31
60	1.0220	-0.003	1.0190	11.27	0.01332	0.0058	59.30	58.68
120	1.0210	-0.003	1.0180	11.54	0.01332	0.0041	56.17	55.59
240	1.0195	-0.003	1.0165	11.94	0.01332	0.0030	51.49	50.96
480	1.0180	-0.003	1.0150	12.33	0.01332	0.0021	46.81	46.33
1440	1.0170	-0.003	1.0140	12.60	0.01332	0.0012	43.69	43.24



4.7 Location: Kebet Tera (TP5) @ 1.5m

Total mass of sample, gm    1200

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75						100.00
No 8	2.36	990.00	991.10	1.10	0.09	0.09	99.91
No 10	2	955.80	956.60	0.80	0.07	0.16	99.84
No 16	1.18	894.40	896.90	2.50	0.21	0.37	99.63
No 30	0.6	830.80	836.50	5.70	0.48	0.84	99.16
No 40	0.425	789.60	792.90	3.30	0.27	1.12	98.88
No 50	0.3	750.10	752.90	2.80	0.23	1.35	98.65
No 100	0.15	777.50	782.70	5.20	0.43	1.78	98.22
No 200	0.075	764.10	767.30	3.20	0.27	2.05	97.95
Pan	-----	387.70	387.7	1175.4	97.95	100	0

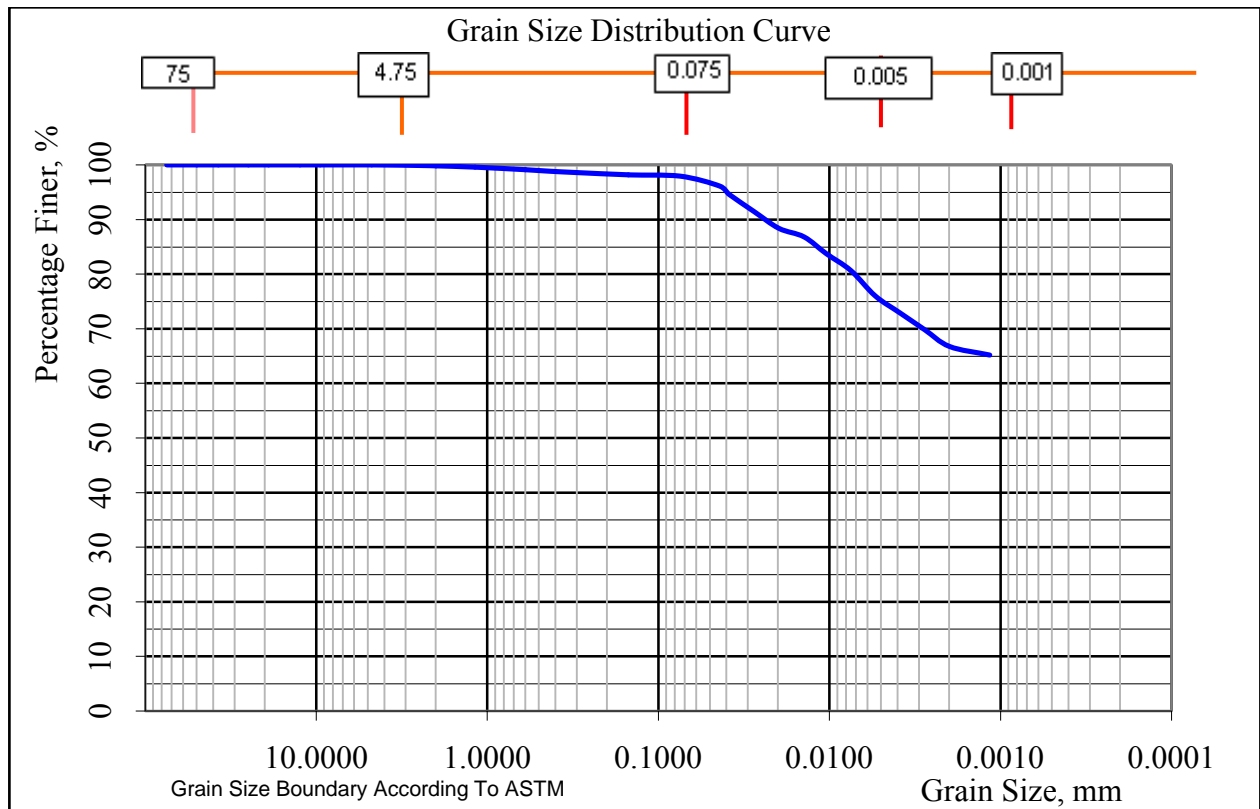
Gravel	sand	silt	clay
0.16	1.89	31.18	66.77

Hydrometer Analysis

Specific Gravity of soil =

2.73 Test Temperature, deg. 19.25

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0340	-0.0029	1.0311	8.07	0.01338	0.0439	98.15	96.13
1	1.0335	-0.0029	1.0306	8.21	0.01338	0.0383	96.57	94.59
2	1.0325	-0.0029	1.0296	8.47	0.01338	0.0275	93.41	91.50
4	1.0315	-0.0029	1.0286	8.73	0.01338	0.0198	90.26	88.41
8	1.0310	-0.0029	1.0281	8.87	0.01338	0.0141	88.68	86.86
15	1.0300	-0.0029	1.0271	9.13	0.01338	0.0104	85.52	83.77
30	1.0290	-0.0029	1.0261	9.40	0.01338	0.0075	82.37	80.68
60	1.0275	-0.0029	1.0246	9.79	0.01338	0.0054	77.63	76.04
120	1.0265	-0.0029	1.0236	10.06	0.01338	0.0039	74.48	72.95
240	1.0255	-0.0029	1.0226	10.32	0.01338	0.0028	71.32	69.86
480	1.0245	-0.0029	1.0216	10.59	0.01338	0.0020	68.17	66.77
1440	1.0240	-0.0029	1.0211	10.72	0.01338	0.0012	66.59	65.22



4.8 Location: Keft Tera (TP5) @ 2.5m

Total mass of sample gm, 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75	1262.80	1263.60	0.80	0.05	0.05	99.95
No 8	2.36	990.00	992.70	2.70	0.18	0.23	99.77
No 10	2	955.80	956.90	1.10	0.07	0.31	99.69
No 16	1.18	894.40	899.90	5.50	0.37	0.67	99.33
No 30	0.6	830.80	839.30	8.50	0.57	1.24	98.76
No 40	0.425	786.40	790.70	4.30	0.29	1.53	98.47
No 50	0.3	750.10	753.60	3.50	0.23	1.76	98.24
No 100	0.15	777.50	784.60	7.10	0.47	2.23	97.77
No 200	0.075	764.10	769.10	5.00	0.33	2.57	97.43
Pan	-----	387.7	387.7	1461.5	97.43	100	0

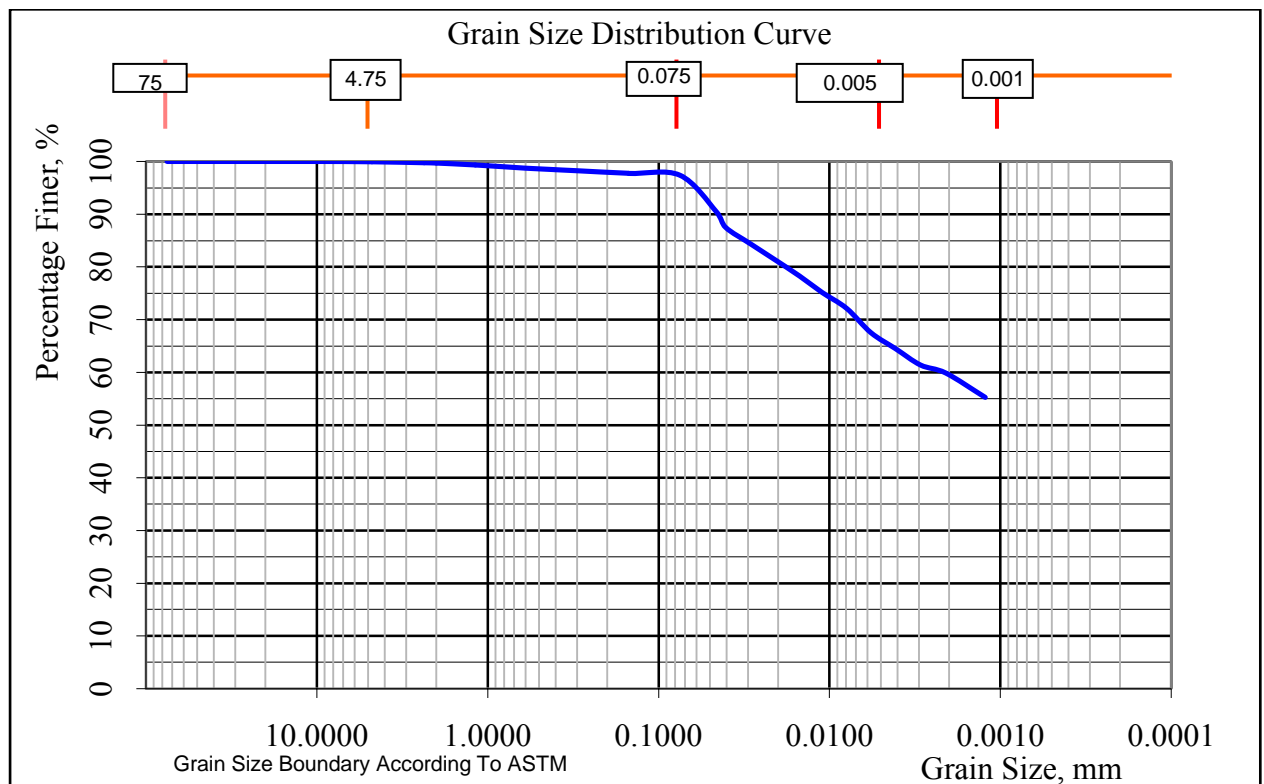
Gravel	sand	silt	clay
0.31	2.26	37.57	59.86

Hydrometer Analysis

Specific Gravity of soil =

2.74 Test Temperature, deg. 18.5

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.003	1.0295	8.50	0.013695	0.0461	92.94	90.55
1	1.0315	-0.003	1.0285	8.76	0.013695	0.0405	89.79	87.48
2	1.0305	-0.003	1.0275	9.03	0.013695	0.0291	86.64	84.42
4	1.0295	-0.003	1.0265	9.29	0.013695	0.0209	83.49	81.35
8	1.0285	-0.003	1.0255	9.55	0.013695	0.0150	80.34	78.28
15	1.0275	-0.003	1.0245	9.82	0.013695	0.0111	77.19	75.21
30	1.0265	-0.003	1.0235	10.08	0.013695	0.0079	74.04	72.14
60	1.0250	-0.003	1.0220	10.48	0.013695	0.0057	69.31	67.53
120	1.0240	-0.003	1.0210	10.75	0.013695	0.0041	66.16	64.46
240	1.0230	-0.003	1.0200	11.01	0.013695	0.0029	63.01	61.39
480	1.0225	-0.003	1.0195	11.14	0.013695	0.0021	61.43	59.86
1440	1.0210	-0.003	1.0180	11.54	0.01370	0.0012	56.71	55.25



4.9 Location: High School (TP6) @ 1.5m

Total mass of sample gm, 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75						100.00
No 8	2.36	990.00	990.30	0.30	0.02	0.02	99.98
No 10	2	955.80	955.90	0.10	0.01	0.03	99.97
No 16	1.18	894.40	894.70	0.30	0.02	0.05	99.95
No 30	0.6	830.80	831.50	0.70	0.05	0.09	99.91
No 40	0.425	789.60	790.00	0.40	0.03	0.12	99.88
No 50	0.3	750.10	750.60	0.50	0.03	0.15	99.85
No 100	0.15	777.50	779.90	2.40	0.16	0.31	99.69
No 200	0.075	764.10	769.10	5.00	0.33	0.65	99.35
Pan	-----	387.70	387.70	1490.30	99.35	100	0

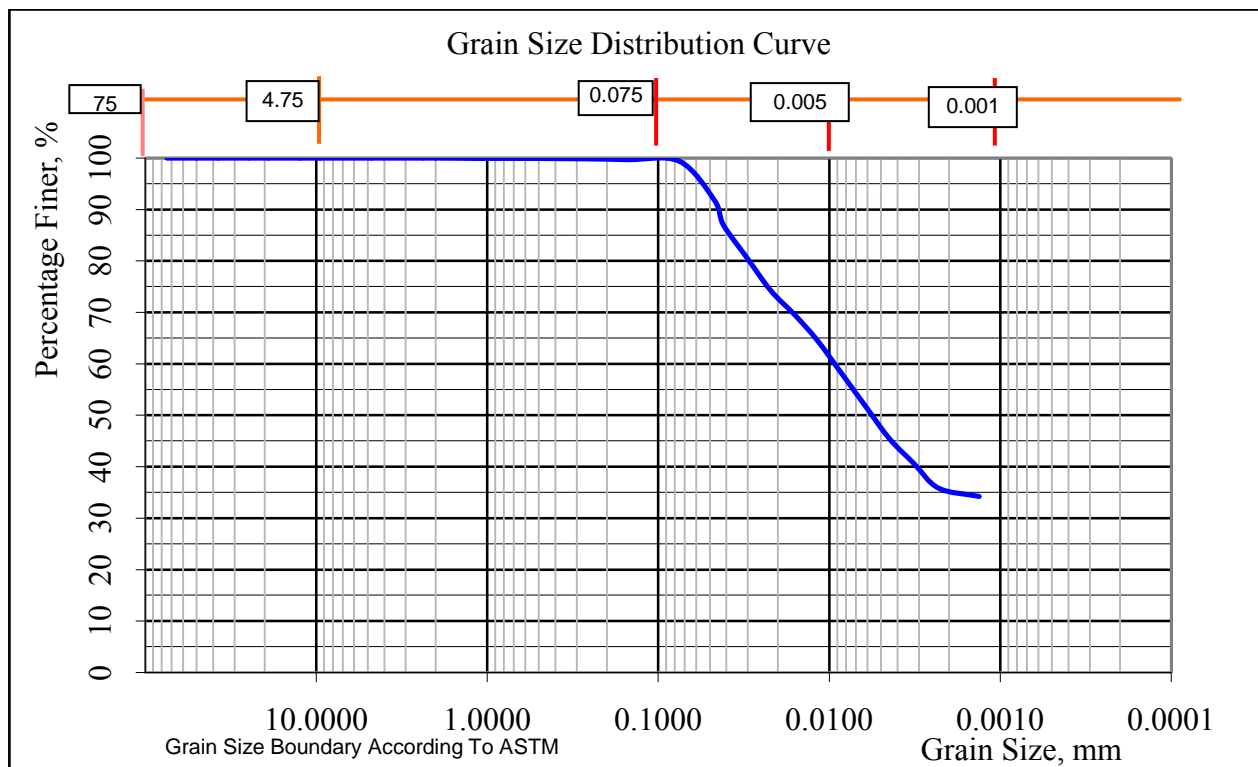
Gravel	sand	silt	clay
0.03	0.62	64.01	35.37

Hydrometer Analysis

Specific Gravity of soil =

2.64 Test Temperature, deg. 19.5

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0315	-0.0028	1.0287	8.71	0.013777	0.0469	92.40	91.80
1	1.0300	-0.0028	1.0272	9.11	0.013777	0.0416	87.57	87.00
2	1.0280	-0.0028	1.0252	9.63	0.013777	0.0302	81.13	80.61
4	1.0260	-0.0028	1.0232	10.16	0.013777	0.0220	74.69	74.21
8	1.0245	-0.0028	1.0217	10.56	0.013777	0.0158	69.86	69.41
15	1.0230	-0.0028	1.0202	10.96	0.013777	0.0118	65.03	64.61
30	1.0210	-0.0028	1.0182	11.49	0.013777	0.0085	58.59	58.22
60	1.0190	-0.0028	1.0162	12.01	0.013777	0.0062	52.16	51.82
120	1.0170	-0.0028	1.0142	12.54	0.013777	0.0045	45.72	45.42
240	1.0155	-0.0028	1.0127	12.94	0.013777	0.0032	40.89	40.62
480	1.0140	-0.0028	1.0112	13.34	0.013777	0.0023	36.06	35.82
1440	1.0135	-0.0028	1.0107	13.47	0.013777	0.0013	34.45	34.23



4.10 Location: High School (TP6) @ 3.0m

Total mass of sample, gm 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5	1164.40	1165.70	1.30	0.09	0.09	99.91
No 4	4.75	1262.80	1272.50	9.70	0.69	0.79	99.21
No 8	2.36	990.00	999.10	9.10	0.65	1.44	98.56
No 10	2	955.80	958.50	2.70	0.19	1.63	98.37
No 16	1.18	894.40	902.30	7.90	0.56	2.19	97.81
No 30	0.6	830.80	842.70	11.90	0.85	3.04	96.96
No 40	0.425	789.60	795.60	6.00	0.43	3.47	96.53
No 50	0.3	750.10	756.40	6.30	0.45	3.92	96.08
No 100	0.15	777.50	791.50	14.00	1.00	4.92	95.08
No 200	0.075	764.10	771.80	7.70	0.55	5.47	94.53
Pan	-----	387.70	387.7	1323.4	94.53	100	0

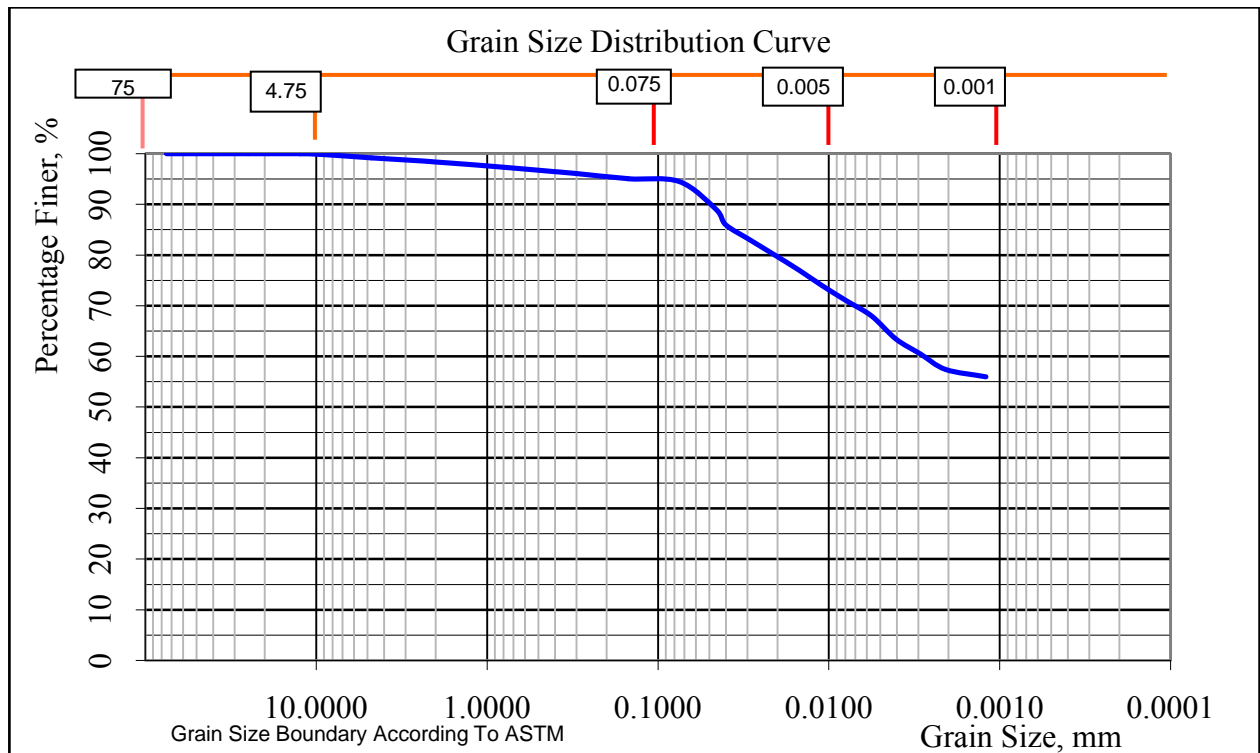
Gravel	sand	silt	clay
1.63	3.84	37.07	57.46

Hydrometer Analysis

Specific Gravity of soil

2.70 Test Temperature, deg. 19.2

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.00286	1.0296	8.46	0.013576	0.0456	94.14	88.99
1	1.0315	-0.00286	1.0286	8.72	0.013576	0.0401	90.96	85.98
2	1.0305	-0.00286	1.0276	8.99	0.013576	0.0288	87.78	82.98
4	1.0295	-0.00286	1.0266	9.25	0.013576	0.0206	84.61	79.98
8	1.0285	-0.00286	1.0256	9.52	0.013576	0.0148	81.43	76.98
15	1.0275	-0.00286	1.0246	9.78	0.013576	0.0110	78.26	73.97
30	1.0265	-0.00286	1.0236	10.05	0.013576	0.0079	75.08	70.97
60	1.0255	-0.00286	1.0226	10.31	0.013576	0.0056	71.90	67.97
120	1.0240	-0.00286	1.0211	10.71	0.013576	0.0041	67.14	63.47
240	1.0230	-0.00286	1.0201	10.97	0.013576	0.0029	63.96	60.46
480	1.0220	-0.00286	1.0191	11.24	0.013576	0.0021	60.79	57.46
1440	1.0215	-0.00286	1.0186	11.37	0.013576	0.0012	59.20	55.96



4.11 Location: Amanuel Church (TP7) @ 1.5m

Total mass of sample, gm

1500

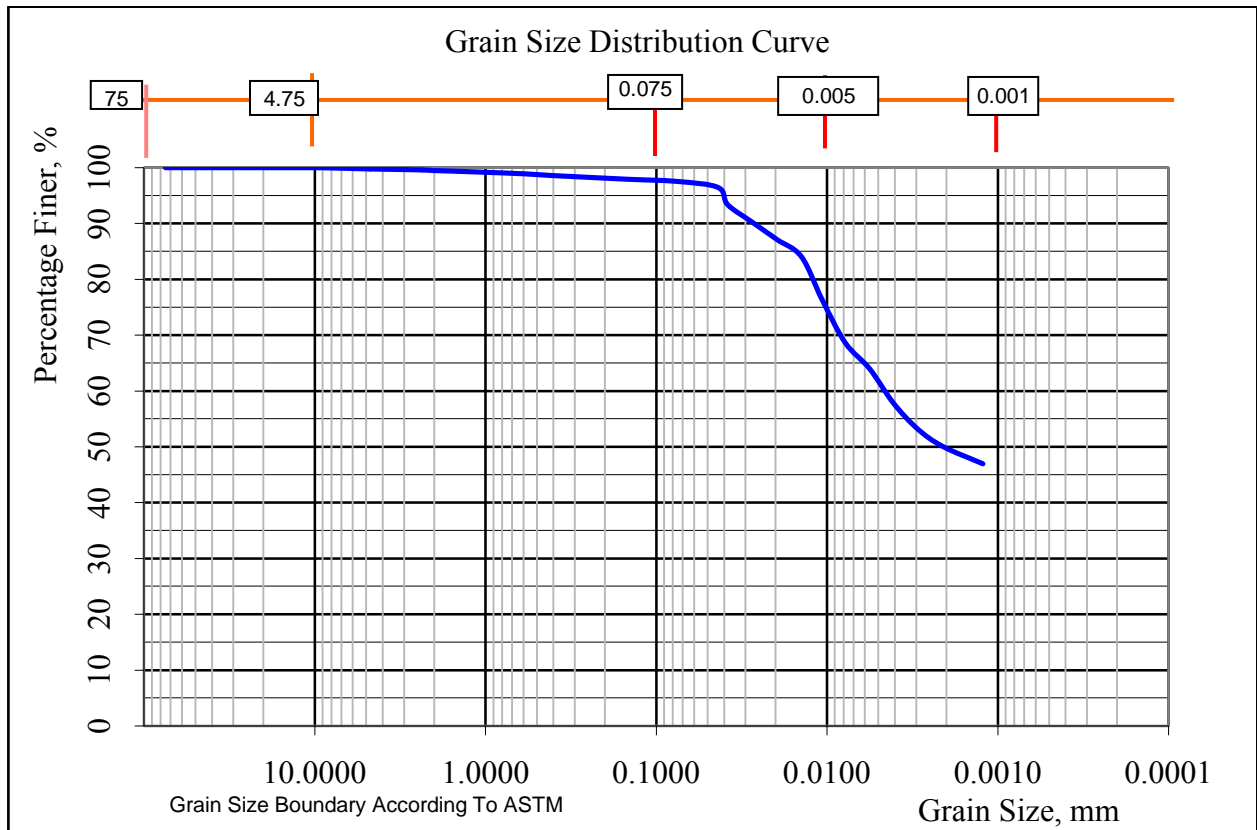
Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75	1262.80	1265.60	2.80	0.19	0.19	99.81
No 8	2.36	990.00	993.30	3.30	0.22	0.41	99.59
No 10	2	955.80	956.90	1.10	0.07	0.48	99.52
No 16	1.18	894.40	897.80	3.40	0.23	0.71	99.29
No 30	0.6	830.80	836.60	5.80	0.39	1.09	98.91
No 40	0.425	786.40	790.30	3.90	0.26	1.35	98.65
No 50	0.3	750.10	753.50	3.40	0.23	1.58	98.42
No 100	0.15	777.50	784.50	7.00	0.47	2.05	97.95
No 200	0.075	764.10	770.50	6.40	0.43	2.47	97.53
pan	-----	387.7	387.7	1462.9	97.53	100	0

Developing Correlation between Index Properties and Swelling Potential of Expansive Soil of Sendafa Town, Ethiopia

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Hydrometer Analysis

Specific Gravity			2.71	Temperature, deg 19.57				
Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0340	-0.0028	1.0312	8.05	0.0132425	0.0434	98.89	96.44
1	1.0330	-0.0028	1.0302	8.31	0.0132425	0.0382	95.72	93.35
2	1.0320	-0.0028	1.0292	8.58	0.0132425	0.0274	92.55	90.26
4	1.0310	-0.0028	1.0282	8.84	0.0132425	0.0197	89.38	87.17
8	1.0300	-0.0028	1.0272	9.11	0.0132425	0.0141	86.21	84.08
15	1.0275	-0.0028	1.0247	9.77	0.0132425	0.0107	78.29	76.35
30	1.0250	-0.0028	1.0222	10.43	0.0132425	0.0078	70.36	68.62
60	1.0235	-0.0028	1.0207	10.82	0.0132425	0.0056	65.61	63.99
120	1.0215	-0.0028	1.0187	11.35	0.0132425	0.0041	59.27	57.80
240	1.0200	-0.0028	1.0172	11.75	0.0132425	0.0029	54.51	53.17
480	1.0190	-0.0028	1.0162	12.01	0.0132425	0.0021	51.35	50.08
1440	1.0180	-0.0028	1.0152	12.28	0.0132425	0.0012	48.18	46.98



Gravel	sand	silt	clay
0.48	1.99	47.45	50.08

4.12 Location: Amanuel Church (@ 2.7)

Total mass of sample, gm 1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75	1262.80	1263.60	0.80	0.05	0.05	99.95
No 8	2.36	990.00	990.70	0.70	0.05	0.10	99.90
No 10	2	955.80	956.80	1.00	0.07	0.17	99.83
No 16	1.18	894.40	897.80	3.40	0.23	0.39	99.61
No 30	0.6	830.80	839.50	8.70	0.58	0.97	99.03
No 40	0.425	786.40	789.80	3.40	0.23	1.20	98.80
No 50	0.3	750.10	753.20	3.10	0.21	1.41	98.59
No 100	0.15	777.50	784.40	6.90	0.46	1.87	98.13
No 200	0.075	764.10	770.30	6.20	0.41	2.28	97.72
Pan	-----	387.7	387.7	1465.8	97.72	100	0

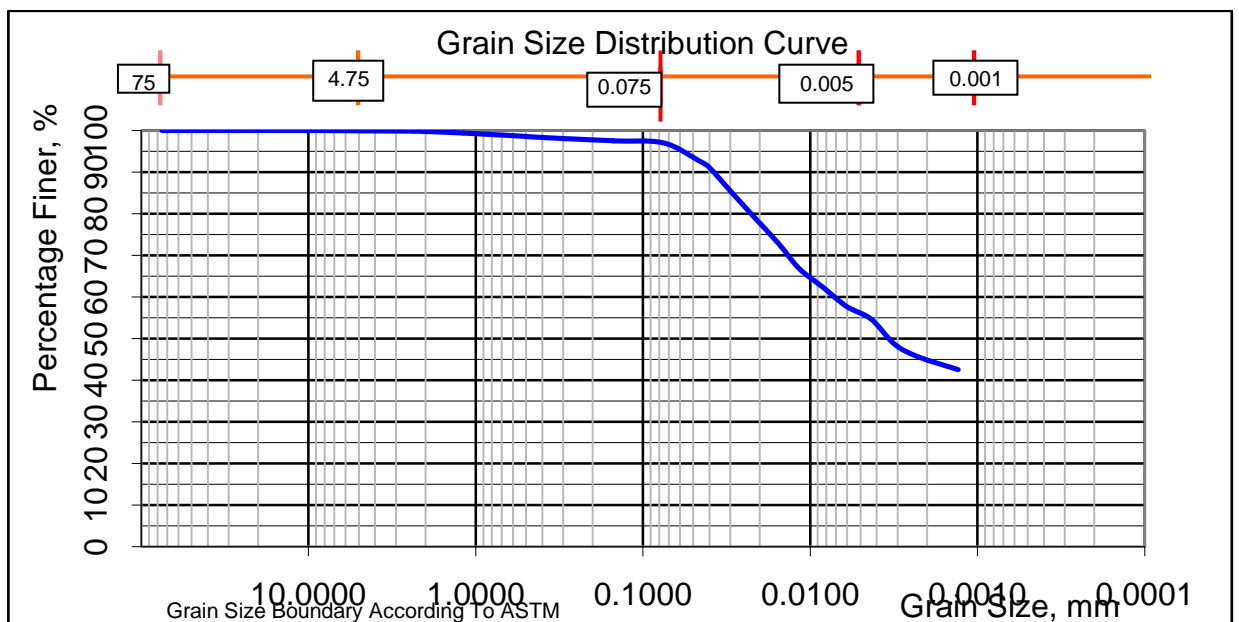
Gravel	sand	silt	clay
0.17	2.11	37.26	60.46

Hydrometer Analysis

Specific Gravity of soil =

2.71 Test Temperature, deg. 21

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0335	-0.0025	1.0310	8.10	0.013402	0.0440	98.26	96.12
1	1.0330	-0.0025	1.0305	8.23	0.013402	0.0385	96.67	94.57
2	1.0320	-0.0025	1.0295	8.50	0.013402	0.0276	93.50	91.46
4	1.0310	-0.0025	1.0285	8.76	0.013402	0.0198	90.33	88.36
8	1.0300	-0.0025	1.0275	9.03	0.013402	0.0142	87.16	85.26
15	1.0290	-0.0025	1.0265	9.29	0.013402	0.0105	83.99	82.16
30	1.0270	-0.0025	1.0245	9.82	0.013402	0.0077	77.65	75.96
60	1.0255	-0.0025	1.0230	10.22	0.013402	0.0055	72.90	71.31
120	1.0240	-0.0025	1.0215	10.61	0.013402	0.0040	68.15	66.66
240	1.0230	-0.0025	1.0205	10.88	0.013402	0.0029	64.98	63.56
480	1.0220	-0.0025	1.0195	11.14	0.013402	0.0020	61.81	60.46
1440	1.0210	-0.0025	1.0185	11.41	0.013402	0.0012	58.64	57.36



4.13 Location: Zenbaba Grocery (TP8) @ 1.3m

Total mass of sample, gm    1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5						100.00
No 4	4.75	1262.80	1264.00	1.20	0.08	0.08	99.92
No 8	2.36	990.00	991.50	1.50	0.10	0.18	99.82
No 10	2	955.80	957.20	1.40	0.09	0.27	99.73
No 16	1.18	894.40	900.10	5.70	0.38	0.65	99.35
No 30	0.6	830.80	840.30	9.50	0.63	1.29	98.71
No 40	0.425	786.10	791.00	4.90	0.33	1.61	98.39
No 50	0.3	750.10	754.60	4.50	0.30	1.91	98.09
No 100	0.15	777.50	786.60	9.10	0.61	2.52	97.48
No 200	0.075	764.10	771.30	7.20	0.48	3.00	97.00
Pan	-----	387.7	387.7	1455.0	97.0	100	0

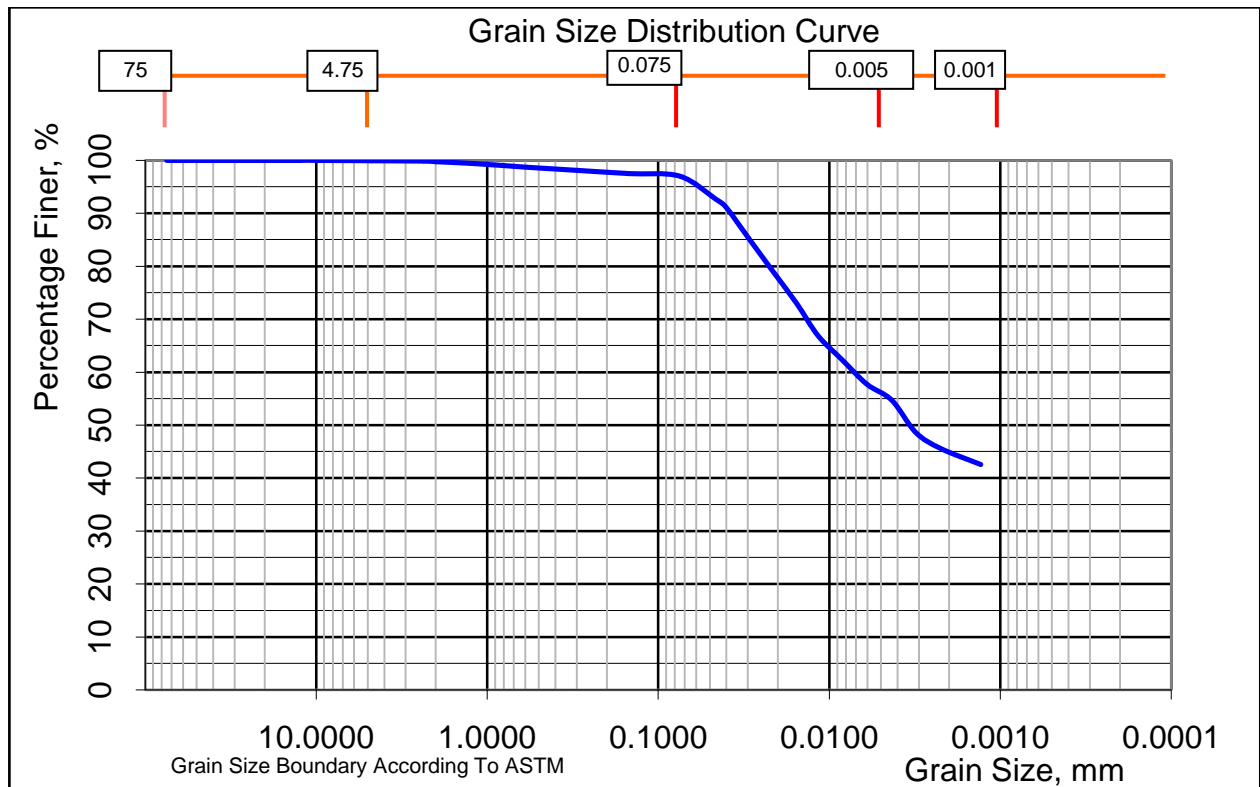
Gravel	sand	silt	clay
0.27	2.73	51.45	45.55

Hydrometer Analysis

Specific Gravity of soil =

2.71 Test Temperature, deg. 21

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0335	-0.00302	1.0305	8.24	0.013922	0.0461	95.55	92.68
1	1.0330	-0.00302	1.0300	8.37	0.013922	0.0403	93.98	91.16
2	1.0310	-0.00302	1.0280	8.90	0.013922	0.0294	87.71	85.08
4	1.0290	-0.00302	1.0260	9.43	0.013922	0.0214	81.44	79.00
8	1.0270	-0.00302	1.0240	9.96	0.013922	0.0155	75.17	72.92
15	1.0250	-0.00302	1.0220	10.49	0.013922	0.0116	68.90	66.83
30	1.0235	-0.00302	1.0205	10.88	0.013922	0.0084	64.20	62.27
60	1.0220	-0.00302	1.0190	11.28	0.013922	0.0060	59.50	57.71
120	1.0210	-0.00302	1.0180	11.54	0.013922	0.0043	56.36	54.67
240	1.0190	-0.00302	1.0160	12.07	0.013922	0.0031	50.09	48.59
480	1.0180	-0.00302	1.0150	12.34	0.013922	0.0022	46.96	45.55
1440	1.0170	-0.00302	1.0140	12.60	0.013922	0.0013	43.82	42.51



4.14 Location: Municipality (TP9) @ 1.4m

Total mass of sample, gm    1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5	1164.40	1165.80	1.40	0.09	0.09	99.91
No 4	4.75	1262.80	1267.80	5.00	0.33	0.43	99.57
No 8	2.36	990.00	993.40	3.40	0.23	0.65	99.35
No 10	2	955.80	957.50	1.70	0.11	0.77	99.23
No 16	1.18	894.40	901.20	6.80	0.45	1.22	98.78
No 30	0.6	830.80	844.10	13.30	0.89	2.11	97.89
No 40	0.425	786.40	791.70	5.30	0.35	2.46	97.54
No 50	0.3	750.10	754.10	4.00	0.27	2.73	97.27
No 100	0.15	777.50	784.70	7.20	0.48	3.21	96.79
No 200	0.075	764.10	769.40	5.30	0.35	3.56	96.44
Pan	-----	387.7	387.7	1446.6	96.44	100	0

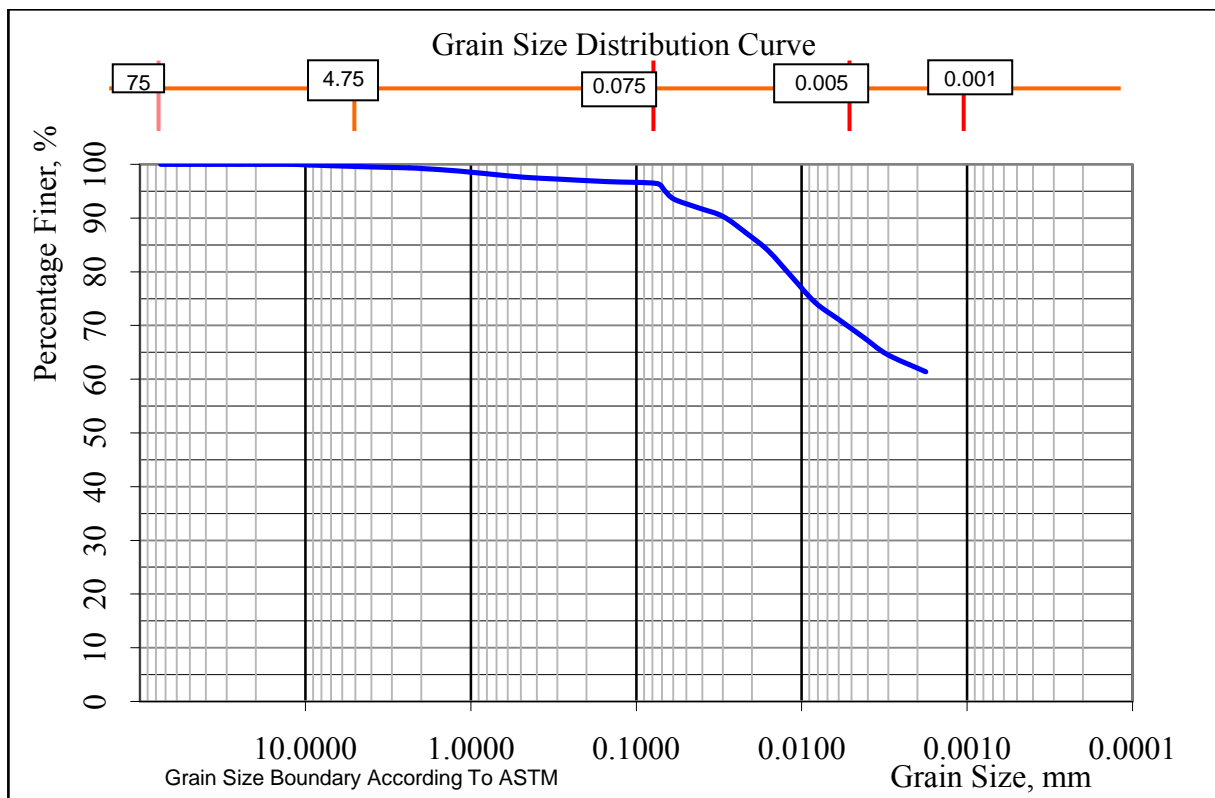
Gravel	sand	silt	clay
0.77	2.79	34.51	61.94

Hydrometer Analysis

Specific Gravity of soil =

2.50 Test Temperature, deg. 19.4083

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0325	-0.0029	1.0296	8.47	0.0201	0.0675	98.67	95.15
1	1.0320	-0.0029	1.0291	8.60	0.0201	0.0589	97.00	93.55
2	1.0315	-0.0029	1.0286	8.73	0.0201	0.0420	95.33	91.94
4	1.0310	-0.0029	1.0281	8.87	0.0201	0.0299	93.67	90.33
8	1.0300	-0.0029	1.0271	9.13	0.0201	0.0215	90.33	87.12
15	1.0290	-0.0029	1.0261	9.40	0.0201	0.0159	87.00	83.90
30	1.0275	-0.0029	1.0246	9.79	0.0201	0.0115	82.00	79.08
60	1.0260	-0.0029	1.0231	10.19	0.0201	0.0083	77.00	74.26
120	1.0250	-0.0029	1.0221	10.45	0.0201	0.0059	73.67	71.04
240	1.0240	-0.0029	1.0211	10.72	0.0201	0.0042	70.33	67.83
480	1.0230	-0.0029	1.0201	10.98	0.0201	0.0030	67.00	64.61
1440	1.0220	-0.0029	1.0191	11.25	0.0201	0.0018	63.67	61.40



4.15 Location: Dabel (TP10) @ 1.5m

Total mass of sample, gm    1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5			0.00	0.00	0.00	100.00
No 4	6.3	1090.75	1090.75	0.00	0.00	0.00	100.00
No 8	4.75	1263.05	1263.50	0.45	0.03	0.03	99.97
No 10	2	955.20	955.70	0.50	0.03	0.06	99.94
No 16	1.18	895.00	898.15	3.15	0.21	0.27	99.73
No 30	0.6	831.50	837.95	6.45	0.43	0.70	99.30
No 40	0.425	787.70	790.65	2.95	0.20	0.90	99.10
No 50	0.3	750.60	753.00	2.40	0.16	1.06	98.94
No 100	0.15	778.60	781.20	2.60	0.17	1.23	98.77
No 200	0.075	743.10	744.10	1.00	0.07	1.30	98.70
Pan	-----	735.0	735.1	1480.5	98.70	100	0

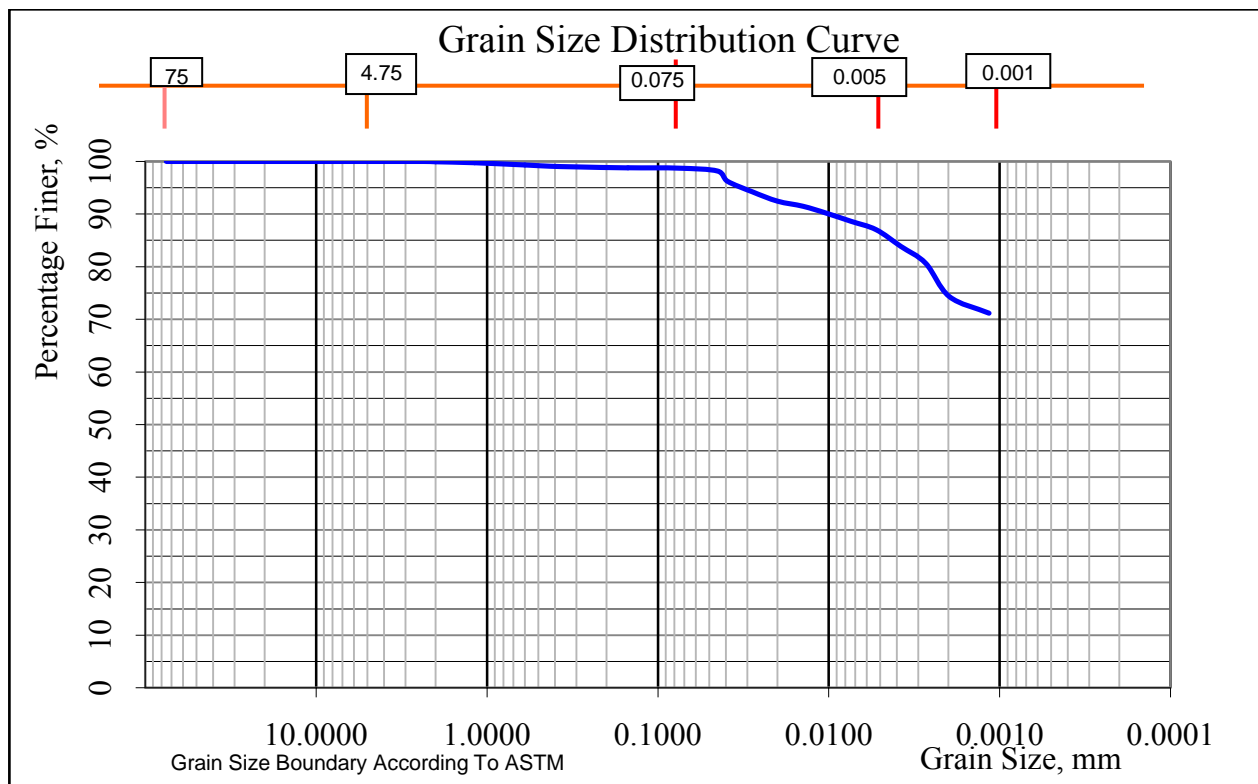
Gravel	sand	silt	clay
0.06	1.24	24.37	74.33

Hydrometer Analysis

Specific Gravity of soil =

2.64 Test Temperature, deg. 20.5

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0335	-0.0026	1.0309	8.13	0.013607	0.0448	99.44	98.15
1	1.0329	-0.0026	1.0303	8.29	0.013607	0.0392	97.51	96.25
2	1.0323	-0.0026	1.0297	8.46	0.013607	0.0280	95.42	94.18
4	1.0317	-0.0026	1.0291	8.60	0.013607	0.0200	93.65	92.43
8	1.0314	-0.0026	1.0288	8.68	0.013607	0.0142	92.69	91.48
15	1.0310	-0.0026	1.0284	8.79	0.013607	0.0104	91.40	90.21
30	1.0305	-0.0026	1.0279	8.92	0.013607	0.0074	89.79	88.62
60	1.0300	-0.0026	1.0274	9.05	0.013607	0.0053	88.18	87.03
120	1.0290	-0.0026	1.0264	9.32	0.013607	0.0038	84.96	83.86
240	1.0280	-0.0026	1.0254	9.58	0.013607	0.0027	81.74	80.68
480	1.0260	-0.0026	1.0234	10.11	0.013607	0.0020	75.31	74.33
1440	1.0250	-0.0026	1.0224	10.37	0.013607	0.0012	72.09	71.15



4.16 Location: Dabel (TP10) @ 3.0m

Total mass of sample, gm    1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5			0.00	0.00	0.00	100.00
No 4	6.3	1090.75	1090.75	0.00	0.00	0.00	100.00
No 8	4.75	1263.05	1263.50	0.45	0.03	0.03	99.97
No 10	2	955.20	958.40	3.20	0.21	0.24	99.76
No 16	1.18	895.00	899.00	4.00	0.27	0.51	99.49
No 30	0.6	831.50	835.80	4.30	0.29	0.80	99.20
No 40	0.425	787.70	789.00	1.30	0.09	0.88	99.12
No 50	0.3	750.60	751.80	1.20	0.08	0.96	99.04
No 100	0.15	778.60	780.15	1.55	0.10	1.07	98.93
No 200	0.075	743.10	744.45	1.35	0.09	1.16	98.84
Pan	-----	735.0	735.0	1482.7	98.84	100	0

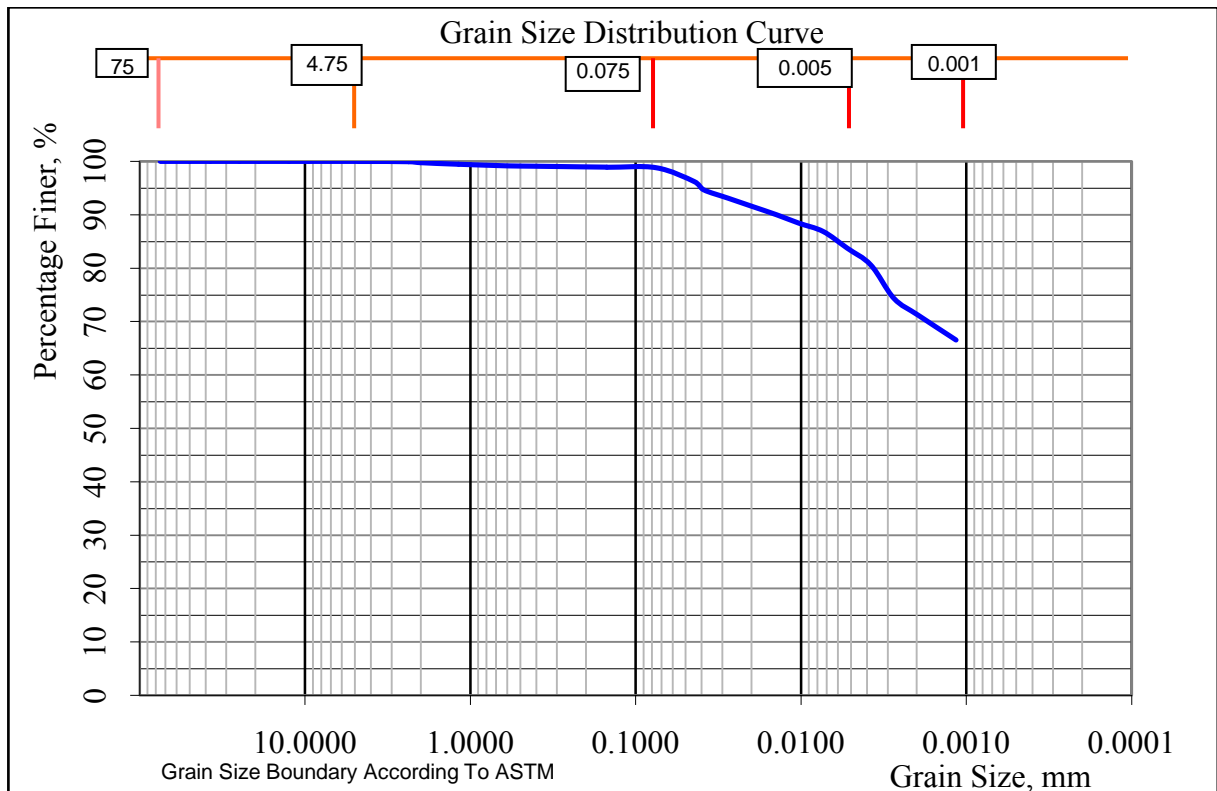
Gravel	sand	silt	clay
0.24	0.91	27.61	71.23

Hydrometer Analysis

Specific Gravity of soil =

2.71 Test Temperature, deg. 19.77

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0335	-0.002746	1.0308	8.16	0.01344	0.0443	97.40	96.27
1	1.0330	-0.002746	1.0303	8.30	0.01344	0.0387	95.82	94.71
2	1.0325	-0.002746	1.0298	8.43	0.01344	0.0276	94.23	93.14
4	1.0320	-0.002746	1.0293	8.56	0.01344	0.0197	92.65	91.58
8	1.0315	-0.002746	1.0288	8.69	0.01344	0.0140	91.07	90.01
15	1.0310	-0.002746	1.0283	8.83	0.01344	0.0103	89.48	88.45
30	1.0305	-0.002746	1.0278	8.96	0.01344	0.0073	87.90	86.88
60	1.0295	-0.002746	1.0268	9.22	0.01344	0.0053	84.73	83.75
120	1.0285	-0.002746	1.0258	9.49	0.01344	0.0038	81.56	80.62
240	1.0265	-0.002746	1.0238	10.02	0.01344	0.0027	75.23	74.36
480	1.0255	-0.002746	1.0228	10.28	0.01344	0.0020	72.06	71.23
1440	1.0240	-0.002746	1.0213	10.68	0.01344	0.0012	67.31	66.53



4.17 Location: Dire Mazoria (TP11) @ 1.5m

Total mass of sample, gm 1300

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5			0.00	0.00	0.00	100.00
No 4	6.3			0.00	0.00	0.00	100.00
No 8	4.75			0.00	0.00	0.00	100.00
No 10	2	955.20	957.00	1.80	0.14	0.14	99.86
No 16	1.18	895.00	898.50	3.50	0.27	0.41	99.59
No 30	0.6	831.50	835.00	3.50	0.27	0.68	99.32
No 40	0.425	787.70	788.40	0.70	0.05	0.73	99.27
No 50	0.3	750.60	751.70	1.10	0.08	0.82	99.18
No 100	0.15	778.60	780.90	2.30	0.18	0.99	99.01
No 200	0.075	743.10	745.30	2.20	0.17	1.16	98.84
Pan	-----	735.0	735.0	1284.9	98.84	100	0

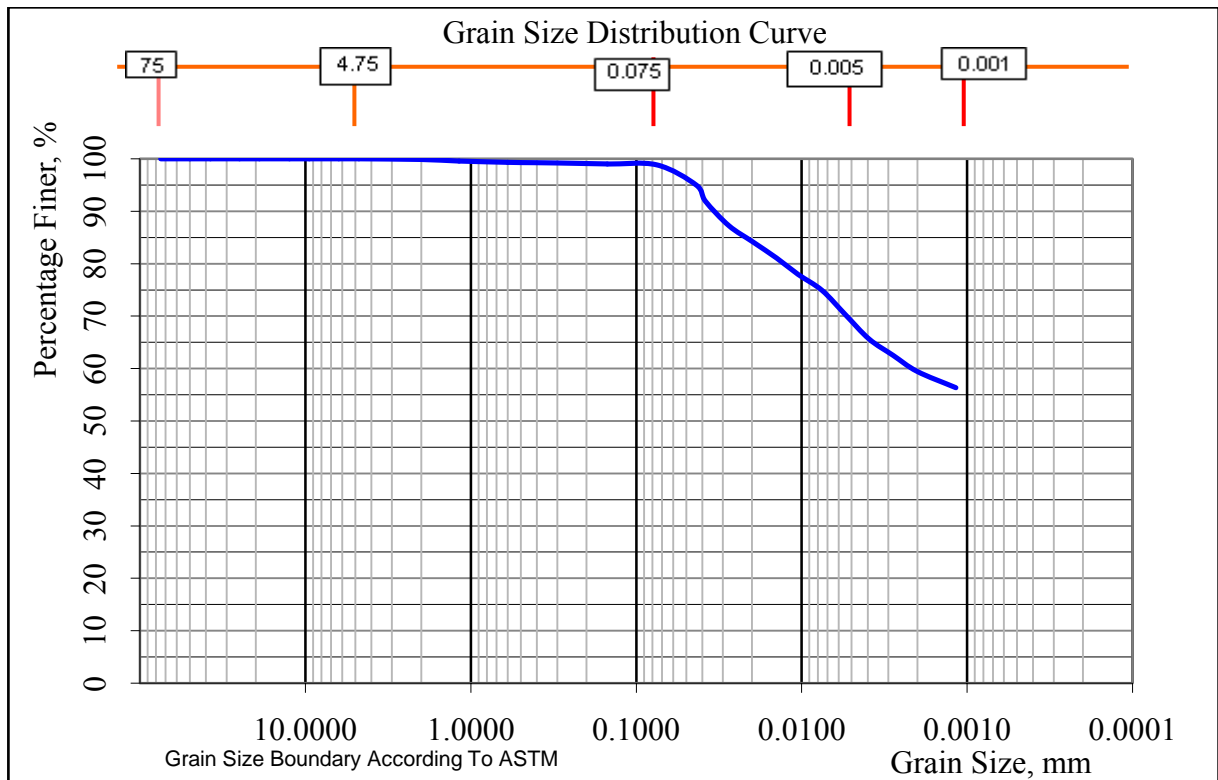
Gravel	sand	silt	clay
0.14	1.02	39.39	59.45

Hydrometer Analysis

Specific Gravity of soil = 2.78

2.71 Test Temperature, deg. 19.8

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0335	-0.00275	1.0308	8.17	0.01314	0.0434	96.08	94.96
1	1.0325	-0.00275	1.0298	8.43	0.01314	0.0381	92.95	91.87
2	1.0310	-0.00275	1.0283	8.83	0.01314	0.0276	88.27	87.24
4	1.0300	-0.00275	1.0273	9.09	0.01314	0.0198	85.14	84.15
8	1.0290	-0.00275	1.0263	9.36	0.01314	0.0142	82.02	81.06
15	1.0280	-0.00275	1.0253	9.62	0.01314	0.0105	78.89	77.98
30	1.0270	-0.00275	1.0243	9.89	0.01314	0.0075	75.77	74.89
60	1.0255	-0.00275	1.0228	10.28	0.01314	0.0054	71.08	70.26
120	1.0240	-0.00275	1.0213	10.68	0.01314	0.0039	66.39	65.62
240	1.0230	-0.00275	1.0203	10.94	0.01314	0.0028	63.27	62.54
480	1.0220	-0.00275	1.0193	11.21	0.01314	0.0020	60.15	59.45
1440	1.0210	-0.00275	1.0183	11.47	0.01314	0.0012	57.02	56.36



Developing Correlation between Index Properties and Swelling Potential of Expansive Soil of Sendafa Town, Ethiopia

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4.18 Location: Dire Mzoria (TP11) @ 3.0m

Total mass of sample, gm    1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5			0.00	0.00	0.00	100.00
No 4	6.3	1090.75	1091.50	0.75	0.05	0.05	99.95
No 8	4.75	1263.05	1263.05	0.00	0.00	0.05	99.95
No 10	2	955.20	956.10	0.90	0.06	0.11	99.89
No 16	1.18	895.00	897.10	2.10	0.14	0.25	99.75
No 30	0.6	831.50	840.80	9.30	0.62	0.87	99.13
No 40	0.425	787.70	794.20	6.50	0.43	1.30	98.70
No 50	0.3	750.60	759.00	8.40	0.56	1.86	98.14
No 100	0.15	778.60	794.50	15.90	1.06	2.92	97.08
No 200	0.075	743.10	750.60	7.50	0.50	3.42	96.58
Pan	-----	735.0	735.1	1448.7	96.58	100	0

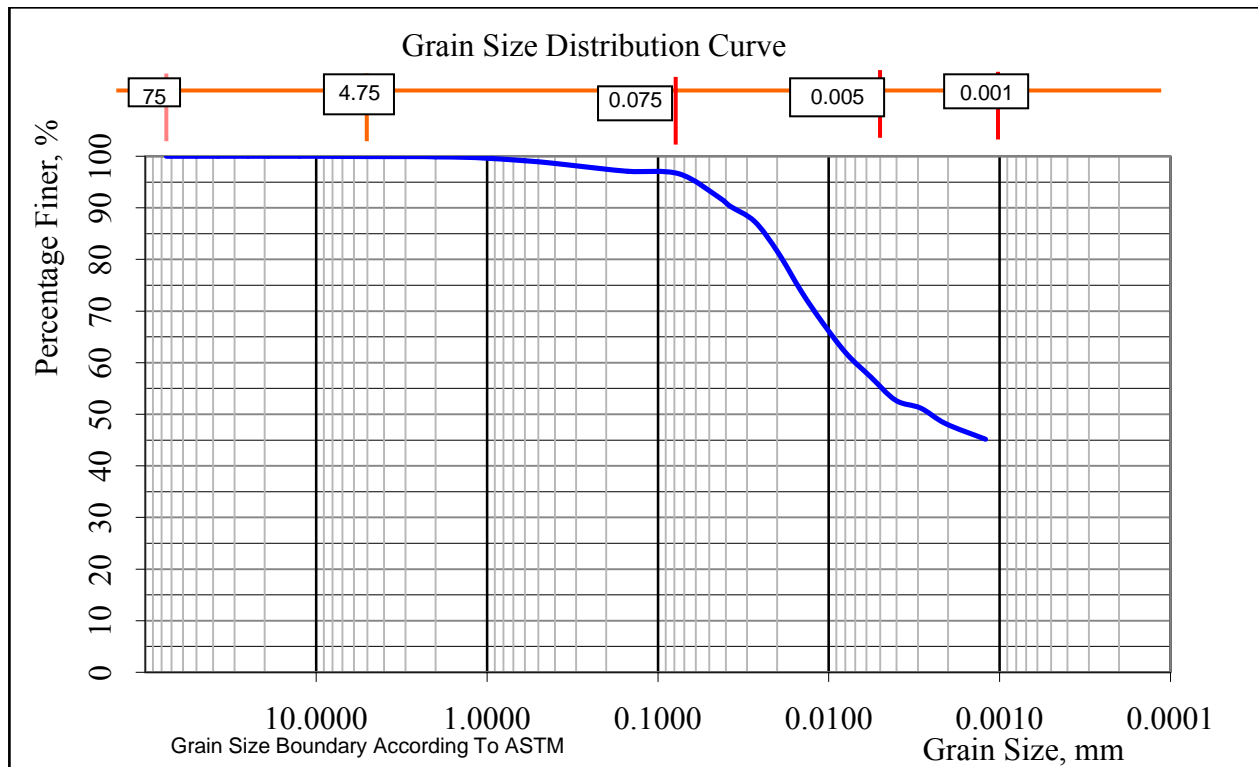
Gravel	sand	silt	clay
0.11	3.31	48.38	48.20

Hydrometer Analysis

Specific Gravity of soil = 2.79

2.71 Test Temperature, deg. 21.03333

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0330	-0.0025	1.0305	8.23	0.01305	0.0432	95.13	91.87
1	1.0325	-0.0025	1.0300	8.36	0.013054	0.0378	93.57	90.37
2	1.0315	-0.0025	1.0290	8.63	0.013054	0.0271	90.45	87.35
4	1.0295	-0.0025	1.0270	9.16	0.013054	0.0198	84.21	81.33
8	1.0270	-0.0025	1.0245	9.82	0.013054	0.0145	76.42	73.80
15	1.0250	-0.0025	1.0225	10.35	0.013054	0.0108	70.18	67.78
30	1.0230	-0.0025	1.0205	10.88	0.013054	0.0079	63.94	61.75
60	1.0215	-0.0025	1.0190	11.27	0.013054	0.0057	59.26	57.23
120	1.0200	-0.0025	1.0175	11.67	0.013054	0.0041	54.58	52.71
240	1.0195	-0.0025	1.0170	11.80	0.013054	0.0029	53.02	51.21
480	1.0185	-0.0025	1.0160	12.07	0.013054	0.0021	49.90	48.20
1440	1.0175	-0.0025	1.0150	12.33	0.013054	0.0012	46.79	45.18



4.19 Location: Dabe2 (TP12) @ 1.5m

Total mass of sample, gm    1500

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5			0.00	0.00	0.00	100.00
No 4	6.3	1090.75	1091.30	0.55	0.04	0.04	99.96
No 8	4.75	1263.05	1263.30	0.25	0.02	0.05	99.95
No 10	2	955.20	965.20	10.00	0.67	0.72	99.28
No 16	1.18	895.00	905.50	10.50	0.70	1.42	98.58
No 30	0.6	831.50	845.30	13.80	0.92	2.34	97.66
No 40	0.425	787.70	793.80	6.10	0.41	2.75	97.25
No 50	0.3	750.60	756.60	6.00	0.40	3.15	96.85
No 100	0.15	778.60	789.60	11.00	0.73	3.88	96.12
No 200	0.075	743.10	748.80	5.70	0.38	4.26	95.74
Pan	-----	735.0	735.0	1436.1	95.74	100	0

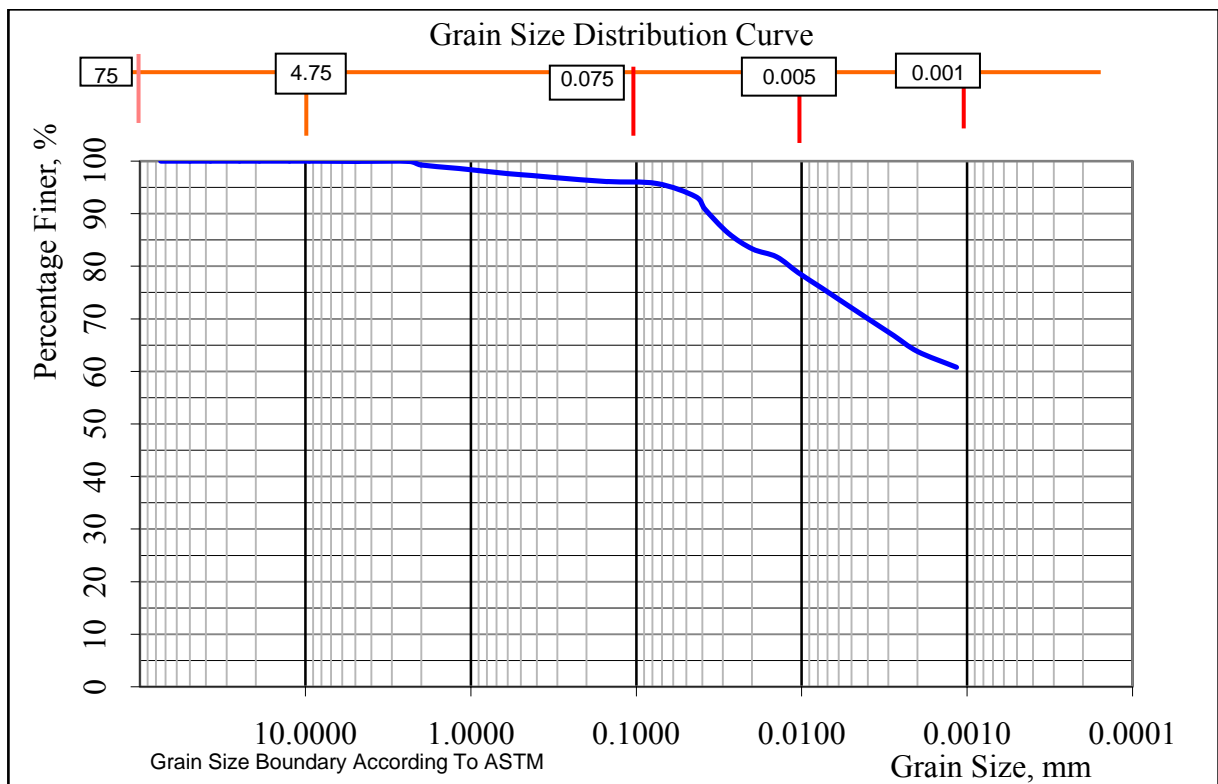
Gravel	sand	silt	clay
0.72	3.54	31.95	63.79

Hydrometer Analysis

Specific Gravity of soil = 2.75

2.71 Test Temperature, deg. 19.58

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0338	-0.00278	1.0310	8.09	0.01332	0.0438	97.39	93.24
1	1.0330	-0.00278	1.0302	8.31	0.01332	0.0384	94.88	90.84
2	1.0315	-0.00278	1.0287	8.70	0.01332	0.0278	90.17	86.33
4	1.0305	-0.00278	1.0277	8.97	0.01332	0.0199	87.03	83.32
8	1.0300	-0.00278	1.0272	9.10	0.01332	0.0142	85.46	81.82
15	1.0290	-0.00278	1.0262	9.36	0.01332	0.0105	82.32	78.81
30	1.0280	-0.00278	1.0252	9.63	0.01332	0.0075	79.18	75.81
60	1.0270	-0.00278	1.0242	9.89	0.01332	0.0054	76.04	72.80
120	1.0260	-0.00278	1.0232	10.16	0.01332	0.0039	72.90	69.80
240	1.0250	-0.00278	1.0222	10.42	0.01332	0.0028	69.76	66.79
480	1.0240	-0.00278	1.0212	10.69	0.01332	0.0020	66.62	63.79
1440	1.0230	-0.00278	1.0202	10.95	0.01332	0.0012	63.48	60.78



4.20 Location: Dire Caf  (TP13) @ 1.7m

Total mass of sample, gm 1400

Sieve No	Sieve opening (mm)	Mass of sieve (g)	Mass of sieve +Retained Soil (g)	Mass of retained soil (g)	Percentage retained (g)	Cum. Percentage retained (%)	Percentage passing (%)
3"	75.0						100.00
2"	50.0						100.00
1.5"	37.5						100.00
1"	25.0						100.00
3/4"	19.0						100.00
1/2"	12.5						100.00
3.8"	9.5			0.00	0.00	0.00	100.00
No 4	6.3	1090.75	1090.75	0.00	0.00	0.00	100.00
No 8	4.75	1263.05	1264.15	1.10	0.08	0.08	99.92
No 10	2	955.20	964.05	8.85	0.63	0.71	99.29
No 16	1.18	895.00	907.50	12.50	0.89	1.60	98.40
No 30	0.6	831.50	845.35	13.85	0.99	2.59	97.41
No 40	0.425	787.70	797.60	9.90	0.71	3.30	96.70
No 50	0.3	750.60	767.35	16.75	1.20	4.50	95.50
No 100	0.15	778.60	789.50	10.90	0.78	5.28	94.73
No 200	0.075	743.10	775.75	32.65	2.33	7.61	92.39
Pan	-----	735.0	735.0	1293.5	92.39	100	0

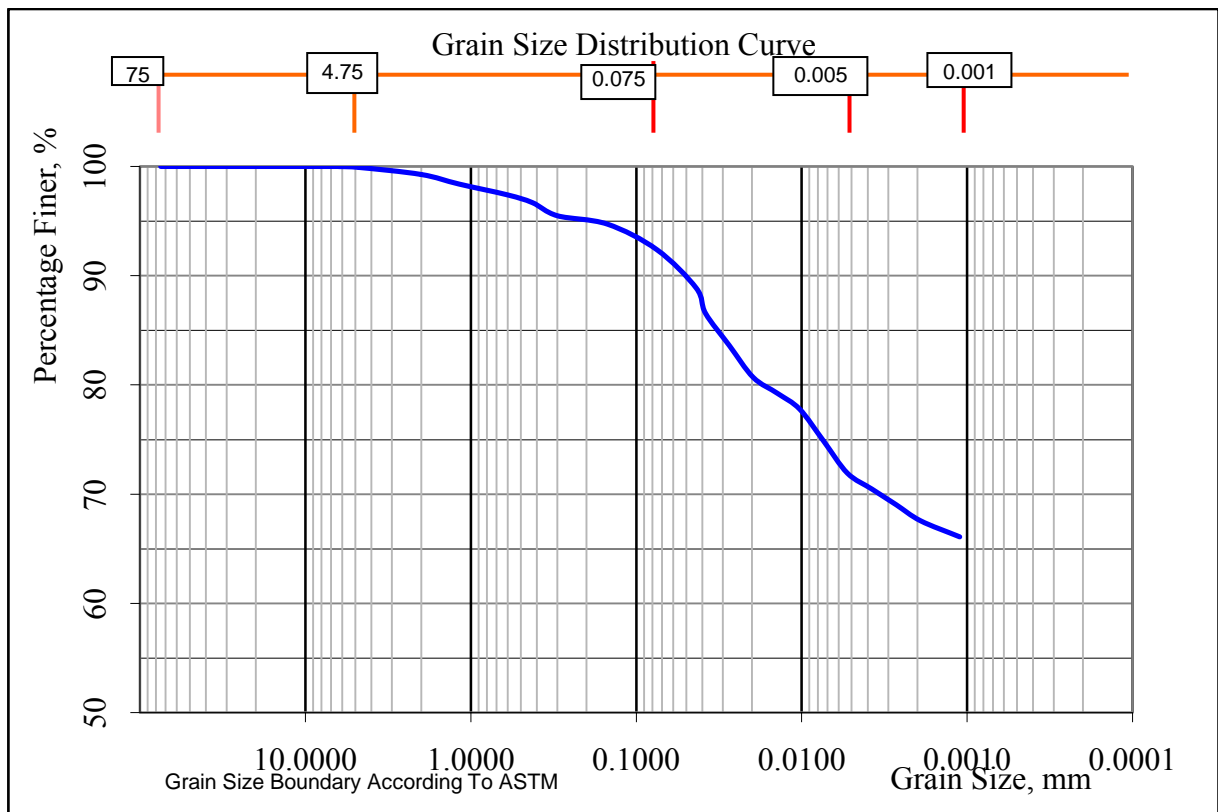
Gravel	sand	silt	clay
0.71	6.90	24.84	67.56

Hydrometer Analysis

Specific Gravity of soil = 2.72

2.71 Test Temperature, deg. 21.6

Elapsed Time (min)	Actual Hydrometer Reading	Composite Correction	Corrected Hydrometer Reading	Effective Depth (cm)	Coefficient K	Grain Size (mm)	Perc. Finer (%)	Perc. Finer Combined (%)
0.75	1.0328	-0.00238	1.0304	8.25	0.01311	0.0435	96.21	88.89
1	1.0320	-0.00238	1.0296	8.46	0.01311	0.0381	93.68	86.55
2	1.0310	-0.00238	1.0286	8.73	0.01311	0.0274	90.51	83.63
4	1.0300	-0.00238	1.0276	8.99	0.01311	0.0197	87.35	80.71
8	1.0295	-0.00238	1.0271	9.13	0.01311	0.0140	85.77	79.25
15	1.0290	-0.00238	1.0266	9.26	0.01311	0.0103	84.19	77.78
30	1.0280	-0.00238	1.0256	9.52	0.01311	0.0074	81.03	74.86
60	1.0270	-0.00238	1.0246	9.79	0.01311	0.0053	77.86	71.94
120	1.0265	-0.00238	1.0241	9.92	0.01311	0.0038	76.28	70.48
240	1.0260	-0.00238	1.0236	10.05	0.01311	0.0027	74.70	69.02
480	1.0255	-0.00238	1.0231	10.18	0.01311	0.0019	73.12	67.56
1440	1.0250	-0.00238	1.0226	10.32	0.01311	0.0011	71.54	66.10



5) Free Swell (section 4.2.2.5)

Test Pits	Location	Depth (m)	Initial volume (cc)	Final volume		Average volume (cc)	Free swell (%)
				Sample 1 (cc)	Sample 2 (cc)		
TP1	Beke Kebele 02	1.2	10	21.1	21.8	21.45	114.50
		2.3	10	22.9	21.9	22.40	124.00
TP2	Beke St. Merry	0.9	10	20.95	21.7	21.33	113.25
TP3	Beke Got 3	1.0	10	16.1	17	16.55	65.50
TP4	Sendafa & Beke border	1.2	10	23.1	21	22.05	120.50
		2.5	10	22.1	23.1	22.60	126.00
TP5	Kebt Tera	1.5	10	21.2	21.3	21.25	112.50
		2.5	10	20.85	23.85	22.35	123.50
TP6	High School	1.5	10	20.3	21	20.65	106.50
		3.0	10	21.1	22.5	21.80	118.00
TP7	Amanuel Church	1.5	10	21.7	22.4	22.05	120.50
		2.7	10	21.8	19.4	20.60	106.00
TP8	Zenbaba Grocery	1.3	10	23.5	25	24.25	142.50
TP9	Municipality	1.4	10	24	24	24.00	140.00
TP10	Dabe1	1.5	10	21.9	22.8	22.35	123.50
		3.0	10	21.8	20.4	21.10	111.00
TP11	Dire Mazoria	1.5	10	17	17.2	17.10	71.00
		3.0	10	16.85	16.8	16.83	68.25
TP12	Dabe2	1.5	10	22.5	23.2	22.85	128.50
TP13	Dire Café	1.7	10	28.3	28.9	28.60	186.00

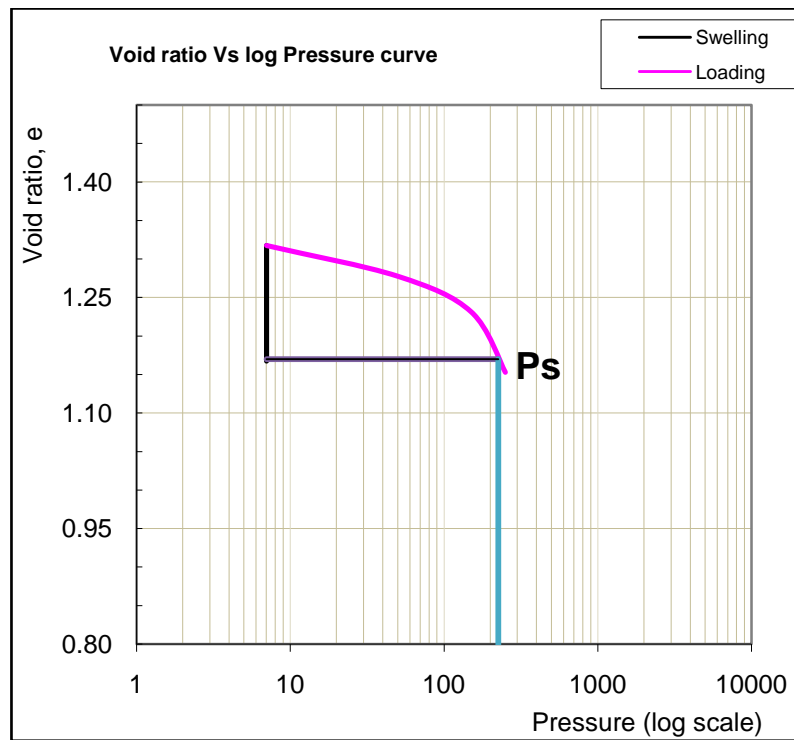
6) Consolidation (Section 4.2.3)

6.1 Location: Beke Kebele 02 (TP1) @ 1.2m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	150 [kPa]	250 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	2.400	3.786	3.416	2.992			
0.1	0.32		3.586	3.284	2.740			
0.25	0.50	-	3.576	3.260	2.692			
0.50	0.71	-	3.562	3.242	2.670			
1	1.00	-	3.548	3.228	2.644			
2	1.41	-	3.530	3.206	2.616			
4	2.00	-	3.516	3.184	2.584			
8	2.83	-	3.502	3.158	2.550			
15	3.87	-	3.490	3.136	2.520			
30	5.48	-	3.478	3.110	2.482			
60	7.75	-	3.466	3.086	2.442			
120	10.95	-	3.440	3.060	2.400			
240	15.49	-	3.434	3.038	2.354			
480	21.91	-	3.426	3.016	2.304			
1440	37.95	3.786	3.416	2.992	2.264			

Developing Correlation between Index Properties and Swelling Potential of Expansive Soil of Sendafa Town, Ethiopia

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	2.400	0.00	20.00	10.77	1.17
7	3.786	1.39	21.39	12.16	1.32
50	3.416	1.02	21.02	11.79	1.28
150	2.992	0.59	20.59	11.36	1.23
250	2.264	-0.14	19.86	10.64	1.15



Swelling potential & Pressure

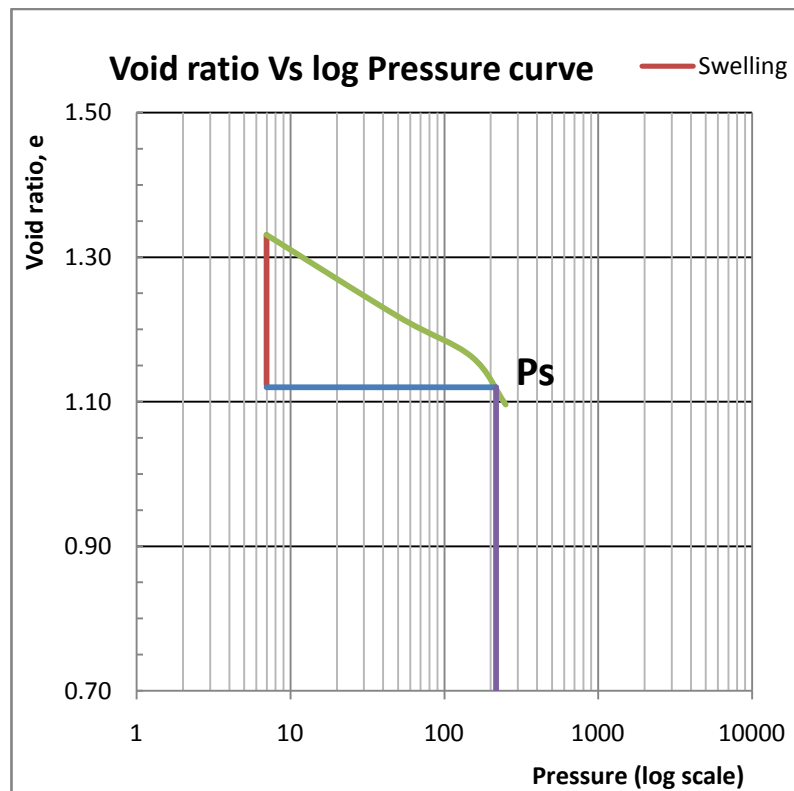
Initial Dial Reading	2.4mm
Final Dial Reading	3.79mm
Swell , [%]	6.93
Swelling Pressure, kPa	225.00

6.2 Location: Beke Kebele 02 (TP1) @ 2.3m

		Dial Gauge Reading, mm						
		7	50	100	200	400	800	1600
Time(min.)	$\sqrt{\text{time}}$	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	2.000	3.950	2.886	2.366			
0.1	0.32		3.768	2.786	2.252			
0.25	0.50	-	3.634	2.776	2.242			
0.50	0.71	-	3.590	2.764	2.230			
1	1.00	-	3.356	2.754	2.216			
2	1.41	-	3.310	2.734	2.196			
4	2.00	-	3.264	2.712	2.174			
8	2.83	-	3.210	2.686	2.144			
15	3.87	-	3.156	2.658	2.132			
30	5.48	-	3.102	2.616	2.068			
60	7.75	-	3.046	2.570	2.014			
120	10.95	-	2.996	2.512	1.956			
240	15.49	-	2.952	2.454	1.866			
480	21.91	-	2.914	2.402	1.794			
1440	37.95	3.950	2.886	2.366	1.740			

Developing Correlation between Index Properties and Swelling Potential of Expansive Soil of Sendafa Town, Ethiopia

Applied pressure P (kPa)	Final Dial Reading (mm)	Change in Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	2.000	0.00	20.00	10.58	1.12
7	3.950	1.95	21.95	12.53	1.33
50	2.886	0.89	20.89	11.47	1.22
150	2.366	0.37	20.37	10.95	1.16
250	1.740	-0.26	19.74	10.32	1.10



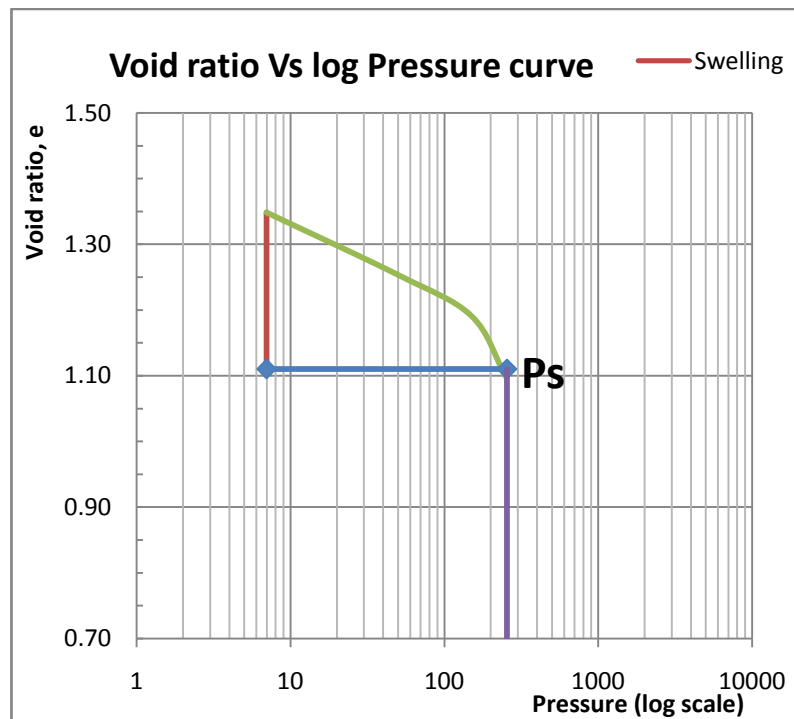
Swelling potential & Pressure

Initial Dial Reading	2mm
Final Dial Reading	3.95mm
Swell , [%]	9.75
Swelling Pressure, kPa	216.67

6.3 Location: St. Merry (TP2) @ 0.9m

		Dial Gauge Reading, mm						
		7	50	150	250	400	800	1600
Time(min.)	$\sqrt{t}$ time	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	3.200	5.470	4.570	3.980			
0.1	0.32		5.010	4.396	3.694			
0.25	0.50	-	4.976	4.380	3.676			
0.50	0.71	-	4.940	4.364	3.654			
1	1.00	-	4.910	4.346	3.650			
2	1.41	-	4.874	4.326	3.606			
4	2.00	-	4.840	4.322	3.576			
8	2.83	-	4.802	4.276	3.536			
15	3.87	-	4.766	4.248	3.516			
30	5.48	-	4.728	4.214	3.470			
60	7.75	-	4.688	4.168	3.422			
120	10.95	-	4.646	4.120	3.352			
240	15.49	-	4.618	4.066	3.264			
480	21.91	-	4.608	4.022	3.180			
1440	37.95	5.470	4.570	3.980	3.108			

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, $E$
<b>Loading</b>					
7	3.200	0.00	20.00	10.52	1.11
7	5.470	2.27	22.27	12.79	1.35
50	4.570	1.37	21.37	11.89	1.25
150	3.980	0.78	20.78	11.30	1.19
250	3.108	-0.09	19.91	10.42	1.10



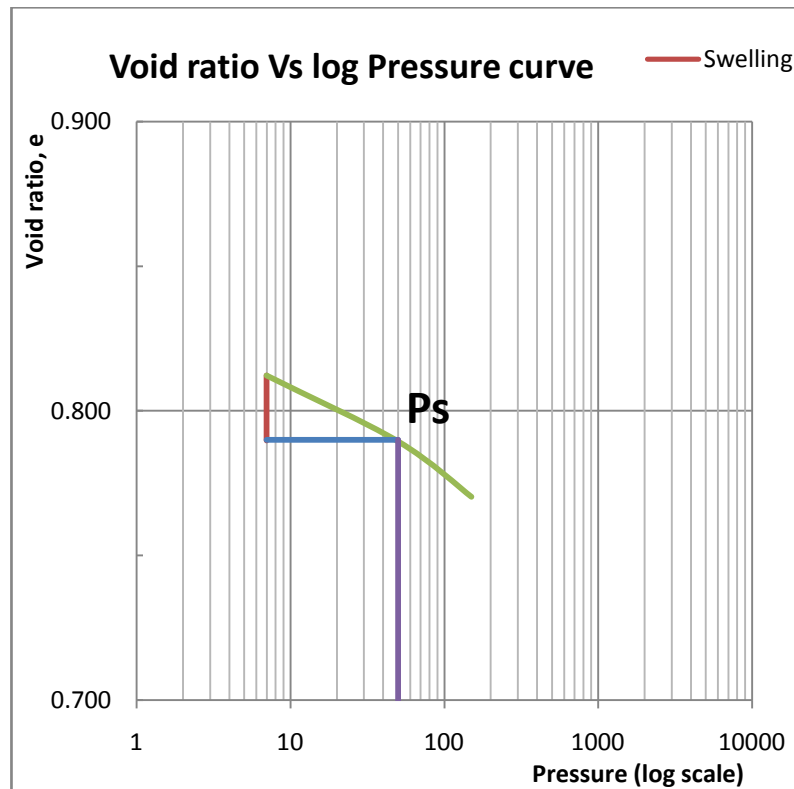
Swelling potential & Pressure

Initial Dial Reading	3.2mm
Final Dial Reading	5.47mm
Swell , [%]	11.35
Swelling Pressure, kPa	255.56

6.4 Location: Got 3 (TP3) @ 1.0 m

		Dial Gauge Reading, mm						
		7	50	150	250	400	800	1600
Time(min.)	$\sqrt{\text{time}}$	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	3.000	3.250	3.004				
0.1	0.32		3.110	2.904				
0.25	0.50	-	3.100	2.890				
0.50	0.71	-	3.090	2.904				
1	1.00	-	3.082	2.880				
2	1.41	-	3.074	2.870				
4	2.00	-	3.060	2.860				
8	2.83	-	3.054	2.852				
15	3.87	-	3.046	2.842				
30	5.48	-	3.038	2.830				
60	7.75	-	3.032	2.820				
120	10.95	-	3.026	2.810				
240	15.49	-	3.018	2.802				
480	21.91	-	3.010	2.794				
1440	37.95	3.250	3.004	2.782				

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	3.000	0.000	20.000	8.826	0.790
7	3.250	0.250	20.250	9.076	0.812
50	3.004	-0.004	19.996	8.822	0.789
150	2.782	-0.218	19.782	8.608	0.770



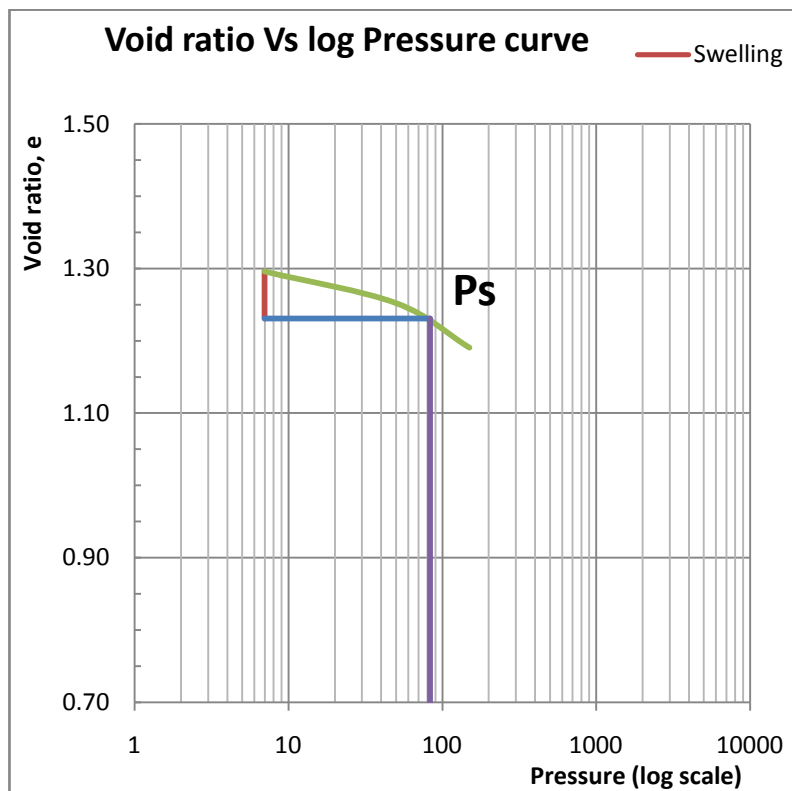
Swelling potential & Pressure

Initial Dial Reading	3mm
Final Dial Reading	3.25mm
Swell , [%]	1.25
Swelling Pressure, kPa	50.00

6.5 Location: Beke and Sendafa Border (TP4) @ 1.2 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	150 [kPa]	250 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	4.400	4.982	4.588				
0.1	0.32		4.900	4.420				
0.25	0.50	-	4.892	4.402				
0.50	0.71	-	4.886	4.382				
1	1.00	-	4.876	4.372				
2	1.41	-	4.870	4.354				
4	2.00	-	4.860	4.352				
8	2.83	-	4.852	4.310				
15	3.87	-	4.842	4.288				
30	5.48	-	4.832	4.262				
60	7.75	-	4.824	4.236				
120	10.95	-	4.788	4.198				
240	15.49	-	4.606	4.166				
480	21.91	-	4.596	4.068				
1440	37.95	4.982	4.588	4.036				

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, $E$
<b>Loading</b>					
7	4.400	0.00	20.00	11.04	1.23
7	4.982	0.58	20.58	11.62	1.30
50	4.588	0.19	20.19	11.22	1.25
150	4.036	-0.36	19.64	10.67	1.19



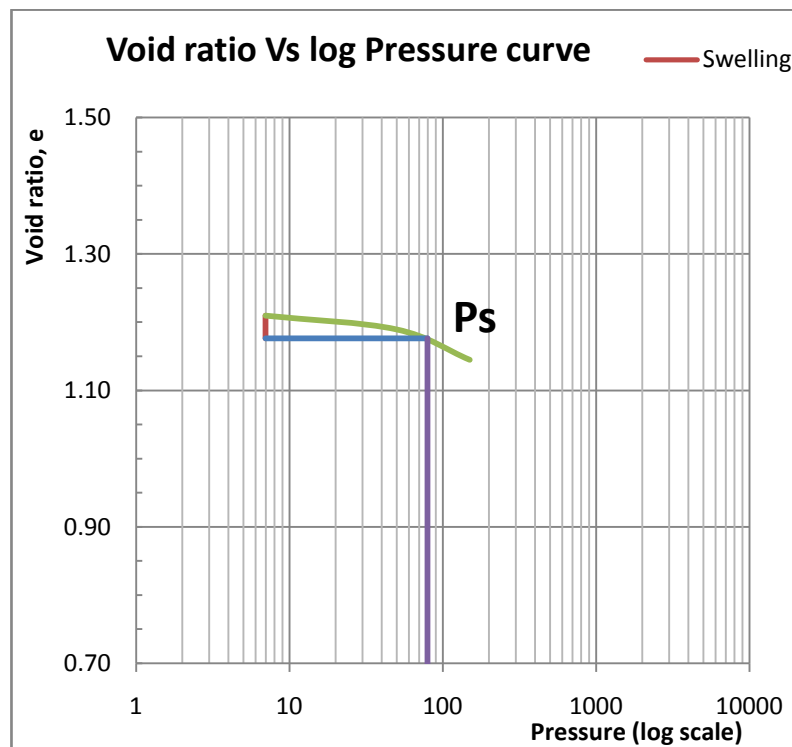
Swelling potential & Pressure

Initial Dial Reading	4.4mm
Final Dial Reading	4.98mm
Swell, [%]	2.91
Swelling Pressure, kPa	83.33

6.6 Location: Beke and Sendafa Border (TP4) @ 2.5 m

		Dial Gauge Reading, mm						
		7	50	150	200	400	800	1600
Time(min.)	$\sqrt{\text{time}}$	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	4.200	4.504	4.322				
0.1	0.32		4.470	4.190				
0.25	0.50	-	4.452	4.164				
0.50	0.71	-	4.438	4.146				
1	1.00	-	4.422	4.122				
2	1.41	-	4.408	4.096				
4	2.00	-	4.394	4.066				
8	2.83	-	4.380	4.036				
15	3.87	-	4.370	4.010				
30	5.48	-	4.358	3.990				
60	7.75	-	4.352	3.972				
120	10.95	-	4.342	3.956				
240	15.49	-	4.336	3.942				
480	21.91	-	4.328	3.920				
1440	37.95	4.504	4.322	3.910				

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	4.200	0.00	20.00	10.81	1.18
7	4.504	0.30	20.30	11.11	1.21
50	4.322	0.12	20.12	10.93	1.19
150	3.910	-0.29	19.71	10.52	1.14



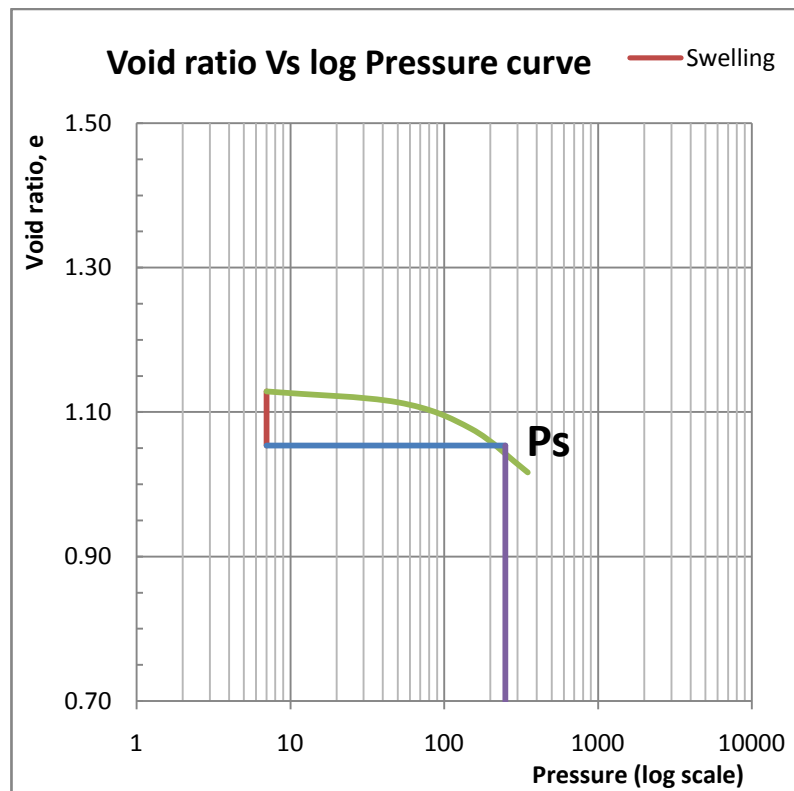
Swelling potential & Pressure

Initial Dial Reading	4.20mm
Final Dial Reading	4.50mm
Swell, [%]	1.52
Swelling pressure, kpa	79.61

6.7 Location: Kebt Tera (TP5) @ 1.5 m

Time(min.)	$\sqrt{t}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	150 [kPa]	350 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	3.800	4.532	4.384	4.026			
0.1	0.32		4.454	4.224	3.750			
0.25	0.50	-	4.446	4.208	3.724			
0.50	0.71	-	4.442	4.196	3.704			
1	1.00	-	4.436	4.182	3.683			
2	1.41	-	4.432	4.162	3.660			
4	2.00	-	4.426	4.154	3.640			
8	2.83	-	4.422	4.141	3.618			
15	3.87	-	4.416	4.127	3.598			
30	5.48	-	4.410	4.110	3.570			
60	7.75	-	4.406	4.089	3.549			
120	10.95	-	4.402	4.068	3.522			
240	15.49	-	4.396	4.053	3.490			
480	21.91	-	4.387	4.038	3.464			
1440	37.95	4.532	4.384	4.026	3.440			

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, $E$
<b>Loading</b>					
7	3.800	0.00	20.00	10.26	1.05
7	4.532	0.73	20.73	10.99	1.13
50	4.384	0.58	20.58	10.84	1.11
150	4.026	0.23	20.23	10.49	1.08
350	3.440	-0.36	19.64	9.90	1.02



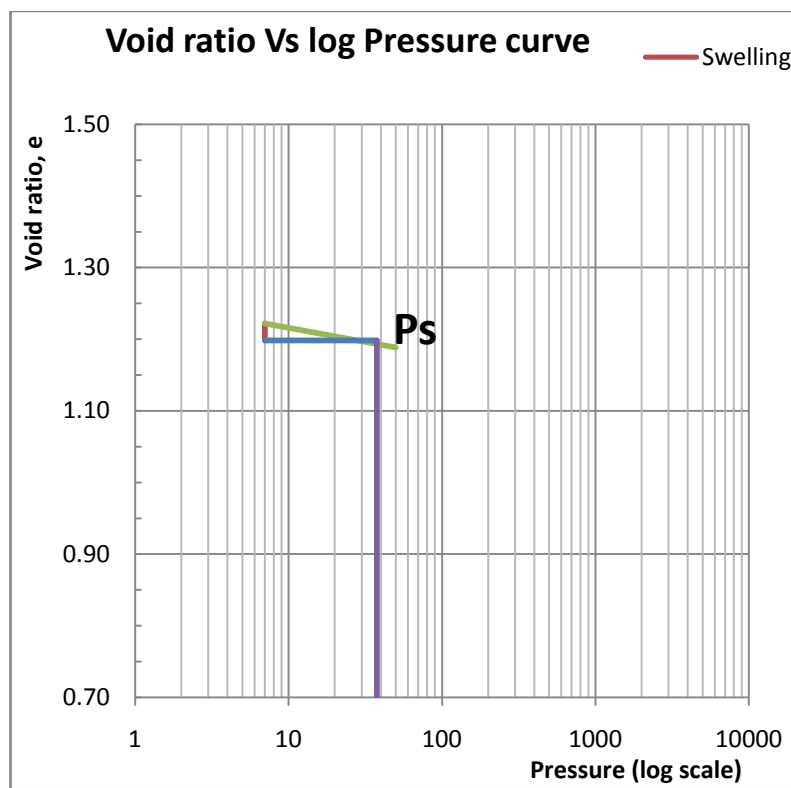
Swelling potential & Pressure

Initial Dial Reading	3.80mm
Final Dial Reading	4.53mm
Swell , [%]	3.66
Swelling Pressure, kPa	250

6.8 Location: Keht Tera (TP5) @ 2.5 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	4.200	4.418					
0.1	0.32		4.322					
0.25	0.50	-	4.308					
0.50	0.71	-	4.298					
1	1.00	-	4.290					
2	1.41	-	4.278					
4	2.00	-	4.268					
8	2.83	-	4.256					
15	3.87	-	4.246					
30	5.48	-	4.234					
60	7.75	-	4.220					
120	10.95	-	4.203					
240	15.49	-	4.188					
480	21.91	-	4.163					
1440	37.95	4.418	4.112					

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	4.200	0.00	20.00	10.90	1.20
7	4.418	0.22	20.22	11.12	1.22
50	4.112	-0.09	19.91	10.81	1.19



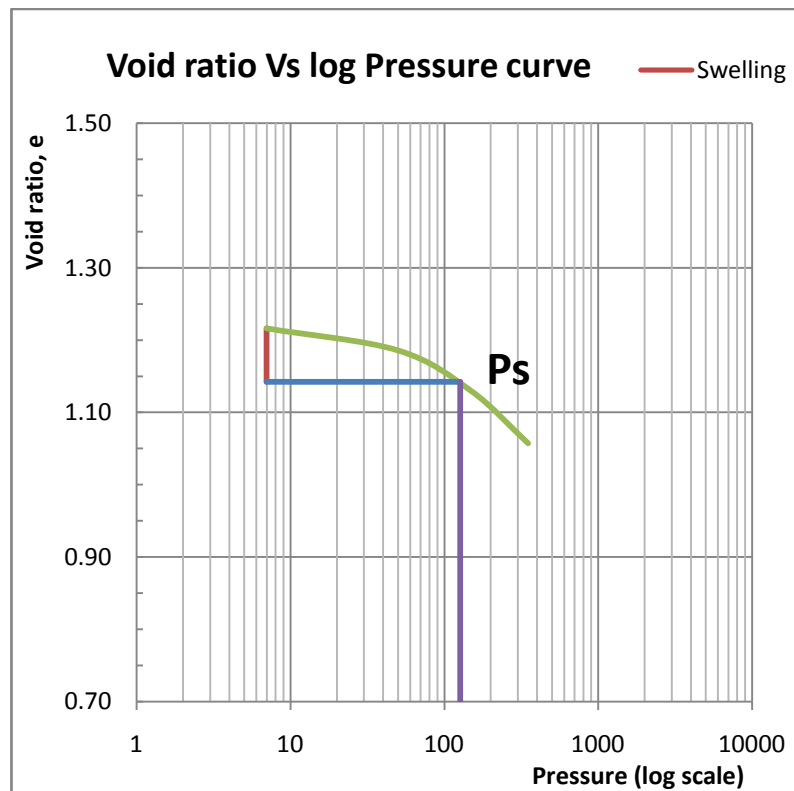
Swelling potential & Pressure

Initial Dial Reading	4.20mm
Final Dial Reading	4.42mm
Swell, [%]	1.09
Swelling Pressure, kPa	37.63

6.9 Location: High School (TP6) @ 1.5 m

		Dial Gauge Reading, mm						
		7	50	150	350	750	800	1600
Time(min.)	$\sqrt{\text{time}}$	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	6.400	7.090	6.806	6.278	5.606		
0.1	0.32		6.946	6.550	5.990	5.606		
0.25	0.50	-	6.936	6.516	5.948	5.280		
0.50	0.71	-	6.922	6.490	5.916	5.240		
1	1.00	-	6.910	6.466	5.886	5.178		
2	1.41	-	6.898	6.446	5.854	5.144		
4	2.00	-	6.886	6.422	5.824	5.110		
8	2.83	-	6.876	6.400	5.796	5.070		
15	3.87	-	6.868	6.382	5.770	5.032		
30	5.48	-	6.858	6.364	5.742	4.984		
60	7.75	-	6.850	6.346	5.716	4.930		
120	10.95	-	6.838	6.328	5.684	4.874		
240	15.49	-	6.828	6.314	5.656	4.814		
480	21.91	-	6.818	6.296	5.632	4.764		
1440	37.95	7.090	6.806	6.278	5.606	4.726		

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	6.400	0.00	20.00	10.66	1.14
7	7.090	0.69	20.69	11.35	1.22
50	6.806	0.41	20.41	11.07	1.19
150	6.278	-0.12	19.88	10.54	1.13
350	5.606	-0.79	19.21	9.87	1.06



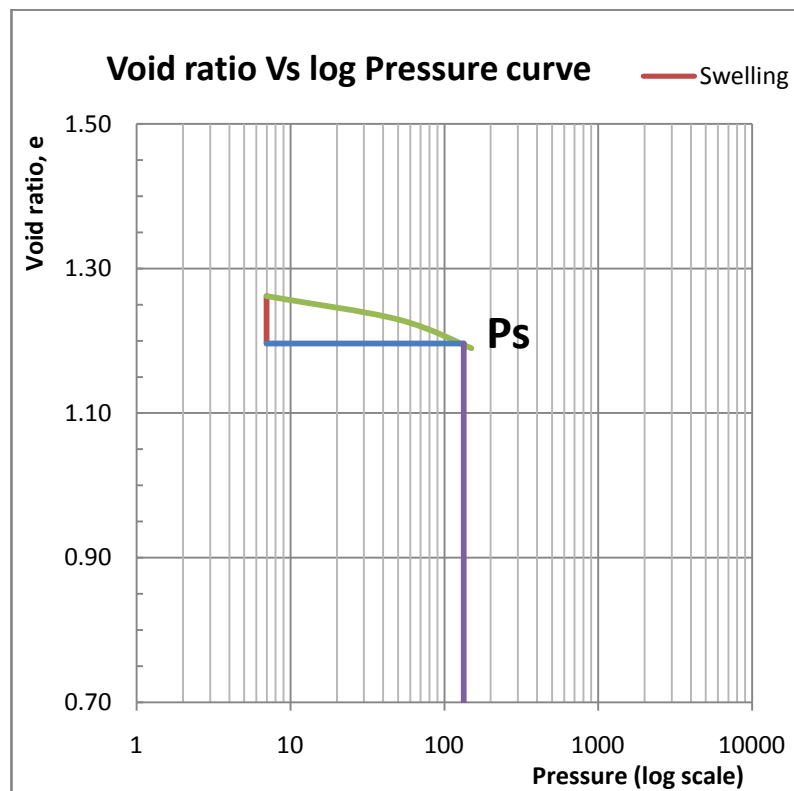
Swelling potential & Pressure

Initial Dial Reading	6.40mm
Final Dial Reading	7.09mm
Swell , [%]	3.45
Swelling Pressure, kPa	126.89

6.10 Location: High School (TP6) @ 3.0 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	150 [kPa]	350 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	5.000	5.598	5.306				
0.1	0.32		5.456	5.280				
0.25	0.50	-	5.442	5.250				
0.50	0.71	-	5.430	5.226				
1	1.00	-	5.418	5.204				
2	1.41	-	5.406	5.178				
4	2.00	-	5.392	5.151				
8	2.83	-	5.366	5.123				
15	3.87	-	5.354	5.096				
30	5.48	-	5.342	5.066				
60	7.75	-	5.342	5.036				
120	10.95	-	5.334	4.998				
240	15.49	-	5.326	4.980				
480	21.91	-	5.310	4.956				
1440	37.95	5.598	5.306	4.940				

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.000	0.00	20.00	10.89	1.20
7	5.598	0.60	20.60	11.49	1.26
50	5.306	0.31	20.31	11.20	1.23
150	4.940	-0.06	19.94	10.83	1.19



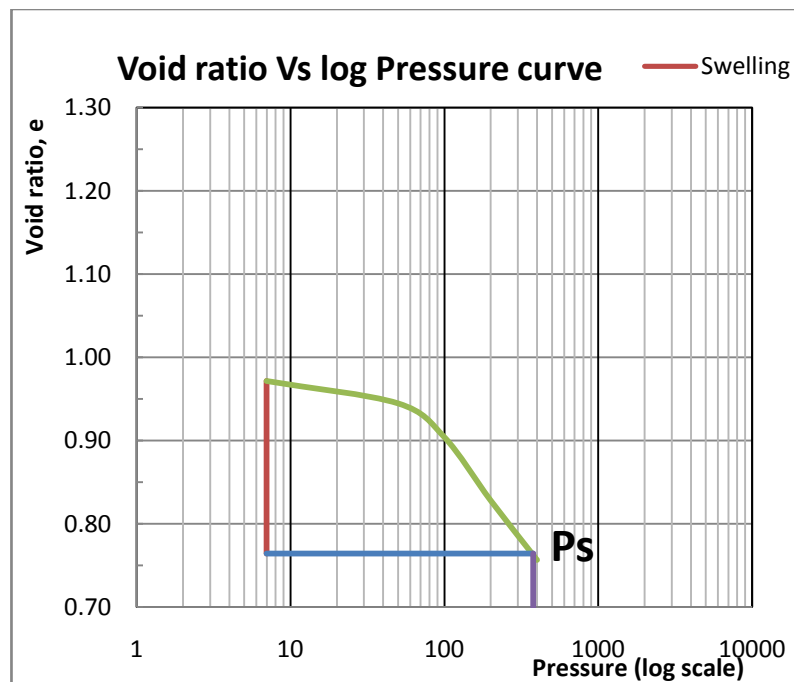
Swelling potential & Pressure

Initial Dial Reading	5
Final Dial Reading	5.60
Swell , [%]	2.99
Swelling Pressure, kPa	133.61

6.11 Location: Amanuel Church (TP7) @ 1.5m

		Dial Gauge Reading, mm						
		7	50	100	200	400	800	1600
Time(min.)	$\sqrt{t}$ time	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	5.800	8.148	7.842	7.384	6.524		
0.1	0.32		8.080	7.817	7.184	6.498		
0.25	0.50	-	8.062	7.786	7.136	6.456		
0.50	0.71	-	8.052	7.770	7.092	6.388		
1	1.00	-	8.032	7.730	7.068	6.342		
2	1.41	-	8.022	7.668	7.016	6.278		
4	2.00	-	8.000	7.646	6.942	6.186		
8	2.83	-	7.982	7.632	6.894	6.072		
15	3.87	-	7.962	7.600	6.832	5.972		
30	5.48	-	7.948	7.570	6.832	5.796		
60	7.75	-	7.894	7.552	6.756	5.762		
120	10.95	-	7.884	7.514	6.672	5.750		
240	15.49	-	7.870	7.480	6.616	5.744		
480	21.91	-	7.852	7.438	6.542	5.724		
1440	37.95	8.148	7.842	7.384	6.524	5.712		

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, $E$
<b>Loading</b>					
7	5.800	0.00	20.00	8.66	0.76
7	8.148	2.35	22.35	11.01	0.97
50	7.842	2.04	22.04	10.71	0.94
100	7.384	1.58	21.58	10.25	0.90
200	6.524	0.72	20.72	9.39	0.83
400	5.712	-0.09	19.91	8.58	0.76



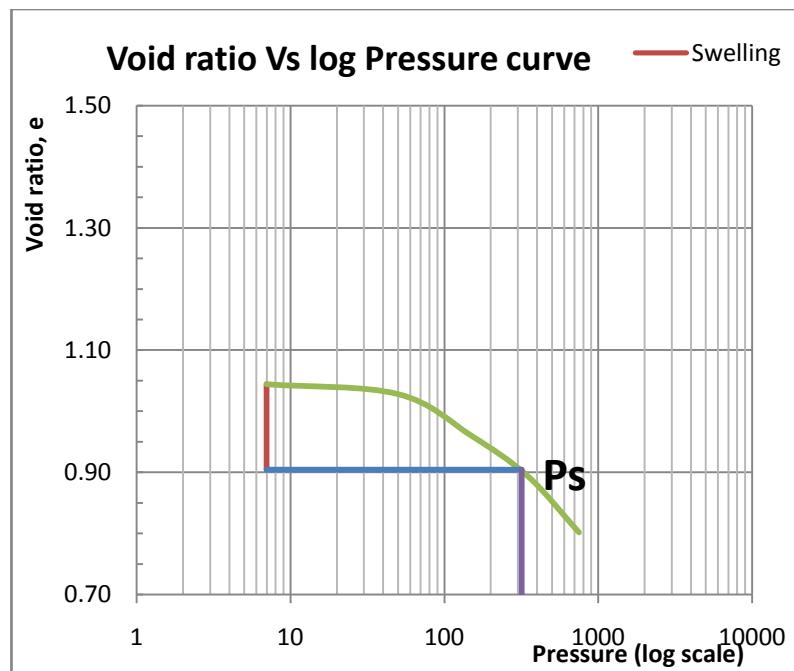
Swelling potential & Pressure

Initial Dial Reading	5.80mm
Final Dial Reading	8.15mm
Swell , [%]	11.74
Swelling Pressure, kPa	378.33

6.12 Location: Amanuel Church (TP7) @ 2.7 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	5.400	6.868	6.702	5.986	5.288		
0.1	0.32		6.838	6.292	5.780	5.034		
0.25	0.50	-	6.828	6.264	5.762	5.000		
0.50	0.71	-	6.822	6.244	5.746	4.968		
1	1.00	-	6.794	6.222	5.726	4.954		
2	1.41	-	6.784	6.204	5.710	4.930		
4	2.00	-	6.774	6.182	5.682	4.902		
8	2.83	-	6.766	6.162	5.656	4.876		
15	3.87	-	6.758	6.140	5.628	4.840		
30	5.48	-	6.748	6.118	5.590	4.792		
60	7.75	-	6.740	6.094	5.548	4.732		
120	10.95	-	6.726	6.068	5.496	4.654		
240	15.49	-	6.722	6.046	5.432	4.552		
480	21.91	-	6.710	6.018	5.364	4.436		
1440	37.95	6.868	6.702	5.986	5.288	4.324		

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.400	0.00	20.00	9.50	0.90
7	6.868	1.47	21.47	10.97	1.04
50	6.702	1.30	21.30	10.80	1.03
150	5.986	0.59	20.59	10.08	0.96
350	5.288	-0.11	19.89	9.39	0.89
750	4.324	-1.08	18.92	8.42	0.80



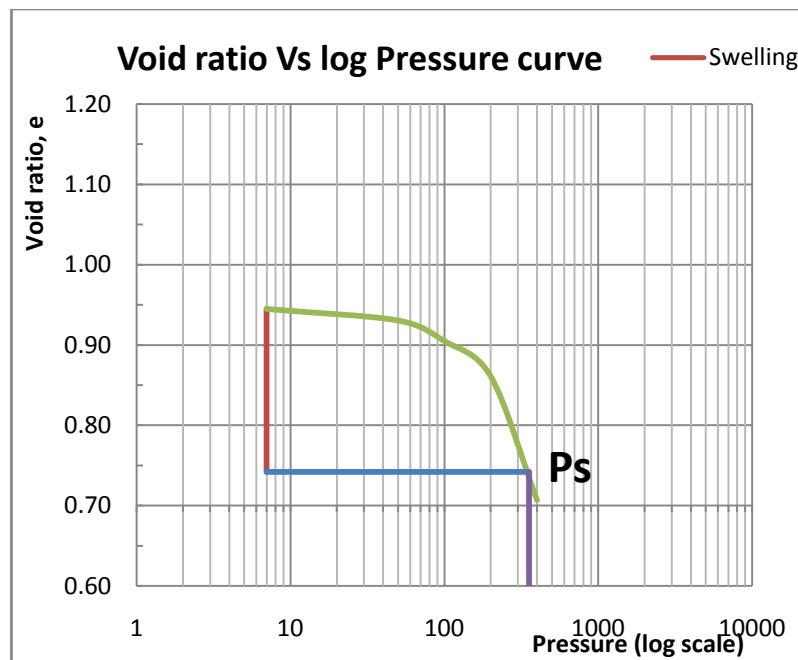
Swelling potential & Pressure

Initial Dial Reading	5.40mm
Final Dial Reading	6.87mm
Swell, [%]	7.34
Swelling Pressure, kPa	317.91

6.13 Location: Zenbaba Grocery (TP8) @ 1.3 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	5.400	7.732	7.564	7.272	6.770		
0.1	0.32		7.676	7.496	7.110	6.570		
0.25	0.50	-	7.672	7.488	7.098	6.464		
0.50	0.71	-	7.666	7.480	7.082	6.436		
1	1.00	-	7.662	7.470	7.062	6.358		
2	1.41	-	7.658	7.458	7.042	6.282		
4	2.00	-	7.650	7.444	7.008	6.232		
8	2.83	-	7.643	7.430	6.992	6.176		
15	3.87	-	7.638	7.414	6.970	6.108		
30	5.48	-	7.629	7.396	6.946	6.004		
60	7.75	-	7.620	7.376	6.908	5.824		
120	10.95	-	7.611	7.350	6.870	5.648		
240	15.49	-	7.584	7.308	6.826	5.430		
480	21.91	-	7.576	7.302	6.770	5.140		
1440	37.95	7.732	7.564	7.272	6.770	4.998		

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.400	0.00	20.00	8.52	0.74
7	7.732	2.33	22.33	10.85	0.95
50	7.564	2.16	22.16	10.68	0.93
100	7.272	1.87	21.87	10.39	0.90
200	6.770	1.37	21.37	9.89	0.86
400	4.998	-0.40	19.60	8.12	0.71



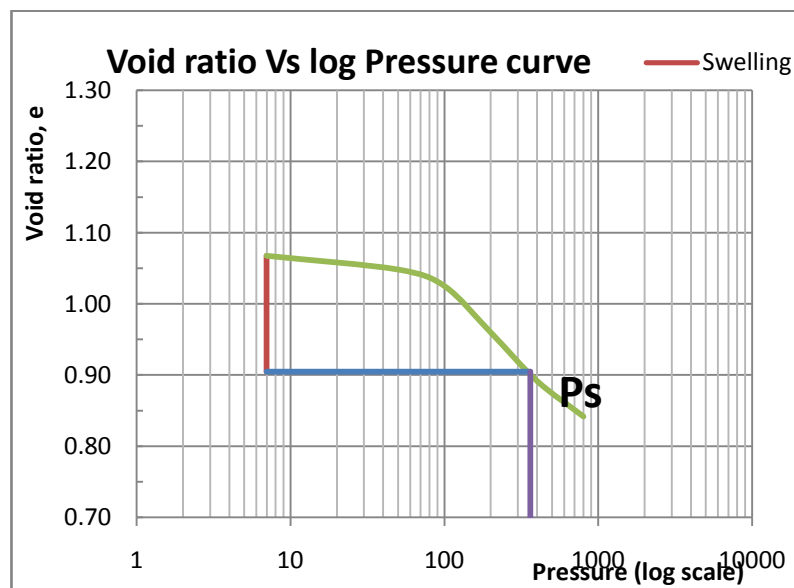
Swelling potential & Pressure

Initial Dial Reading	5.40mm
Final Dial Reading	7.73mm
Swell, [%]	11.66
Swelling Pressure, kPa	354.63

6.14 Location: Municipality (TP9) @ 1.4m

		Dial Gauge Reading, mm						
		7	50	100	200	400	800	1600
Time(min.)	$\sqrt{\text{time}}$	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	5.400	7.106	6.904	6.664	5.978	5.264	
0.1	0.32		7.028	6.838	6.492	5.906	5.234	
0.25	0.50	-	7.016	6.828	6.478	5.866	5.202	
0.50	0.71	-	7.004	6.818	6.450	5.796	5.180	
1	1.00	-	6.996	6.808	6.428	5.700	5.156	
2	1.41	-	6.986	6.798	6.412	5.648	5.118	
4	2.00	-	6.978	6.786	6.374	5.592	5.090	
8	2.83	-	6.968	6.776	6.326	5.548	5.046	
15	3.87	-	6.960	6.763	6.298	5.496	5.008	
30	5.48	-	6.950	6.748	6.237	5.430	4.958	
60	7.75	-	6.940	6.734	6.212	5.376	4.908	
120	10.95	-	6.932	6.718	6.124	5.330	4.874	
240	15.49	-	6.922	6.700	6.040	5.310	4.828	
480	21.91	-	6.912	6.682	6.004	5.288	4.804	
1440	37.95	7.106	6.904	6.664	5.978	5.264	4.738	

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.400	0.00	20.00	9.50	0.90
7	7.106	1.71	21.71	11.21	1.07
50	6.904	1.50	21.50	11.00	1.05
100	6.664	1.26	21.26	10.76	1.03
200	5.978	0.58	20.58	10.08	0.96
400	5.264	-0.14	19.86	9.36	0.89
800	4.738	-0.66	19.34	8.84	0.84



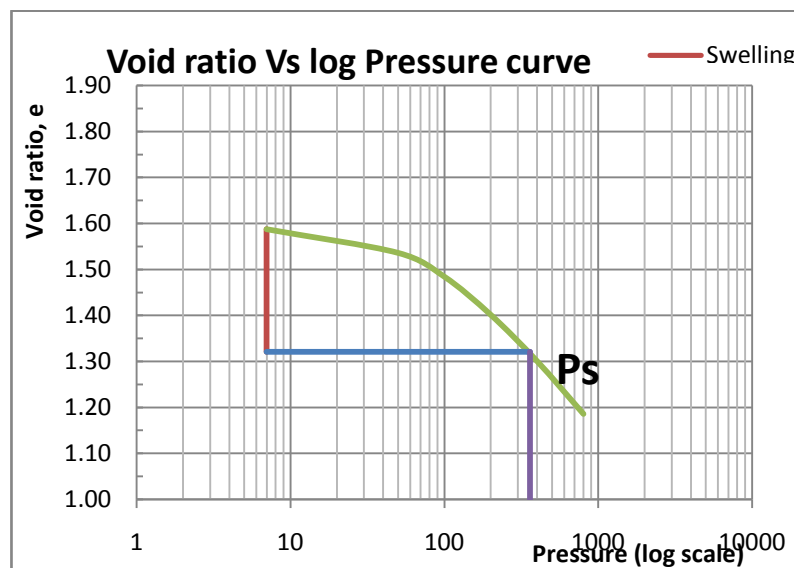
Swelling potential & Pressure

Initial Dial Reading	5.40mm
Final Dial Reading	7.11mm
Swell, [%]	8.53
Swelling Pressure, kPa	361.90

6.15 Location: Dabe 1 (TP10) @ 1.5 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	5.000	7.300	6.856	6.408	5.694	4.826	
0.1	0.32		7.200	6.830	6.288	5.584	4.760	
0.25	0.50	-	7.186	6.796	6.268	5.566	4.750	
0.50	0.71	-	7.172	6.772	6.256	5.552	4.744	
1	1.00	-	7.160	6.758	6.236	5.536	4.734	
2	1.41	-	7.142	6.740	6.216	5.516	4.716	
4	2.00	-	7.118	6.730	6.192	5.490	4.694	
8	2.83	-	7.096	6.718	6.164	5.444	4.654	
15	3.87	-	7.078	6.698	6.130	5.412	4.600	
30	5.48	-	7.048	6.668	6.084	5.360	4.510	
60	7.75	-	7.018	6.626	6.030	5.286	4.400	
120	10.95	-	6.990	6.582		5.270	4.394	
240	15.49	-	6.950	6.528		5.224	4.090	
480	21.91	-	6.914	6.466	5.758	5.122	3.926	
1440	37.95	7.300	6.856	6.408	5.694	4.826	3.838	

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.000	0.00	20.00	11.38	1.32
7	7.300	2.30	22.30	13.68	1.59
50	6.856	1.86	21.86	13.24	1.54
100	6.408	1.41	21.41	12.79	1.48
200	5.694	0.69	20.69	12.08	1.40
400	4.826	-0.17	19.83	11.21	1.30
800	3.838	-1.16	18.84	10.22	1.19



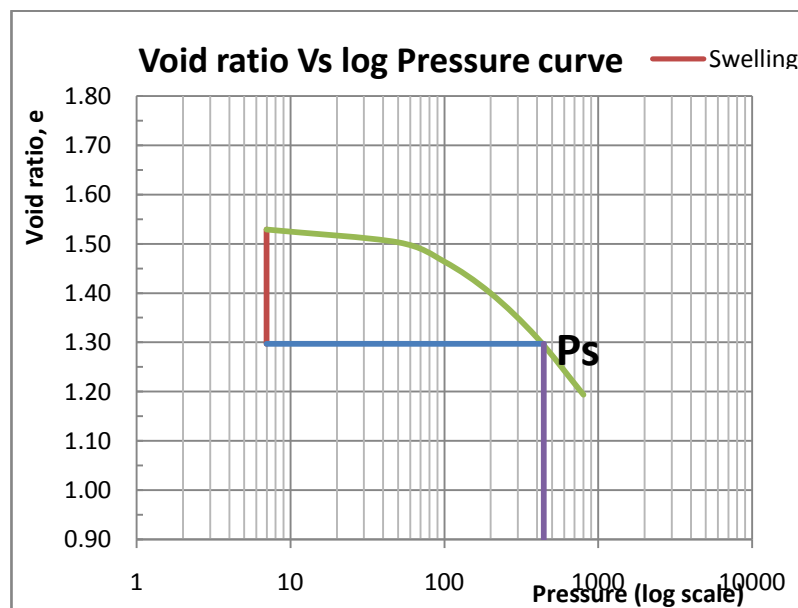
Swelling potential & Pressure

Initial Dial Reading	5.00mm
Final Dial Reading	7.30mm
Swell, [%]	11.50
Swelling Pressure, kPa	359.91

6.16 Location: Dabe 1 (TP10) @ 3.0 m

		Dial Gauge Reading, mm						
		7	50	100	200	400	800	1600
Time(min.)	$\sqrt{\text{time}}$	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]	[kPa]
0	0.00	6.000	8.020	7.794	7.458	6.898	6.110	
0.1	0.32		7.928	7.706	7.298	6.702	5.978	
0.25	0.50	-	7.916	7.696	7.258	6.680	5.964	
0.50	0.71	-	7.904	7.688	7.244	6.666	5.954	
1	1.00	-	7.896	7.678	7.226	6.650	5.942	
2	1.41	-	7.888	7.668	7.212	6.632	5.922	
4	2.00	-	7.878	7.658	7.196	6.610	5.898	
8	2.83	-	7.868	7.646	7.178	6.582	5.864	
15	3.87	-	7.860	7.636	7.158	6.550	5.814	
30	5.48	-	7.850	7.626	7.137	6.510	5.738	
60	7.75	-	7.842	7.548	7.110	6.456	5.654	
120	10.95	-	7.832	7.540	7.072	6.384	5.538	
240	15.49	-	7.822	7.518	7.020	6.294	5.338	
480	21.91	-	7.810	7.482	6.954	6.190	5.200	
1440	37.95	8.020	7.794	7.458	6.898	6.110	5.104	

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	6.000	0.00	20.00	11.29	1.30
7	8.020	2.02	22.02	13.31	1.53
50	7.794	1.79	21.79	13.09	1.50
100	7.458	1.46	21.46	12.75	1.46
200	6.898	0.90	20.90	12.19	1.40
400	6.110	0.11	20.11	11.40	1.31
800	5.104	-0.90	19.10	10.40	1.19



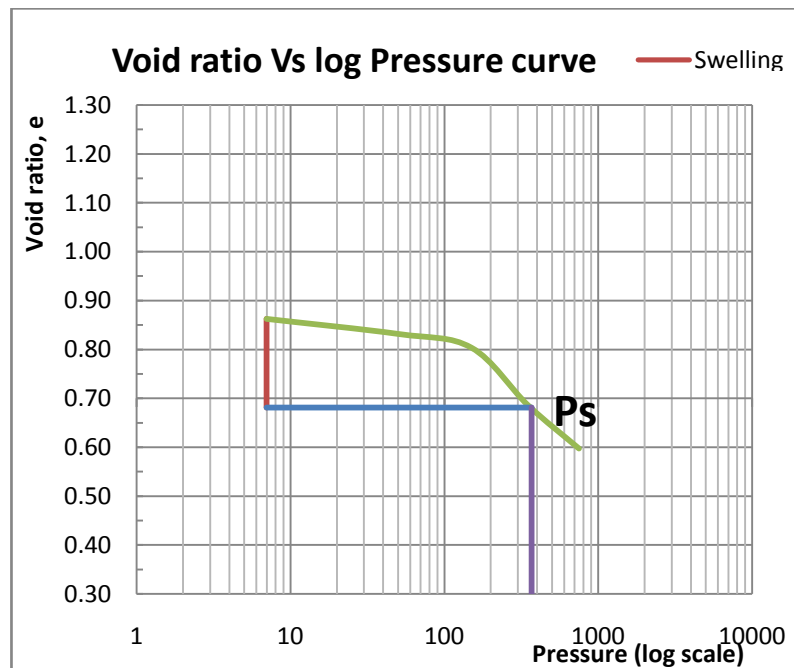
Swelling potential & Pressure

Initial Dial Reading	6.00mm
Final Dial Reading	8.02mm
Swell , [%]	10.10
Swelling Pressure, kPa	443.74

6.17 Location: Dire Mazoria (TP11) @ 1.5 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	150 [kPa]	350 [kPa]	750 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	6.200	8.352	7.986	7.654	6.250		
0.1	0.32		8.288	7.858	7.598	6.116		
0.25	0.50	-	8.282	7.850	7.574	6.006		
0.50	0.71	-	8.276	7.844	7.520	5.922		
1	1.00	-	8.272	7.840	7.448	5.862		
2	1.41	-	8.266	7.832	7.334	5.830		
4	2.00	-	8.258	7.822	7.220	5.738		
8	2.83	-	8.250	7.810	7.130	5.688		
15	3.87	-	8.244	7.796	7.044	5.644		
30	5.48	-	8.236	7.782	6.964	5.614		
60	7.75	-	8.216	7.768	6.896	5.542		
120	10.95	-	8.202	7.754	6.804	5.508		
240	15.49	-	8.146	7.740	6.638	5.472		
480	21.91	-	8.082	7.690	6.578	5.438		
1440	37.95	8.352	7.986	7.654	6.250	5.204		

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	6.200	0.00	20.00	8.11	0.68
7	8.352	2.15	22.15	10.26	0.86
50	7.986	1.79	21.79	9.89	0.83
150	7.654	1.45	21.45	9.56	0.80
350	6.250	0.05	20.05	8.16	0.69
750	5.204	-1.00	19.00	7.11	0.60



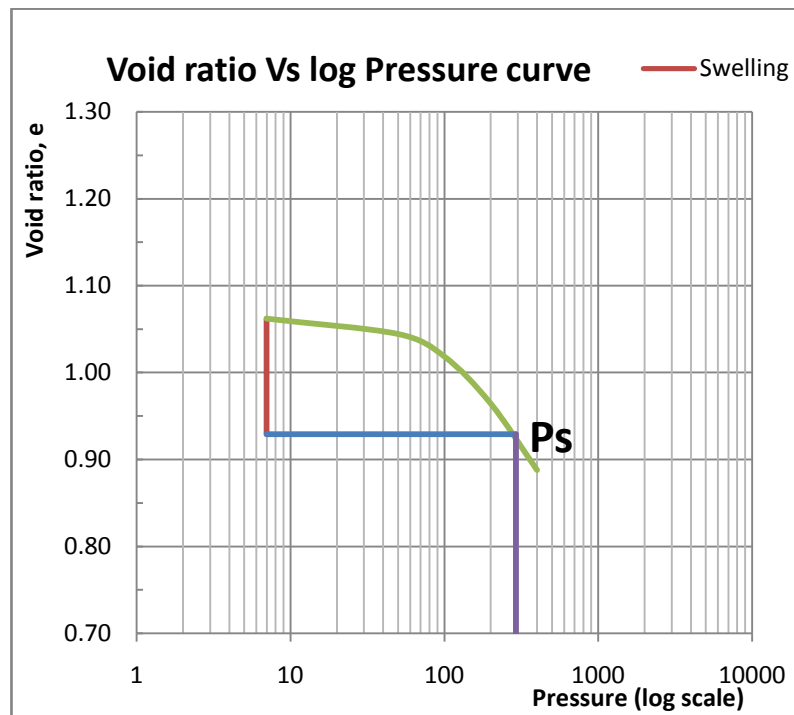
Swelling potential & Pressure

Initial Dial Reading	6.20mm
Final Dial Reading	8.35mm
Swell , [%]	10.76
Swelling Pressure, kPa	369.12

6.18 Location: Dire Mazoria (TP11) @ 3.0 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	6.600	7.980	7.794	7.530	6.968		
0.1	0.32		7.888	7.696	7.332	6.658		
0.25	0.50	-	7.884	7.686	7.298	6.616		
0.50	0.71	-	7.878	7.680	7.276	6.588		
1	1.00	-	7.874	7.670	7.252	6.554		
2	1.41	-	7.868	7.660	7.224	6.526		
4	2.00	-	7.860	7.648	7.196	6.494		
8	2.83	-	7.856	7.636	7.170	6.478		
15	3.87	-	7.848	7.622	7.144	6.426		
30	5.48	-	7.838	7.610	7.114	6.386		
60	7.75	-	7.830	7.594	7.062	6.350		
120	10.95	-	7.822	7.578	7.050	6.300		
240	15.49	-	7.814	7.564	7.018	6.246		
480	21.91	-	7.804	7.546	6.992	6.202		
1440	37.95	7.980	7.794	7.530	6.968	6.172		

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	6.600	0.00	20.00	9.63	0.93
7	7.980	1.38	21.38	11.01	1.06
50	7.794	1.19	21.19	10.83	1.04
100	7.530	0.93	20.93	10.56	1.02
200	6.968	0.37	20.37	10.00	0.96
400	6.172	-0.43	19.57	9.20	0.89



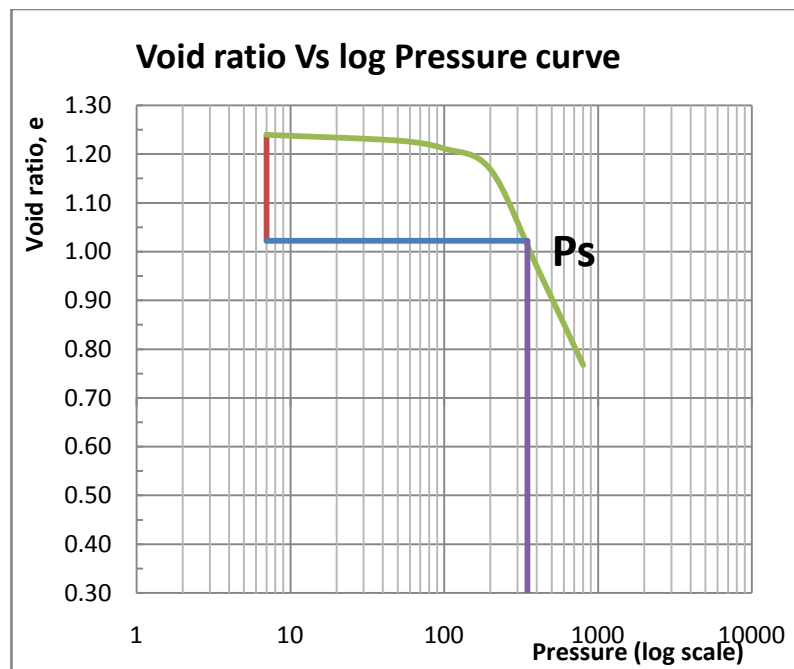
Swelling potential & Pressure

Initial Dial Reading	6.60mm
Final Dial Reading	7.98mm
Swell , [%]	6.90
Swelling Pressure, kPa	292.46

6.19 Location: Dabe 2 (TP12) @ 1.5 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	5.200	7.350	7.228	7.066	6.638		
0.1	0.32		7.310	7.190	6.960			
0.25	0.50	-	7.302	7.186	6.960			
0.50	0.71	-	7.298	7.180	6.960			
1	1.00	-	7.292	7.178	6.960			
2	1.41	-	7.286	7.174	6.960			
4	2.00	-	7.282	7.170	6.960			
8	2.83	-	7.276	7.162	6.960			
15	3.87	-	7.272	7.152	6.960			
30	5.48	-	7.268	7.142	6.960			
60	7.75	-	7.254	7.130	6.960			
120	10.95	-	7.250	7.118	6.960			
240	15.49	-	7.242	7.086	6.960			
480	21.91	-	7.236		6.960			
1440	37.95	7.350	7.228	7.066	6.638			

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.200	0.00	20.00	8.60	0.75
7	7.350	2.15	22.15	10.75	0.94
50	7.228	2.03	22.03	10.62	0.93
100	7.066	1.87	21.87	10.46	0.92
200	6.638	1.44	21.44	10.03	0.88
400	0.000	-5.20	14.80	3.40	0.30



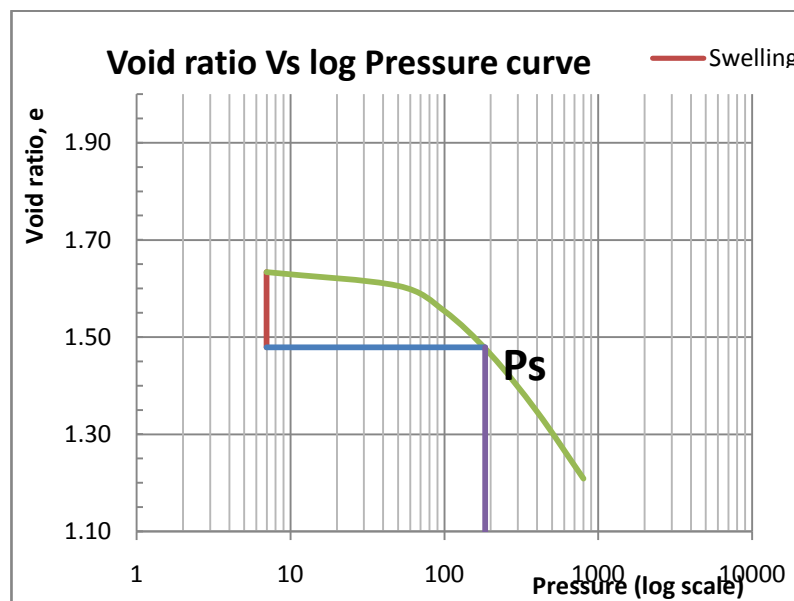
Swelling potential & Pressure

Initial Dial Reading	5.20mm
Final Dial Reading	7.35mm
Swell , [%]	10.75
Swelling Pressure, kPa	369.12

6.20 Location: Dire Cafe (TP13) @ 1.7 m

Time(min.)	$\sqrt{\text{time}}$	Dial Gauge Reading, mm						
		7 [kPa]	50 [kPa]	100 [kPa]	200 [kPa]	400 [kPa]	800 [kPa]	1600 [kPa]
0	0.00	5.800	7.048	6.822	6.404	5.684	4.734	
0.1	0.32		6.988	6.704	6.216	5.480	4.632	
0.25	0.50	-	6.970	6.696	6.196	5.460	4.614	
0.50	0.71	-	6.960	6.686	6.176	5.444	4.604	
1	1.00	-	6.948	6.662	6.126	5.432	4.584	
2	1.41	-	6.938	6.652	6.112	5.402	4.570	
4	2.00	-	6.926	6.638	6.084	5.376	4.542	
8	2.83	-	6.918	6.614	6.070	5.332	4.506	
15	3.87	-	6.904	6.580	6.038	5.286	4.448	
30	5.48	-	6.892	6.570	6.000	5.230	4.370	
60	7.75	-	6.878	6.530	5.898	5.160	4.284	
120	10.95	-	6.860	6.492	5.870	5.038	4.110	
240	15.49	-	6.846	6.458	5.778	4.908	3.912	
480	21.91	-	6.830	6.428	5.726	4.804		
1440	37.95	7.048	6.822	6.404	5.684	4.734	3.620	

Applied pressure P (kPa)	Final Dial Reading (mm)	Change In Specimen Height (mm)	Final Specimen Height (mm)	Void Height, $H_v$ (mm)	Void Ratio, E
<b>Loading</b>					
7	5.800	0.00	20.00	11.93	1.48
7	7.048	1.25	21.25	13.18	1.63
50	6.822	1.02	21.02	12.95	1.61
100	6.404	0.60	20.60	12.54	1.55
200	5.684	-0.12	19.88	11.82	1.46
400	4.734	-1.07	18.93	10.87	1.35
800	3.620	-2.18	17.82	9.75	1.21



Swelling potential & Pressure

Initial Dial Reading	5.80mm
Final Dial Reading	7.05mm
Swell , [%]	6.24
Swelling Pressure, kPa	183.89

## Appendix B: - Scatter Plot of Swelling Potential with Index Properties

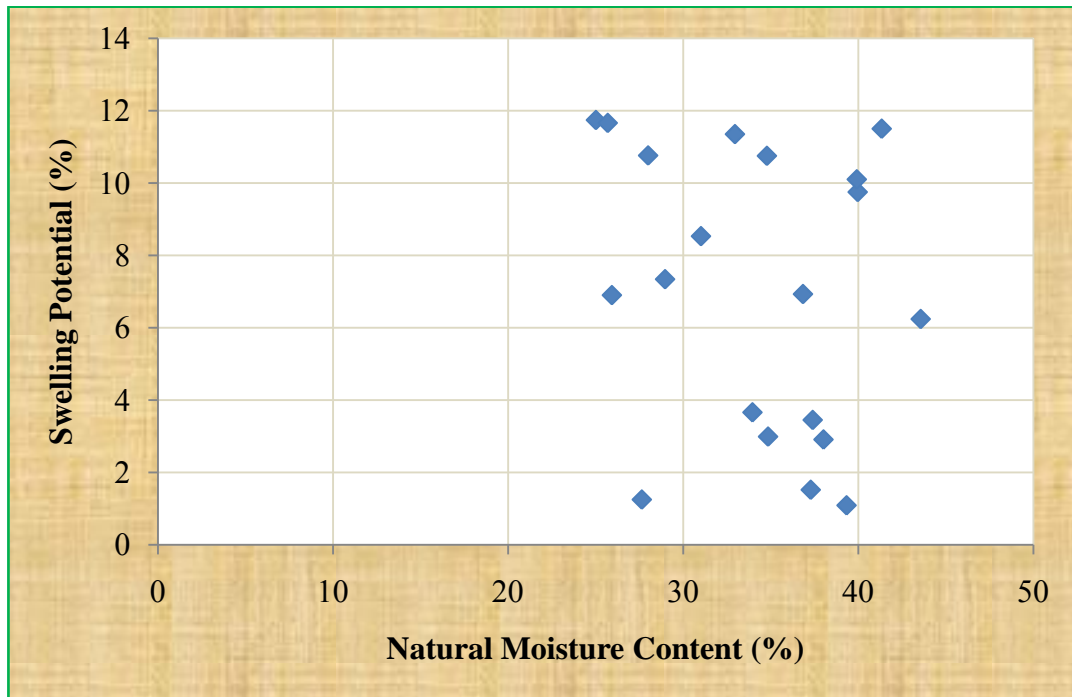


Figure: Scatter plots of Sp vs. Moisture content

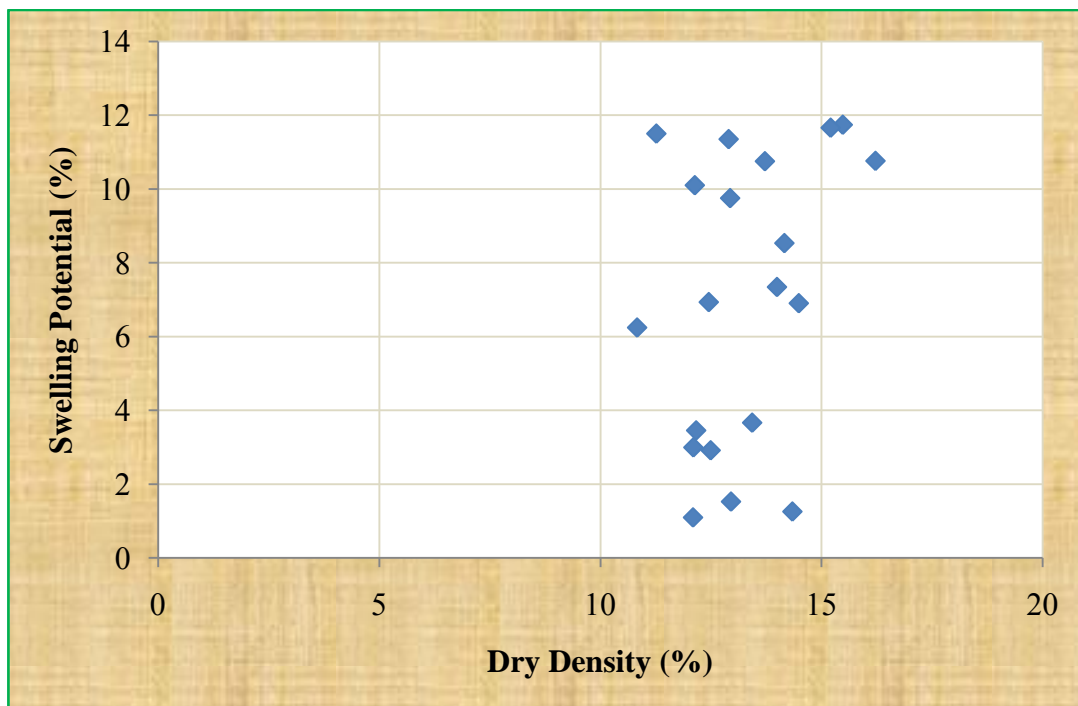


Figure: Scatter plots of Sp vs. Dry density

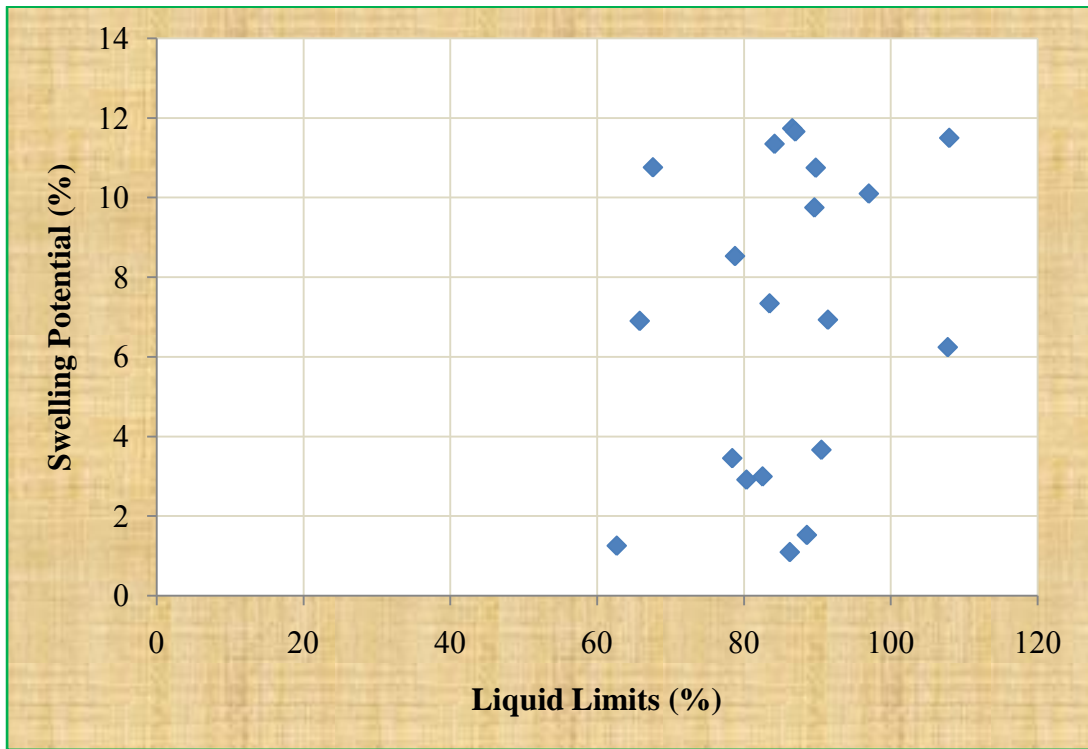


Figure: Scatter plots of Sp vs. Liquid Limit

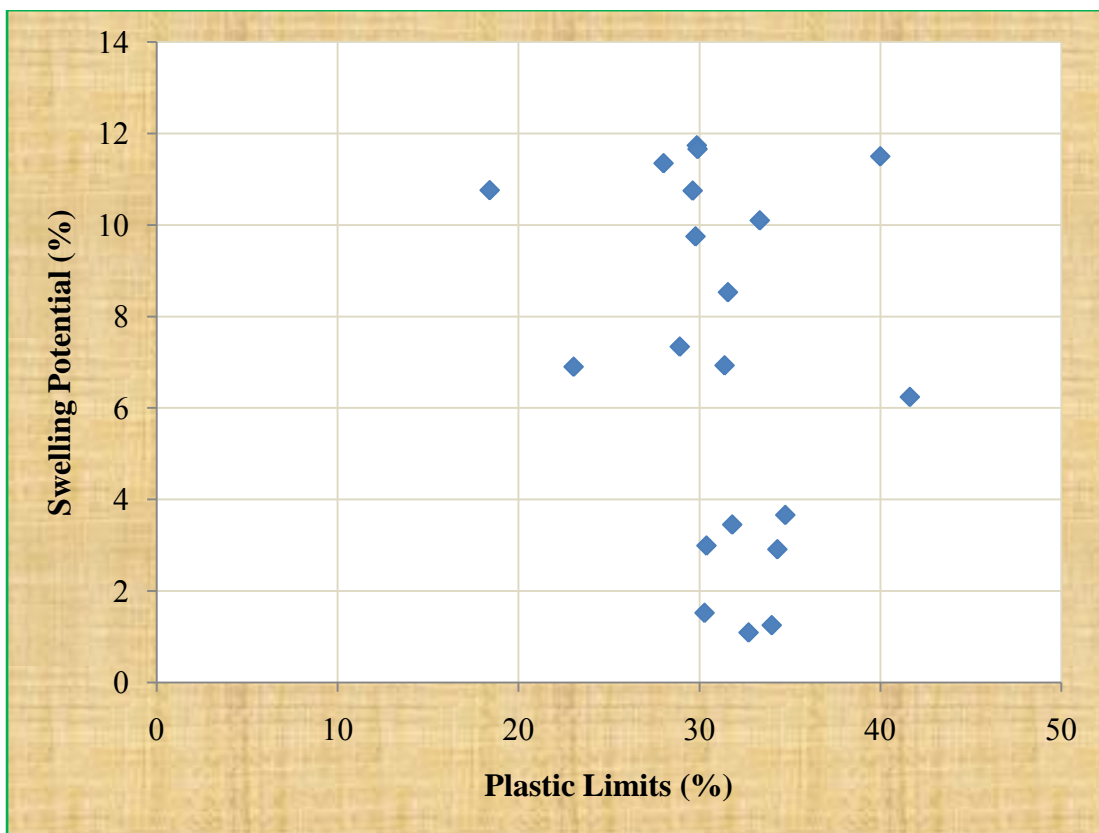


Figure: Scatter plots of Sp vs. Plastic Limit

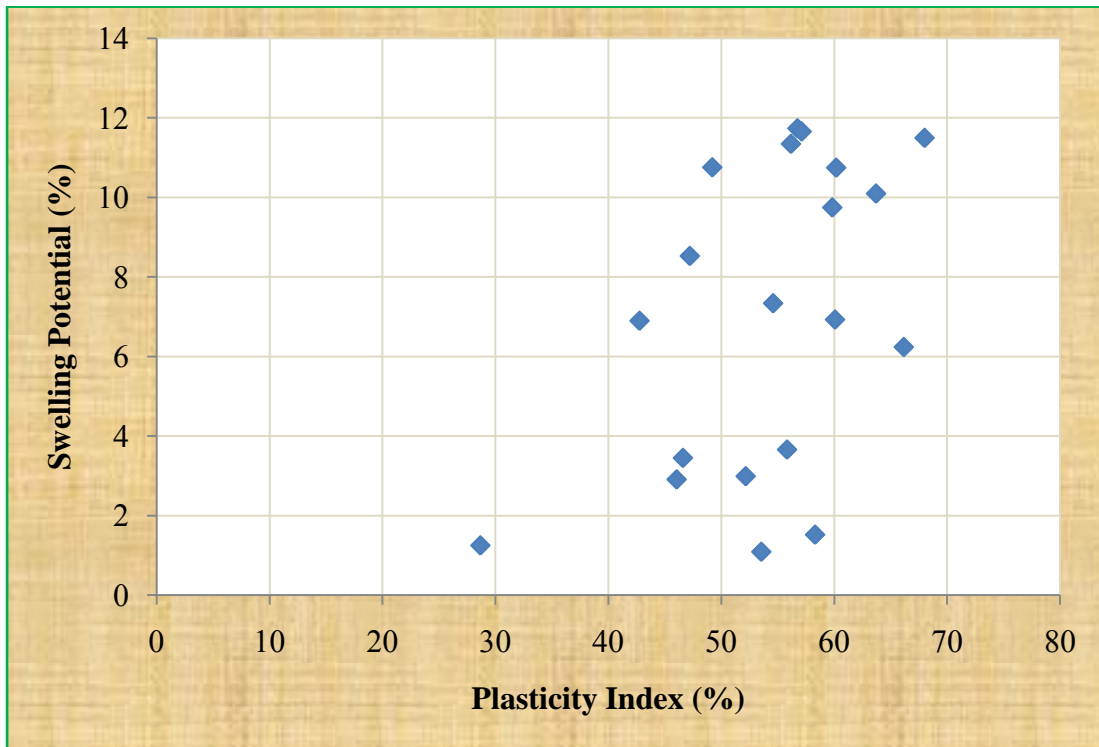


Figure: Scatter plots of Sp vs. Plastic Index

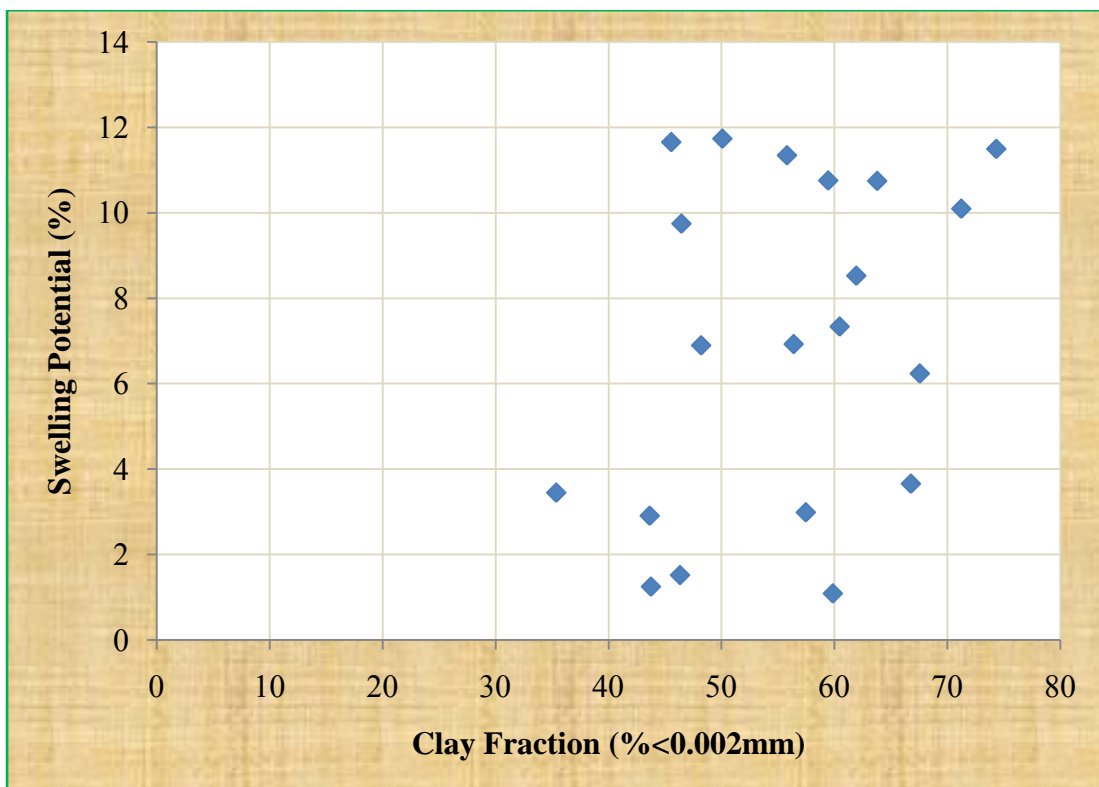


Figure: Scatter plots of Sp vs. Clay content

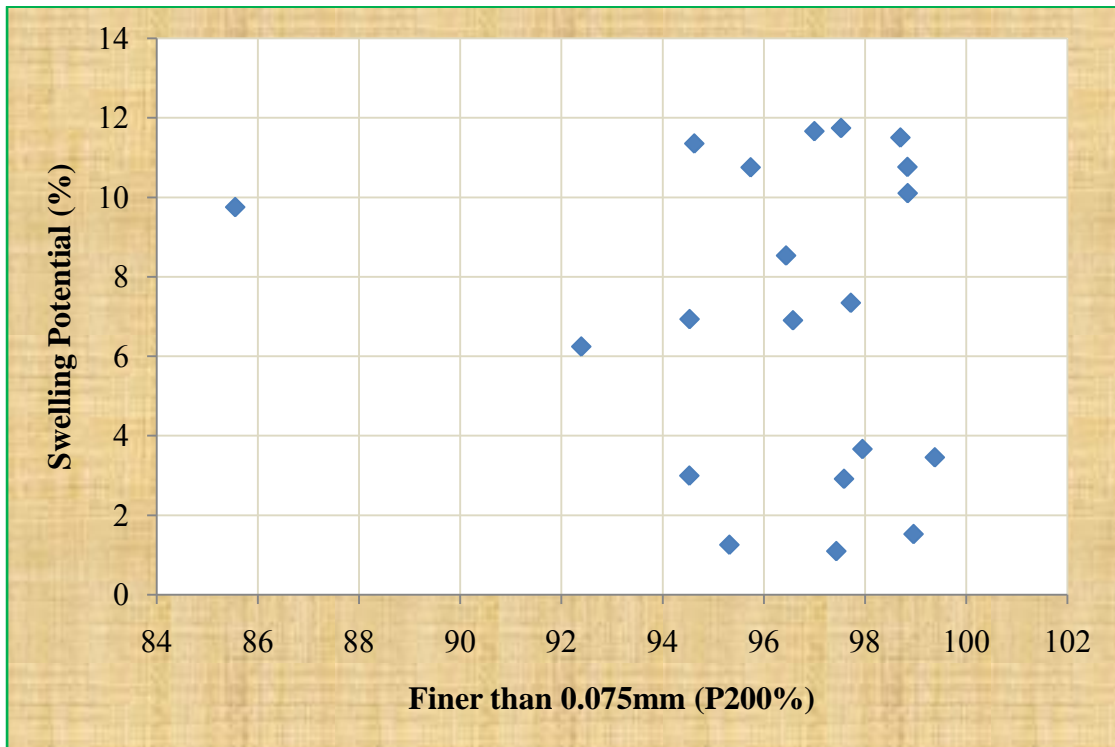


Figure: Scatter plots of Sp vs. % Finer than 0.075mm (P200 %)

## Appendix C: - ANOVAs Excel Analyses Outputs

## 1) Simple Linear Regression Method Summary Outputs

### 1.1) Water Content and Swelling Potential (EQ.1)

<i>Regression Statistics</i>						
Multiple R	0.226555511					
R Square	0.051327399					
Adjusted R Square	-0.001376634					
Standard Error	3.8848558					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	14.6978975	14.6978975	0.97387991	0.336795049	
Residual	18	271.6578825	15.09210458			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	12.28392436	5.403319927	2.273403116	0.03548415	0.931970451	23.6358783
X Variable 1	-0.154217091	0.156271508	-0.986853542	0.33679505	-0.482531345	0.17409716
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	6.601856803	0.328143197	0.086781879		2.5	1.09
2	6.120234127	3.629765873	0.959940374		7.5	1.25
3	7.200662079	4.149337921	1.097348186		12.5	1.52
4	8.020608395	-6.770608395	-1.790578396		17.5	2.91
5	6.421244591	-3.511244591	-0.928595828		22.5	2.99
6	6.533408525	-5.013408525	-1.325863271		27.5	3.45
7	7.046585076	-3.386585076	-0.895627944		32.5	3.66
8	6.218171589	-5.128171589	-1.356213906		37.5	6.24
9	6.516273322	-3.066273322	-0.810917195		42.5	6.9
10	6.909249028	-3.919249028	-1.036498085		47.5	6.93
11	8.424640842	3.315359158	0.876791292		52.5	7.34
12	7.815789441	-0.475789441	-0.125828913		57.5	8.53
13	8.320610798	3.339389202	0.88314636		62.5	9.75
14	7.499729619	1.030270381	0.27246885		67.5	10.1
15	5.908721618	5.591278382	1.478688722		72.5	10.75
16	6.128209083	3.971790917	1.050393494		77.5	10.76
17	7.965063858	2.794936142	0.73915843		82.5	11.35
18	8.284013897	-1.384013897	-0.366021078		87.5	11.5
19	6.919390257	3.830609743	1.013056235		92.5	11.66
20	5.565537051	0.674462949	0.178370792		97.5	11.74

1.2) Dry Density and Swelling Potential (EQ.2)

<i>Regression Statistics</i>						
Multiple R	0.327893292					
R Square	0.107514011					
Adjusted R Square	0.057931456					
Standard Error	3.768056687					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	30.78725847	30.78725847	2.1683838	0.158144745	
Residual	18	255.5685215	14.1982512			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-4.86173554	8.113400024	-0.599222955	0.5564919	-21.90735644	12.183885
X Variable 1	0.895701479	0.608268337	1.472543324	0.1581447	-0.382222875	2.1736258
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	6.288514159	0.641485841	0.17490821		2.5	1.09
2	6.721232353	3.028767647	0.825827		7.5	1.25
3	6.690913702	4.659086298	1.27035141		12.5	1.52
4	7.982695311	-6.732695311	-1.83574385		17.5	2.91
5	6.326834101	-3.416834101	-0.93163761		22.5	2.99
6	6.738862441	-5.218862441	-1.42298057		27.5	3.45
7	7.167514156	-3.507514156	-0.95636253		32.5	3.66
8	5.969506362	-4.879506362	-1.33045138		37.5	6.24
9	6.033052267	-2.583052267	-0.70429777		42.5	6.9
10	5.976736897	-2.986736897	-0.81436685		47.5	6.93
11	9.003152953	2.736847047	0.74623162		52.5	7.34
12	7.669970086	-0.329970086	-0.08996999		57.5	8.53
13	8.757251148	2.902748852	0.79146658		62.5	9.75
14	7.820265633	0.709734367	0.19351693		67.5	10.1
15	5.226576852	6.273423148	1.71051821		72.5	10.75
16	6.006017773	4.093982227	1.11626954		77.5	10.76
17	9.665609212	1.094390788	0.29839775		82.5	11.35
18	8.112350075	-1.212350075	-0.33056066		87.5	11.5
19	7.425844045	3.324155955	0.90636789		92.5	11.66
20	4.837100474	1.402899526	0.38251607		97.5	11.74

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1.3) Liquid Limits and Swelling Potential (EQ.3)

<i>Regression Statistics</i>						
Multiple R	0.264016898					
R Square	0.069704922					
Adjusted R Square	0.018021863					
Standard Error	3.8470434					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	19.96040742	19.9604074	1.3487	0.260675163	
Residual	18	266.3953726	14.7997429			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-0.438611286	6.480651318	-0.0676801	0.946786	-14.05395445	13.17673188
X Variable 1	0.087420609	0.075275945	1.16133527	0.260675	-0.070728282	0.2455695
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	7.556815965	-0.626815965	-0.1673993		2.5	1.09
2	7.395417865	2.354582135	0.62882139		7.5	1.25
3	6.920804774	4.429195226	1.18287345		12.5	1.52
4	5.039934387	-3.789934387	-1.0121506		17.5	2.91
5	6.586136465	-3.676136465	-0.9817594		22.5	2.99
6	7.305910087	-5.785910087	-1.5452016		27.5	3.45
7	7.479227464	-3.819227464	-1.0199737		32.5	3.66
8	7.102284834	-6.012284834	-1.6056579		37.5	6.24
9	6.416626369	-2.966626369	-0.7922757		42.5	6.9
10	6.777887777	-3.787887777	-1.0116041		47.5	6.93
11	7.131577848	4.608422152	1.23073831		52.5	7.34
12	6.861228805	0.478771195	0.12786199		57.5	8.53
13	7.167824103	4.492175897	1.19969325		62.5	9.75
14	6.449335531	2.080664469	0.55566816		67.5	10.1
15	9.00277734	2.49722266	0.66691537		72.5	10.75
16	8.044550877	2.055449123	0.54893408		77.5	10.76
17	5.471234219	5.288765781	1.41243281		82.5	11.35
18	5.313826014	1.586173986	0.42360813		87.5	11.5
19	7.411618767	3.338381233	0.89155757		92.5	11.66
20	8.984980509	-2.744980509	-0.7330823		97.5	11.74

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1.4) Plastic Limits and Swelling Potential (EQ.4)

<i>Regression Statistics</i>						
Multiple R	0.239879071					
R Square	0.057541969					
Adjusted R Square	0.005183189					
Standard Error	3.872110425					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	16.47747535	16.47747535	1.0989937	0.308360092	
Residual	18	269.8783046	14.99323915			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	12.80486788	5.584750945	2.292827023	0.03411963	1.071741554	24.5379942
X Variable 1	-0.18543686	0.176888035	-1.048329	0.30836009	-0.557064829	0.18619111
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	6.98311712	-0.05311712	-0.01409377		2.5	1.09
2	7.281216808	2.468783192	0.655051983		7.5	1.25
3	7.60893129	3.74106871	0.992632518		12.5	1.52
4	6.499568071	-5.249568071	-1.3928886		17.5	2.91
5	6.441838458	-3.531838458	-0.93711663		22.5	2.99
6	7.188691003	-5.668691003	-1.50409615		27.5	3.45
7	6.360491652	-2.700491652	-0.7165321		32.5	3.66
8	6.737056337	-5.647056337	-1.49835573		37.5	6.24
9	6.904604235	-3.454604235	-0.91662377		42.5	6.9
10	7.169041821	-4.179041821	-1.10884165		47.5	6.93
11	7.267818859	4.472181141	1.186621464		52.5	7.34
12	7.442751784	-0.102751784	-0.02726354		57.5	8.53
13	7.260290075	4.399709925	1.16739239		62.5	9.75
14	6.948629526	1.581370474	0.419591266		67.5	10.1
15	5.38657161	6.11342839	1.622100071		72.5	10.75
16	6.622349824	3.477650176	0.92273864		77.5	10.76
17	9.392206388	1.367793612	0.362922075		82.5	11.35
18	8.531353527	-1.631353527	-0.43285347		87.5	11.5
19	7.310442475	3.439557525	0.912631366		92.5	11.66
20	5.083029135	1.156970865	0.306983644		97.5	11.74

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1.5) Plastic Index and Swelling Potential (EQ.5)

<i>Regression Statistics</i>						
Multiple R	0.476227114					
R Square	0.226792264					
Adjusted R Square	0.183836279					
Standard Error	3.50723462					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	64.94327571	64.943276	5.2796429	0.033781783	
Residual	18	221.4125043	12.300695			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-4.06407283	4.887649353	-0.831498	0.4165867	-14.33264307	6.204497404
X Variable 1	0.204749717	0.08910889	2.2977474	0.0337818	0.017538886	0.391960548
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	8.234117964	-1.304117964	-0.382026		2.5	1.09
2	8.185250097	1.564749903	0.4583747		7.5	1.25
3	7.435493675	3.914506325	1.1467077		12.5	1.52
4	1.805365017	-0.555365017	-0.162688		17.5	2.91
5	5.363016622	-2.453016622	-0.718582		22.5	2.99
6	7.873449803	-6.353449803	-1.861167		27.5	3.45
7	7.36492564	-3.70492564	-1.085314		32.5	3.66
8	6.897863186	-5.807863186	-1.701344		37.5	6.24
9	5.476965187	-2.026965187	-0.593775		42.5	6.9
10	6.615061623	-3.625061623	-1.061918		47.5	6.93
11	7.552511318	4.187488682	1.2266746		52.5	7.34
12	7.112472743	0.227527257	0.0666514		57.5	8.53
13	7.62909157	4.03090843	1.1808063		62.5	9.75
14	5.602184462	2.927815538	0.8576685		67.5	10.1
15	9.857913289	1.642086711	0.4810296		72.5	10.75
16	8.978112094	1.121887906	0.3286436		77.5	10.76
17	6.009422293	4.750577707	1.3916248		82.5	11.35
18	4.69024422	2.20975578	0.6473215		87.5	11.5
19	8.255464041	2.494535959	0.7307444		92.5	11.66
20	9.481075157	-3.241075157	-0.949434		97.5	11.74

1.6) Liquid Index and Swelling Potential (EQ.6)

<i>Regression Statistics</i>						
Multiple R	0.046302007					
R Square	0.002143876					
Adjusted R Square	-0.053292575					
Standard Error	3.984287673					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	0.613911252	0.613911252	0.0386727	0.846301872	
Residual	18	285.7418687	15.87454826			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	6.931017002	1.001548049	6.920304031	1.81E-06	4.826842635	9.03519137
X Variable 1	0.018495115	0.094049161	0.196653694	0.8463019	-0.17909484	0.21608507
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	7.098828203	-0.168828203	-0.04353463		2.5	1.09
2	7.245742948	2.504257052	0.645756469		7.5	1.25
3	7.093751624	4.256248376	1.09753107		12.5	1.52
4	6.520840444	-5.270840444	-1.35915732		17.5	2.91
5	7.079727995	-4.169727995	-1.07522062		22.5	2.99
6	7.153145288	-5.633145288	-1.45258252		27.5	3.45
7	6.904788916	-3.244788916	-0.8367126		32.5	3.66
8	7.159392829	-6.069392829	-1.56507483		37.5	6.24
9	7.152543672	-3.702543672	-0.95475084		42.5	6.9
10	7.089142366	-4.099142366	-1.05701917		47.5	6.93
11	6.773418669	4.966581331	1.280700007		52.5	7.34
12	6.932944613	0.407055387	0.104964724		57.5	8.53
13	6.794982084	4.865017916	1.25451051		62.5	9.75
14	6.909144944	1.620855056	0.417959345		67.5	10.1
15	6.967322047	4.532677953	1.168812166		72.5	10.75
16	7.121943758	2.978056242	0.767931983		77.5	10.76
17	7.291968387	3.468031613	0.894278743		82.5	11.35
18	7.056083166	-0.156083166	-0.04024815		87.5	11.5
19	7.089505013	3.660494987	0.943908021		92.5	11.66
20	6.984783036	-0.744783036	-0.19205235		97.5	11.74

1.7) Percentage of Clay and Swelling Potential (EQ.7)

<i>Regression Statistics</i>						
Multiple R	0.328155033					
R Square	0.107685726					
Adjusted R Square	0.05811271					
Standard Error	3.767694182					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	30.83642993	30.8364299	2.17226499	0.157793269	
Residual	18	255.5193501	14.1955194			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	0.235552403	4.680310029	0.05032838	0.96041499	-9.597414077	10.068519
X Variable 1	0.121780785	0.082627073	1.47386057	0.15779327	-0.051812253	0.2953738
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	7.102632043	-0.172632043	-0.04707456		2.5	1.09
2	5.892269858	3.857730142	1.051954		7.5	1.25
3	7.030350705	4.319649295	1.17791348		12.5	1.52
4	5.563461739	-4.313461739	-1.17622621		17.5	2.91
5	5.550065852	-2.640065852	-0.71991242		22.5	2.99
6	5.877114219	-4.357114219	-1.18812969		27.5	3.45
7	8.366624617	-4.706624617	-1.28343673		32.5	3.66
8	7.525350182	-6.435350182	-1.75483823		37.5	6.24
9	4.542532826	-1.092532826	-0.29791982		42.5	6.9
10	7.233339	-4.243339	-1.15710463		47.5	6.93
11	6.333789713	5.406210287	1.47420486		52.5	7.34
12	7.598372932	-0.258372932	-0.07045502		57.5	8.53
13	5.782628344	5.877371656	1.60268458		62.5	9.75
14	7.778045311	0.751954689	0.20504849		67.5	10.1
15	9.287357894	2.212642106	0.60335939		72.5	10.75
16	8.910009428	1.189990572	0.32449531		77.5	10.76
17	7.475095752	3.284904248	0.89575165		82.5	11.35
18	6.104872658	0.795127342	0.21682112		87.5	11.5
19	8.003348022	2.746651978	0.7489771		92.5	11.66
20	8.462738907	-2.222738907	-0.60611266		97.5	11.74



1.9) Shrinkage Limits and Swelling Potential (EQ.9)

<i>Regression Statistics</i>						
Multiple R	0.276033321					
R Square	0.076194395					
Adjusted R Square	-0.23174081					
Standard Error	3.360497673					
Observations	5					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	1	2.794286173	2.794286	0.247436	0.653059081	
Residual	3	33.87883383	11.29294			
Total	4	36.67312				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	6.602232981	6.700739572	0.985299	0.397126	-14.72251091	27.92697687
X Variable 1	-0.25862494	0.519922444	-0.49743	0.653059	-1.913250202	1.396000317
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residual s</i>		<i>Percentile</i>	<i>Y</i>
1	3.243792979	-1.993792979	-0.685087		10	1.09
2	3.513429661	-0.603429661	-0.207344		30	1.25
3	3.987069467	-2.897069467	-0.995462		50	2.91
4	1.982517943	1.007482057	0.346181		70	2.99
5	4.043189949	4.486810051	1.541713		90	8.53

## 2) Multiple Linear Regression Method Summary Outputs

### 2.1) Natural Moisture Content, Plastic Index and Swelling Potential (EQ10)

<i>Regression Statistics</i>						
Multiple R	0.748379262					
R Square	0.56007152					
Adjusted R Square	0.508315228					
Standard Error	2.722197026					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	2	160.379717	80.18985848	10.82132241	0.000930567	
Residual	17	125.976063	7.410356649			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	3.221451137	4.302677279	0.74870852	0.46426679	-5.856404329	12.2993066
X Variable 1	-0.4678179	0.130358476	-3.588703374	0.00226373	-0.742850246	-0.192785563
X Variable 2	0.365067957	0.082336157	4.433871712	0.000363775	0.191353852	0.538782062
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	7.912512794	-0.982512794	-0.381567168		2.5	1.09
2	6.364378063	3.385621937	1.314834965		7.5	1.25
3	8.305045963	3.044954037	1.1825337		12.5	1.52
4	0.753857302	0.496142698	0.192681221		17.5	2.91
5	2.245462586	0.664537414	0.258078735		22.5	2.99
6	7.061804839	-5.541804839	-2.152206864		27.5	3.45
7	7.711830481	-4.051830481	-1.573562697		32.5	3.66
8	4.366065678	-3.276065678	-1.272287863		37.5	6.24
9	2.736902317	0.713097683	0.276937527		42.5	6.9
10	5.958216603	-2.968216603	-1.152732067		47.5	6.93
11	12.2266304	-0.486630402	-0.18898704		52.5	7.34
12	9.595091173	-2.255091173	-0.875783764		57.5	8.53
13	12.04759732	-0.387597316	-0.150526702		62.5	9.75
14	5.943484774	2.586515226	1.004495103		67.5	10.1
15	8.705106408	2.794893592	1.085420607		72.5	10.75
16	7.80224000	2.29776000	0.892354564		77.5	10.76
17	8.081180759	2.678819241	1.040342149		82.5	11.35
18	6.696627021	0.203372979	0.07898162		87.5	11.5
19	8.913811241	1.836188759	0.713099462		92.5	11.66
20	6.992154284	-0.752154284	-0.292105489		97.5	11.74

2.2) Dry Density, Plastic Index and Swelling Potential(EQ11)

<i>Regression Statistics</i>						
Multiple R	0.76200275					
R Square	0.58064818					
Adjusted R Square	0.53131268					
Standard Error	2.65777236					
Observations	20					
ANOVA						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	2	166.2719638	83.1359819	11.7693769	0.000619323	
Residual	17	120.0838162	7.06375389			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-34.7185826	8.90090505	-3.9005677	0.00115028	-53.49785056	-15.93931
X Variable 1	1.8053847	0.476673851	3.78746327	0.00147033	0.799690796	2.8110786
X Variable 2	0.3285694	0.075023921	4.37952849	0.00040876	0.170282765	0.486856
RESIDUAL OUTPUT				PROBABILITY OUTPUT		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	7.49132936	-0.561329356	-0.2232813		2.5	1.09
2	8.28510034	1.464899665	0.58269654		7.5	1.25
3	7.02082806	4.329171941	1.72202477		12.5	1.52
4	0.58968124	0.660318764	0.26265653		17.5	2.91
5	2.96120549	-0.051205487	-0.0203681		22.5	2.99
6	7.82027831	-6.300278314	-2.5060763		27.5	3.45
7	7.8682255	-4.208225495	-1.6739156		32.5	3.66
8	4.70399692	-3.613996915	-1.4375479		37.5	6.24
9	2.55191339	0.898086612	0.357234		42.5	6.9
10	4.26474878	-1.274748783	-0.5070598		47.5	6.93
11	11.8691827	-0.12918273	-0.0513853		52.5	7.34
12	8.47586016	-1.135860157	-0.4518137		57.5	8.53
13	11.4964318	0.163568216	0.06506291		62.5	9.75
14	6.35518219	2.174817813	0.86508233		67.5	10.1
15	7.95664216	3.543357837	1.40944967		72.5	10.75
16	8.11584161	1.984158392	0.78924329		77.5	10.76
17	10.7281844	0.031815635	0.01265538		82.5	11.35
18	5.48048641	1.419513586	0.56464321		87.5	11.5
19	9.81799749	0.932002515	0.3707248		92.5	11.66
20	6.56688374	-0.326883737	-0.1300253		97.5	11.74

2.3) Dry Density, Liquid Limit, Plastic Limit and Swelling Potential(EQ12)

<i>Regression Statistics</i>						
Multiple R	0.762303144					
R Square	0.581106084					
Adjusted R Square	0.502563475					
Standard Error	2.738072931					
Observations	20					
<i>ANOVA</i>						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	3	166.403086	55.46769532	7.39860936	0.002506164	
Residual	16	119.952694	7.497043378			
Total	19	286.35578				
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	-33.15501538	14.96216863	-2.21592312	0.0415421	-64.87339572	-1.436635
X Variable 1	1.743358027	0.679065014	2.567291776	0.02066733	0.303804514	3.1829115
X Variable 2	0.328893891	0.077329592	4.253144026	0.00060719	0.164962481	0.4928253
X Variable 3	-0.353204635	0.201677156	-1.75133685	0.09903118	-0.780741104	0.0743318
<i>RESIDUAL OUTPUT</i>				<i>PROBABILITY OUTPUT</i>		
<i>Observation</i>	<i>Predicted Y</i>	<i>Residuals</i>	<i>Standard Residuals</i>		<i>Percentile</i>	<i>Y</i>
1	7.539009593	-0.609009593	-0.24237953		2.5	1.09
2	8.341818529	1.408181471	0.560441676		7.5	1.25
3	7.121420891	4.228579109	1.682930794		12.5	1.52
4	0.446459085	0.803540915	0.319800982		17.5	2.91
5	2.930720389	-0.020720389	-0.0082465		22.5	2.99
6	7.863151373	-6.343151373	-2.52450871		27.5	3.45
7	7.772032012	-4.112032012	-1.63654625		32.5	3.66
8	4.739391966	-3.649391966	-1.4524203		37.5	6.24
9	2.602621577	0.847378423	0.337247857		42.5	6.9
10	4.355828167	-1.365828167	-0.5435855		47.5	6.93
11	11.76512034	-0.025120339	-0.00999764		52.5	7.34
12	8.486356012	-1.146356012	-0.45623785		57.5	8.53
13	11.40853226	0.251467742	0.100081563		62.5	9.75
14	6.288097308	2.241902692	0.892254107		67.5	10.1
15	7.871127328	3.628872672	1.444253829		72.5	10.75
16	8.136967069	1.963032931	0.781266824		77.5	10.76
17	10.85430873	-0.09430873	-0.0375339		82.5	11.35
18	5.599224517	1.300775483	0.517695202		87.5	11.5
19	9.829864588	0.920135412	0.366204387		92.5	11.66
20	6.467948269	-0.227948269	-0.09072106		97.5	11.74

## Appendix D: - Metrological Data of Sendafa Town (Rain fall)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1975	0.0	0.0	43.2	58.7	22.0	95.0	274.4	296.0	100.2	6.5	0.0	0.0
1976	0.0	0.0	50.5	115.6	103.9	57.3	261.0	214.8	89.9	10.1	57.6	23.5
1977	76.9	21.4	22.0	42.4	73.4	133.5	384.3	406.1	242.7	165.1	18.0	0.0
1978	0.5	87.7	47.9	43.5	35.7	91.6	276.8	283.6		63.7	0.0	0.0
1979	133.7	8.6	82.3	56.2	81.1	117.8	422.9	256.9	136.4	9.9	0.0	56.4
1980	0.0	66.4	37.2	64.2	41.2	88.8	336.6	364.6		28.0	7.1	0.0
1981	0.0	8.9	246.3	94.3	0.0	24.0	413.6	241.0		9.3	0.0	5.4
1982	39.4	84.7	54.8	31.7	64.5	31.3	232.6	282.9		42.7	14.5	14.1
1983	1.4	25.4	43.1	91.6	167.6	71.1	247.1	430.4	124.0	4.7	0.0	0.0
1984	0.0	0.0	45.2	0.0	78.4	169.1	340.3	184.9	109.3	0.0	0.0	1.2
1985	9.5	1.3	38.6	158.9	157.9	76.4	394.1	451.5	106.0	10.8	0.0	0.0
1986	0.0	28.1	117.3	193.7	32.3	164.7	270.9	244.5	143.2	0.0	0.0	0.0
1987	0.2	33.1	128.9	80.5	110.1	55.7	223.6	143.6	105.3	8.7	0.0	0.0
1988	0.0	32.9	0.9	132.9	22.1	104.6	451.1	330.2	237.6	5.2	0.0	0.0
1989	18.0	10.1	43.3	112.0	21.4	46.3	357.5	339.4	139.9	10.2	0.4	0.6
1990	21.5	190.4	35.7	148.4	38.2	87.8	282.7	469.9		3.8	2.4	0.0
1991	15.9	20.5	118.1	0.5	34.5	72.7	216.8	9.4	134.5		0.0	5.6
1992	10.7	46.5	1.0			69.6	253.2	357.9	151.6	55.5	0.0	0.0
1993	4.3	105.2	0.0				457.2	353.2	153.8	13.7	0.0	0.0
1994	0.0	0.0	0.0	64.1	11.0	130.7	337.7	184.1	122.0	0.0	6.4	0.0
1995	0.0	11.4	106.2	116.7	42.4	22.5	230.8	388.8		0.0	0.0	0.0
1996	69.4	5.6	99.3			187.2	339.2	338.6	121.4	0.0	0.0	0.0
1997	44.5	0.0	29.4	60.0	44.8	149.7	303.8	251.1	84.7	72.0	34.6	0.0
1998	28.9	23.3	5.8	27.0	38.2	68.8	359.1	289.7	152.0	98.9	0.0	0.0
1999	0.0	1.2	56.3	11.8	25.4	144.7	441.6	365.2		79.6	0.0	0.0
2000	0.0	0.0	35.5	44.0	87.9	166.0	352.2	373.4	113.9	5.0	10.0	0.0
2001	0.0	35.3	154.1	9.2	134.9	149.5	335.5	276.8	27.4	9.8	0.0	0.0
2002	21.2	3.4	67.2	20.6	60.9	144.4	246.8	289.1	85.4	0.0	0.0	27.4
2003	75.5	0.0	29.7	122.9	1.7	120.6	304.4	373.4	122.4	0.0	0.0	19.7
2004	15.2	7.1	2.2	118.9	0.0	69.8	315.0	319.0	30.6	0.0	0.0	0.0
2005	24.5	22.3	12.3	136.1	150.2	57.7	381.3	282.9	73.3	34.6	0.0	0.0
2006	0.0			77.2	31.1	126.2	455.8	398.7		0.0	0.0	0.0
2007	38.0		8.2	92.9	24.2	162.0	288.8	343.4	114.1	0.0	0.0	
2008	0.0	0.0	0.0	0.0	0.0	87.9	290.3	306.2	175.3	24.7	63.7	
2010	0.0	12.5	18.0	205.3	76.4	106.7		295.8	65.6	1.5	0.0	
2011				71.5	136.7	86.8	216.8	328.6				
2013	7.3	3.4		44.7	45.3	274.7	374.6	449.0	27.5	0.0	0.0	5.9
2014		11.3	42.4	0.0	73.8	79.1	211.5	731.3	139.0	6.4		