



ENGINEERING CHARACTERIZATION OF EXPANSIVE SOIL IN ARBAMINCH TOWN
(CASE STUDY OF ARBA MINCH TOWN)

MSc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE FACULTY OF CIVIL ENGINEERING AND BUILT
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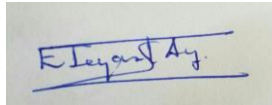
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HAWASSA UNIVERSITY
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This is to certify that the thesis entitled “Engineering characterization of expansive soil (case study of Arba Minch town)” submitted in partial fulfillment of the requirements for the degree of Master’s with specialization in geotechnical engineering. The Graduate Program of the School of Graduate Study, has been carried out by Kalkidan Alemayehu, under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department for defense.

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DECLARATION

I hereby declare that this thesis is my original work and has not been presented for a thesis degree in any other university, and all resources of material used for this thesis have been duly acknowledged.

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LIST OF ACRONYMS/SYMBOLS

%	Percent
ANN	Artificial neural network
ASCE	American society of civil engineers
ASTM	American society of testing and material
Cm	centimeter
Cv	Coefficient of consolidation
H.s	High school
hr	hour
K	Hydraulic conductivity
LL	liquid limit
mm	millimeter
MRA	Multiple regression analysis
MS	Microsoft
PI	Plastic Index
PL	Plastic limit
PVC	potential volume change
SPSS	statistical package for social science

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ABSTRACT

Expansive soils, which are considered as problematic soils, have worldwide distribution and hence, their proper identification and characterization becomes an absolute requirement in the perspective of the present day geotechnical engineering practice. Expansive soils experience significant volume change associated with changes in moisture contents, these volume changes can either be in the form of swell or in the form of shrinkage; and this is why they are sometime known as Swell/Shrink soils. Arba Minch town experiences more damage from expansive soils throughout the year. It is known that the magnitude of swelling for expansive soil varies with environmental conditions. This study intends to characterize expansive soil found in Arba Minch town and develop correlation between index properties and swelling pressure (Ps) for the study area. The soil specimen were obtained from ten different test pits from which index properties, engineering properties and swell-consolidation tests were conducted according to American Society for Testing Materials (ASTM) standard. Tested soil samples from the study area have been found to meet the diagnostic criteria for expansive soils, having LL in the range from 96% to 120%, PL ranges from 36% to 51%, free swell ranges from 97.5% to 155%, PI from 49% to 77%, GS from 2.61 to 2.83, Clay content ranges between 35.18% and 48.94%. The laboratory results revealed that the study area has plastic-behavior. In this study, efforts were made to develop Artificial Neural Network (ANN) and Multiple Regression Analysis (MRA) models that can be employed for estimating swelling pressure. Equation with high regression coefficient has been selected to predict the swelling pressure. Comparison between two software (ANN and SPSS) was conducted, ANN resulted good prediction than SPSS. Further, different parameters were used to develop the prediction model and among those Atterberg's Limit, Dry density and Moisture content result good coefficient of correlation. Furthermore, Index properties which are used for establishing the model can be conducted easily in soil laboratory without any tedious and time consuming procedure.

Key Words: Swelling pressure, Expansive soil, Characterization, ANN, SPSS, Arba Minch, Index Properties, MRA.

1. INTRODUCTION

1.1 General

Expansive soils are regarded as problematic soils as their volume is moisture sensitive, they affect the stability of structures founded on them. Hence, it becomes very essential for a geotechnical engineer to appropriately identify and characterize such soils. This in turn will help in efficient management of material, time, financial and human resources, which are the vital gears of any engineering project management.

Expansive soils are clayey minerals which exhibit significant volume change when subjected to moisture variations. This continuous change in soil volume cause buildings built on this type of soil to move unevenly and show polygonal crack. Expansive soil swells if its moisture content increases and shrinks when its moisture content decreases. Extent of expansion depends upon the kind and amount of clay minerals present, their exchangeable ions, electrolyte content of the aqueous phase, and the internal structure. The three most significant groups of clay minerals are Montmorillonite, Illite and Kaolinite. Montmorillonite is the clay mineral that presents in most of expansive soils (Magdi M. E. Zumrawi, 2017).

The problem of expansive soil is widespread throughout the world which possesses a significant hazard to foundations of buildings which exert uplift pressures that cause considerable damage to lightly loaded structure. In the undeveloped nations, many of the expansive soil problems may not have been recognized. It is expected that more expansive soil regions will be discovered each year as the amount of construction increase (Uge, 2017). The degree of expansiveness of soils varies from place to place depending upon type of parent material, climate and topography. It is really important to make localized study for different area. This paper mainly intends on identification and characterization of these problematic soil found in Arba Minch town.

1.2 Statement of the Problem

Conventional geotechnical site investigation tends to overlook problematic soils. As a result, significant economic damage has been reported throughout the world in general and in Ethiopia in particular. The situation is not different for Arba Minch town. To further complicate the problems most expansive soils are residuals soils and the conventional procedures for laboratory test do not give consistence results. The total magnitude of swell is a function of the laboratory

swelling potential but the overall thickness of expansive soil layer, the initial field density, initial moisture content, permeability i.e. rate of ingress of water into the soil and the local climate conditions. The impact of swelling on structures also depends on the nature of structure large structure which can counter the swelling pressure are less affected than smaller structures like pavements , walls and small buildings.

There are numerous approaches to deal with expansive soil related problems. These include removing the problematic soil, undercutting to tolerable depth, treating the soil with various types of stabilizers and designing the structure to withstand the swelling pressure. The application of all these potential solutions is predicated on the due recognition of the problem of expansiveness and a characterization local study of the swells extent of expansiveness. Hence, it is the first and most important step to address the challenges posed by expansive soils. For determining swelling pressure, the laboratory procedures are tedious to perform and time consuming. Therefore, it is desirable to find simpler and less time consuming methods for determining swelling pressure by using index property of soil which can be predicted satisfactorily, especially, for preliminary design purpose without time consuming and laborious process.

1.3 Objectives

1.3.1 General Objective

The main objective of this research was to study and characterize the expansive nature of the soil found in Arba Minch town, Ethiopia.

1.3.2 Specific Objective

- To determine index and Engineering properties of the soil
- To evaluate swelling pressure of the soil in the town for the study area.
- To correlate index property with swelling characteristics which helps to predict swelling pressure.

1.4 Significance of the Study

Expansive soil are very problematic soil and it is really inappropriate to plan huge projects without knowing the expansive nature of the soil. In this study different area are characterized and the degree of their expansion has been identified by conducting laboratory tests. It is known that the magnitude of the swelling pressure of expansive soils varies with environmental conditions, and determining swelling pressure in the laboratory is found to be time consuming with laborious testing procedures. Therefore, the empirical equations which could be developed can be comparatively easy to predict the swelling pressure of the study area. The results obtained from this research are necessary in the preliminary foundation design of constructions in Arba Minch town.

1.5 Scope of the investigation

This thesis addresses the described objective and provides a correlation between swelling pressure and index properties of expansive soil of Arba Minch town by using Artificial Neural Network (ANN) and Statistical Package for Social Science (SPSS). All transportation and test methods followed as per American society for testing and material (ASTM) standards. Finally, the scope of the developed correlation is limited to expansive soils in Arba Minch town.

1.6 Organization of the thesis

This thesis work contains five chapter, references and appendices, each with detail coverage of specific topics. Chapter one contains the general background of the thesis, problem statement, objective, scope of the thesis, and organization of the study. Chapter two contains literature review. Chapter three covers material and methods. In Chapter four, results and discussion were presented. Under Chapter five, conclusion and recommendation were presented. Finally, detailed laboratory test results are presented in appendices.

2. LITERATURE REVIEW

2.1 General

Plastic clays revealing volume changes when subjected to moisture variations due to seasonal climatic conditions or artificial causes are named expansive soil. These soils are commonly known as black clays. The fact that they are found favorable in some regions for growing cotton in India has also given them the name black cotton soil (Alemayehu Tefera and Mesfin, 1999). Expansive soil has opposing effect on any engineering structure built on it. Affects the structure negatively and the consequence causes tremendous loss on the economy of a country. (Nelson J. D., 1991).

Different researchers tried to characterize expansive soil in different regions of Ethiopia and they also tried to develop empirical equations to predict swelling pressure by relating index properties with swelling pressure for Ambo town (Debelo, 2015) and (Negussie, 2007) for Bahirdar. However, soil exhibits complex characteristics that varies even within the same area. Therefore, specific investigations for particular areas are needed.

2.2 Expansive Soil

Expansive soils are clay soils containing considerable amount of montmorillonite mineral which has a potential for swelling or shrinking due to changes in its moisture content. Expansive soil can be classified into two main groups with respect to the parent rock. The first group comprises the basic igneous rocks. In this group, the Feldspar and Pyroxene minerals of the parent rocks have decomposed to form montmorillonite and other secondary materials (Magdi M. E. Zumrawi, 2017). The three most important minerals of expansive clay are montmorillonite, illite and kaolinite. The montmorillonite is considered as a highly expansion and the most effective one for swelling behavior (Nelson J. D., 1991). Potentially swelling clays can be recognized in the laboratory by their plastic and swelling properties. Generally, clays of high plasticity usually have high swelling potential. Expansive soils are characterized by plasticity index over 30%, liquid limit exceeding 50% and have high swelling potential. In the field, expansive clays can be recognized in the dry season by the deep cracks of roughly polygonal patterns (Das, 2014).

2.2.1 Formation of Expansive Soil

The origin of Expansive soil is related to a combination of conditions and processes that results in the formation of clay minerals having a particular chemical and mineralogical make up, which, when in contact with water expands. Variations in the conditions and processes may also form other clay minerals, most of which are non-Expansive. The conditions or processes that determine the clay mineralogy include composition of the parent material and degree of physical and chemical weathering to which the materials are subjected (Das, 2014)

2.3 Clay Mineralogy

Agreeing to the clay mineral concept, clay materials are basically composed of extremely small crystalline particles of one or more members of a small group of minerals that are commonly known as clay minerals. These minerals are essentially hydrous aluminum silicates, with magnesium or iron replacing wholly or in part for the aluminum, in some minerals. Many clay materials may contain organic material and water-soluble salts (Murthy, 2001).

2.3.1 Structure of Clay Minerals

Clay mineral is composed of two structural units:

- 1) A silicon–oxygen tetrahedron unit
- 2) An aluminum or magnesium octahedron unit

The Tetrahedral Unit consists of four oxygen atoms (or hydroxyls, if needed to balance the structure) placed at the apices of a tetrahedron enclosing a silicon atom which combines together to form a shell-like structure with all the tips pointing in the same direction. The oxygen at the bases of all the units lies in a common plane (Chen, 1975).

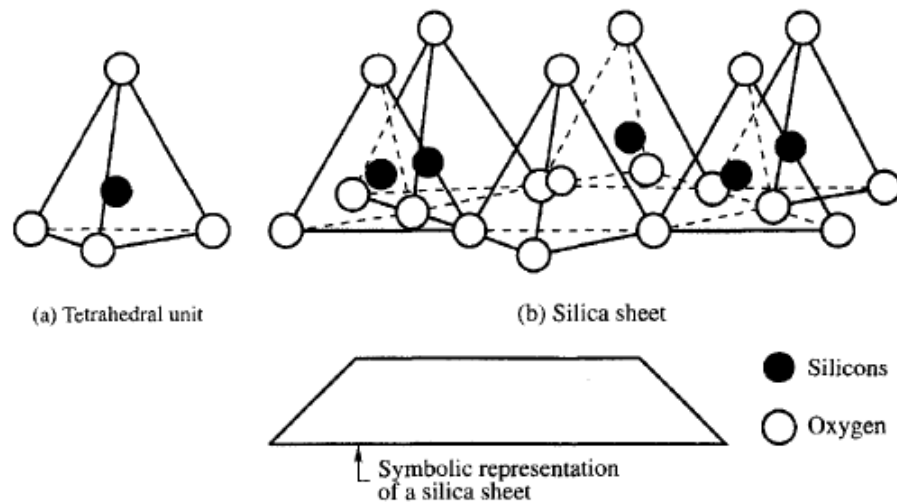


Figure 2. 1 Basic structural units in the silicon sheet (*Murthy, 2001*).

The Octahedral Unit: consists of six hydroxyls forming a configuration of an octahedron and having one aluminum ion at the center. Iron or magnesium ions may replace aluminum ions in some units. These octahedral units are bound together in a sheet structure with each hydroxyl ion common to three octahedral units. This sheet is sometimes called as gibbsite sheet. The Al ion has 3 positive charges and each hydroxyl ion divides its -1 charge with two other neighboring units. This sharing of negative charge with other units leaves a total of 2 negative charges per unit $[(1/3) \times 6]$. The net charge of a unit with an aluminum ion at the center is +1. Sometimes, magnesium replaces the aluminum atoms in the octahedral units in this case; the octahedral sheet is called a brucite sheet.

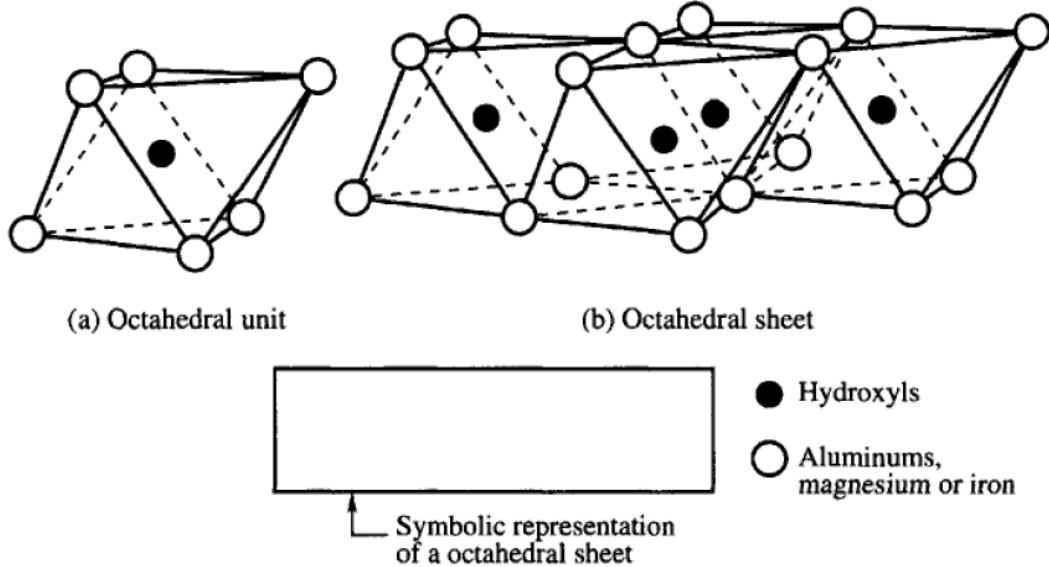


Figure 2. 2 Basic structural unit in octahedral sheet

2.3.2 Formation of Clay Minerals

The combination of two sheets of silica and gibbsite in different arrangements and conditions lead to the formation of different clay minerals. In the actual formation of the sheet silicate minerals, the phenomenon of isomorphous substitution frequently occurs. Isomorphous (meaning same form) substitution consists of the substitution of one kind of atom for another.

2.3.3 Clay Mineral Classification

Clay minerals are a very distinctive type of particles that give particular characteristics to the soils in which they occur. The most well-known clay minerals are montmorillonite, illite and kaolinite.

Montmorillonite

The structural arrangement of this mineral is composed of two silica tetrahedral sheets with a central alumina octahedral sheet. The silica and gibbsite sheets are combined in such a way that the tips of the tetrahedrons of each silica sheet and one of the hydroxyl layers of the octahedral sheet form a common layer. The atoms common to both the silica and gibbsite layer become oxygen instead of hydroxyls. In stacking these combined units one above the other, oxygen layers of each unit are adjacent to oxygen of the neighboring units with a consequence that there is a very weak bond and an excellent cleavage between them. Water can enter between the

sheets, causing them to expand significantly. Soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics.

Illite

The basic structural unit of illite is similar to that of montmorillonite except that some of the silicons are always replaced by aluminum atoms and the resultant charge deficiency is balanced by potassium ions. The potassium ions occur between unit layers. The bonds with the nonexchangeable K^+ ions are weaker than the hydrogen bonds, but stronger than the water bond of montmorillonite. Illite, therefore, does not swell as much in the presence of water as does montmorillonite. (Craig, 2004)

Kaolinite

The basic structure consisting of a single sheet of silica tetrahedrons and a single sheet of alumina octahedrons. These combined sheets are then held in a stack fairly tightly by hydrogen bonding. Kaolinite has no or a few exchangeable cation, and the interlayer bonds are relatively strong to prevent any hydration between layers. Kaolinite is relatively stable.

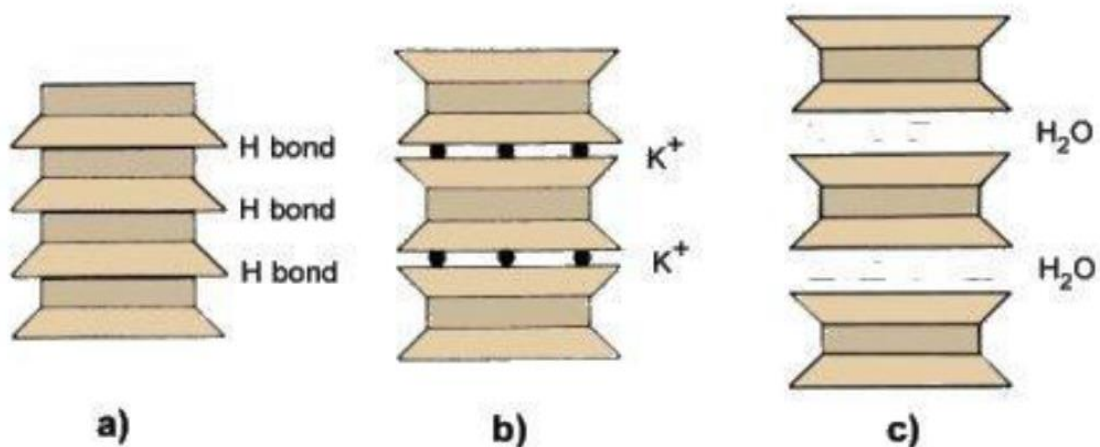


Figure 2. 3 Structure of the main clay minerals: (a) kaolinite, (b) Illite and (c) Montmorillonite, based on combined sheets (Craig, 2004).

2.4 Characterization of Expansive Soil

Various criteria adopted to recognize the presence of expanding types of clay minerals in a natural soil. Important measure to be taken prior to any design is whether the soil is potential expansive or not this can be broadly classified into two categories namely mineralogical identification and inferential testing methods.

2.4.1 Mineralogical Identification

The techniques belonging to this category of methods are:

- X-ray diffraction analysis
- Differential thermal analysis.
- Dye adsorption.
- Chemical analysis.
- Scanning electron microscopy.

Chen (1988) opined that these techniques should be used in combination for better and reliable results. However, these techniques have restricted usage and are confined to research laboratory only in view of their requirement of sophisticated and specialized instrument, which are costly and also expert interpretation of the resulting data.

2.4.2 Inferential Testing Methods

These methods try to link some of the index properties of fine-grained soils with the soil clay mineralogical composition and hence, to estimate their swell potential. They can be classified as indirect methods and direct methods.

2.4.2.1 Indirect Methods

These methods make use of soil index properties such as liquid limit, shrinkage limit, percent clay size composition of soils and also some of the indices such as plasticity index, shrinkage index and the like to estimate the swell potential of soils.

Liquid Limit:

This upper bound plasticity limit is determined in the laboratory by the conventional Casagrande method or by the fall cone method. Liquid limit of a soil is regarded as the water holding capacity of the soil, which in turn has been taken as a measure of soil swell potential. Many classification schemes are available in the geotechnical engineering literature to recognize the degree of soil swell potential based on the liquid limit of fine-grained soils.

Plasticity Index:

It is the difference between the liquid limit and plastic limit of fine-grained soils. Higher the plasticity index, more plastic the soil is and higher will be the soil swell potential.

2.4.2.2 Direct Methods

This type of test directly measures the pressure that a swelling soil exerts on any structure resting on it. It is a convenient and more reliable test because it directly tells the likely insitu response of the soil for moisture variations. The test can be done by the use of a conventional one-dimensional Consolidometer which is available in most soil mechanics laboratories.

2.5 Classification of Expansive Soil

Soil classification is an important aspect of laboratory test, which tells the characteristic of the soil under interest. There are different methods of classification based on the identification tests performed on the soil.

2.5.1 General Classification Systems

The most widely used general classification systems are (ASTM, 1996):-

I. Unified Soil Classification Systems

The basis for USCS is liquid limit and plasticity index of a soil. The plasticity chart is a plot of PI and LL (in the ordinate and abscissa respectively) that describes the properties of clay and silt soils in terms of Atterberg limits. This chart consist of two lines namely A-line and U-line as shown below. The A-line is assumed to be a boundary between clay and silt soils. Which is defined by an equation $PI = 0.73 * (LL - 20)$. In this classification system a correlation is made between swell potential and unified soil classification as follows below (Daniel Tekle, 2003).

Table 2.1 Unified Soil Classification System (USCS)

Category	Symbols	Soil classification in unified system
Little or no expansion	1	GW,GP,GM,SW,SP,SM
Moderate expansion	2	GW,SC,ML,MH
High volume change	3	CL,OL,CH,OH
No rating		PT

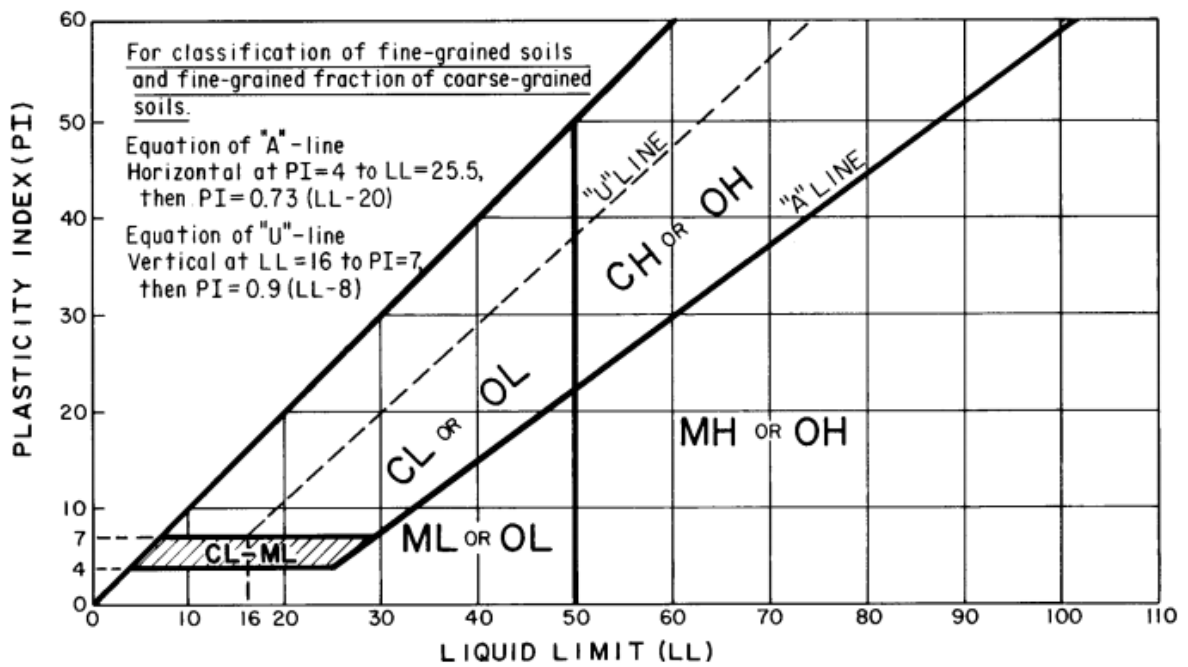


Figure 2. 4 Plasticity chart

II. AASHTO Classification

The AASHTO system uses similar techniques but the dividing line has an equation of the form $PI = LL - 30$. It generally classifies a soil broadly into granular material and silt-clay material.

Soils classified under groups A-1, A-2 and A-3 are granular materials with 35% or less passing through a No. 200 sieve but A-1 & A-3 non-plastic. Soils with more than 35% passing a No. 200 sieves are classified under groups A-4, A-5, A-6 and A-7. These soils are mostly silt and clay type materials.

Group A-4:-The typical material of this group is a non-plastic or moderately plastic silt soil usually having 75 % or more passing a No. 200 sieve.

Group A-5:-The typical material of this group is similar to that described under Group A-4, except that it may be highly elastic as indicated by the high liquid limit.

Group A-6:-The typical material of this group is a plastic clay soil usually having 75 % or more passing a No. 200 sieve. Materials of this group usually have a high volume change between wet and dry states.

Group A-7:-The typical material of this group is similar to that described under Group A-6, except that it has the high liquid limits characteristic of Group A-5 and may be elastic as well

as subject to high-volume change. Subgroup A-7-5 includes those materials with moderate plasticity indexes in relation to the liquid limit and which may be highly elastic as well as subject to considerable volume change. Subgroup A-7-6 includes those materials with high plasticity indexes in relation to liquid limit and which are subject to extremely high volume change (ASTM, 1996).

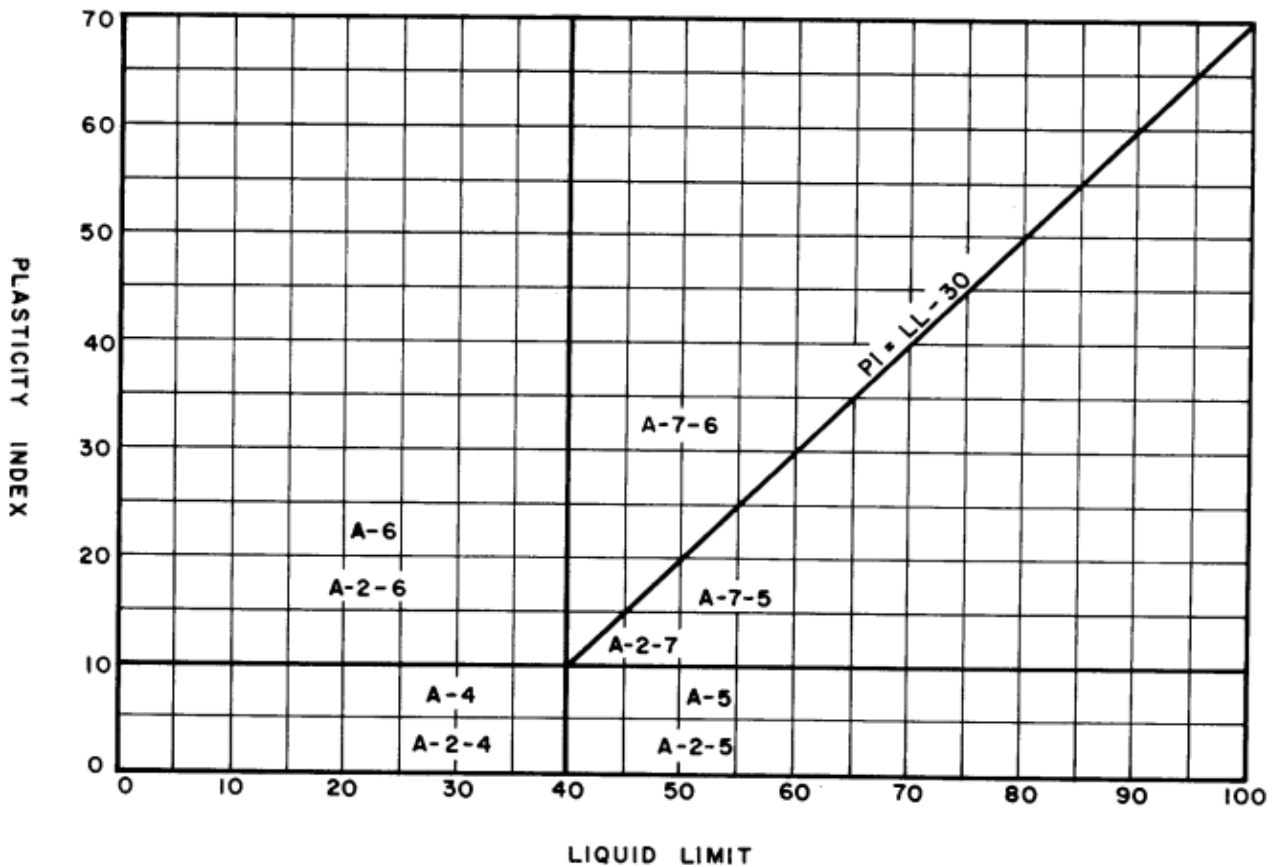


Figure 2. 5 Liquid limit Vs plasticity index chart for AASHTO soil classification method

2.5.2 Classification Specific to Expansive Soil

The above classification system may give an initial alert that the soil may have expansive character and doesn't provide useful information. A parameter determined from the expansive soil identification tests have been combined in a number of different classification schemes to give qualitative rating on the expansiveness of the soil. But the direct use of such classification systems as a basis for design may lead to an overly conservative construction in some places and inadequate construction in some areas. Hence, it is very important to emphasize that design decision has to be based on predicting testing and analysis, which provide reliable information.

2.5.2.1 Classification Based on Indirect Predictions of Swell Potential

An indirect prediction of swell potential includes correlations based on index properties, swell, physical indicator and a combination of them. Some of such classification systems are:-

I. Skempton's method (Mckeen, 1976)

This method is developed, by combining Atterberg limits and clay content into a single parameter called Activity. Activity is defined as the ratio of the plastic index to percent of clay fraction finer than $2\mu\text{m}$. Skempton suggested three classes of clays according to their activity.

Table 2.2 Soil expansion prediction (Skempton, 1953)

Activity	Potential expansion
$Ac < 0.75$	Low (in active)
$0.75 > Ac < 1.25$	Medium (normal)
$Ac > 1.25$	High (active)

II. Seed, Woodward and Lundgreen

According to (Seed, 1962), plasticity index is a parameter which can be used as a preliminary indicator of the swelling characteristics of a soil.

Seed, Woodward and Lundgreen suggested different classes of clays according to their plasticity index.

Table 2.3 Expansive Soil Classification

Plasticity index	Swell potential
0-10	Low
10-35	Medium
20-55	High
55 and above	very high

2.6 Swelling Pressure

Swelling pressure is a very useful index of the trouble potential of an expansive soil. This pressure is the maximum force per unit area that needs to be applied over a swelling soil to prevent volume increase.

2.7 Factor Affecting Swelling Characteristics of Expansive Soil

The mechanism of swelling in expansive clays is complex and is influenced by a number of factors. Expansion is a change of particle spacing and this is a result of changes in the soil water system that disturb the internal stress equilibrium. The factors influencing the swell potential of a soil can be considered in three different groups; the soil characteristics that influence the basic nature of the internal force field, the environmental factors that influence the changes that may occur in the internal force system, and the state of stress. According to (Nelson J. M., 1992) the expansive soil's swelling and shrinkage affecting factors are shown in the following table

Table 2.4 Factors influencing the swell potential of a soil (Nelson J. M., 1992).

Factors	Description
Initial water Content	Small amount of initial water content on the other hand indicates small degree of saturation. The tendency of soil to observe water will increase and this condition increases swelling potential.
Clay mineralogy	Clay soils which have clay minerals with higher swelling potential like Montmorillonite have hinge swelling potential.as the amount of clay mineral with high swell potential increases the swelling potential of the soil increases.
Dry density	The higher the value of initial dry density implies, closer particle spacing have large swelling potential.

Factors	Description
Particle size	Fine particles in a soil exists densely, and the finer the particle the higher will be its expansion potential.
Concentration of pore fluid salts	Higher concentration of Cation in the pore field. Decreases expansion potential.
Pore field. composition	Prevalence of monovalent Cation increases swelling potential while divalent inhabits shrinkage.
Climate	Arid climate courses desiccation of water content. This reduction of water content may lead to increase swelling potential of clay.
Location of water table	Fluctuating the location of water table causes variation of water content along the depth of the clay stratum, and the water content variation affects the soil swell-shrinkage property.
Thickness of clay stratum and confining pressure	High thickness of soil strata and large confining pressure reduces the soils swelling potential.
Field. permeability	Joints and fissures in a soil allows to pass water through, and significantly affects swelling capacity.

2.7.1 Swell-Consolidation Method

In this method an undisturbed sample is allowed to absorb water under a load of 1psi (7kpa) and is put aside to fully expand and reach equilibrium. Then it is consolidated by increasing the

applied pressure in intervals following the conventional consolidation test procedure. The load increment is continued until the sample reaches its initial volume (zero volume change). The load correspond to zero volume change is taken as swelling pressure. This method is quite popular and many investigators have used this method to establish a relationship between swell and applied pressure and to evaluate swelling pressure. The most serious drawback of this method is that it does not represent the normal sequence of load-submersion. In the field the soils is first subjected to the structural load and then swell later following exposure to moisture but not vice versa.

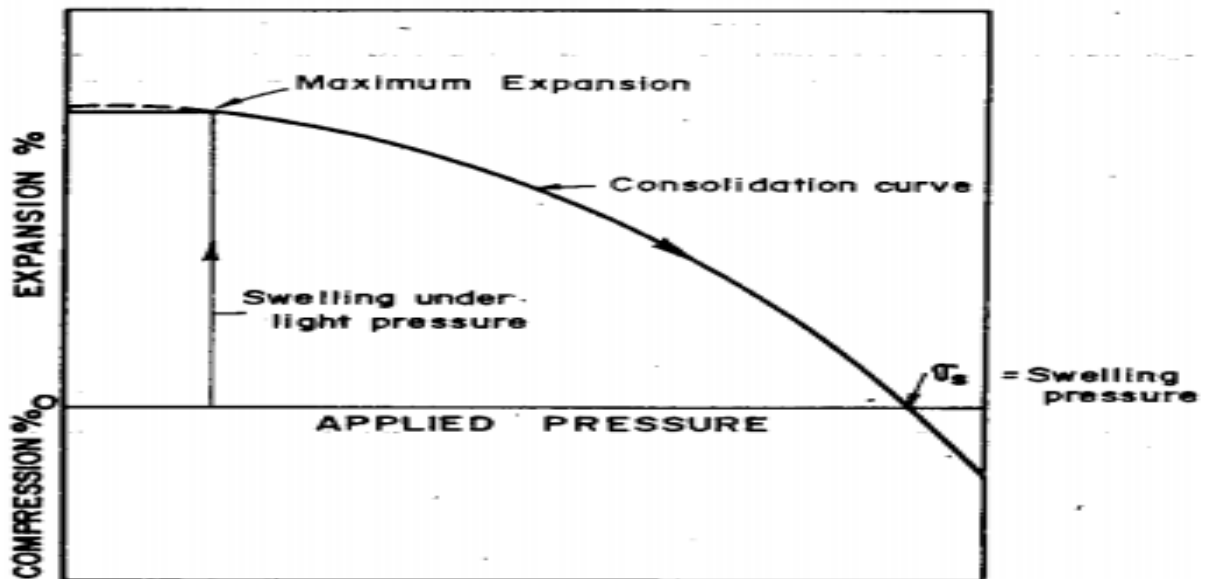


Figure 2. 6 Determination of swelling pressure by swelling consolidation method

2.8 Artificial Neural Network

Artificial neural networks (ANN) model are widely used by researchers to solve a variety of problems in science and engineering, particularly for some areas where the conventional modeling methods fail.

2.8.1 Application of ANN in Geotechnical Engineering

Artificial Neural Networks for Engineering Applications presents current trends for the solution of complex engineering problems that cannot be solved through conventional methods. The proposed methodologies can be applied to modeling, pattern recognition, classification, forecasting, estimation, and more. Geotechnical engineering is the basis for the various

engineering project construction. Nowadays, owing to the climate change, extreme weather often happens worldwide, such as rainstorm, hail, which causes the damage of foundation of engineering projects and makes these engineering problems become more pronounced. More importantly, with the development of technology, the stresses that the engineering facilities tolerate are getting larger and the frequency of the stresses become more frequent. For example, the transportation infrastructures have to sustain bigger and more frequent pressures because vehicles become heavier and faster. It would cause more and increasingly severe geotechnical accidents than before.

2.8.2 Difference between ANN and Conventional Regression Analysis

The prediction by a well-trained ANN is normally much faster than the conventional simulation programs or mathematical models as no lengthy iterative calculations are needed to solve differential equations using numerical methods but the selection of an appropriate neural network topology is important in terms of model accuracy and model simplicity.

2.9 Review of Previous Work Related To This Study

Correlations are very important to estimate engineering properties of soils, especially for preliminary investigation of projects. Correlations may be also used for projects where there is financial limitation, lack of test equipment and limited time.

Several investigators attempted to develop correlations for prediction of swelling characteristics in terms of either compositional factors or environmental factors or combination of both. Many relationships have been established from which swelling pressure can be estimated based on index test and the physical state of the soil. Some of the researches are listed:-

(Komornik, 1969) Found out this empirical equation:-

$$\text{Log Ps} = 0.132 + 0.0208 * \text{LL} + 0.0006688 * \gamma_d - 0.0269 * w \dots\dots\dots \text{Eqn 2.1}$$

Vijayvergiya and Ghazzaly (1973) found out those empirical equations: -

$$\text{Log Ps} = \frac{1}{2} (0.4 * \text{LL} - w + 23.6) \dots\dots\dots \text{Eqn 2.2}$$

$$\text{Log Ps} = \frac{1}{19.5} (6.24 * \gamma_d + 0.65 * \text{LL} - 100) \dots\dots\dots \text{Eqn 2.3}$$

The engineering properties of expansive soil of Ethiopia are different from those in other locality; researches on relationship between index properties and swelling pressure of expansive soils of Ethiopia have been done. Some of the researches undertaken are listed below:-

Ashenafi Tamrat, studied about Index Properties and Swelling Pressure of Expansive soils found in Dukem using the regression analysis based on experimental results from 15 samples and found out this empirical equation (Tamrat, Thesis, 2013).

$$P_s = 1.639 \cdot \gamma_d + 32.676 \cdot PL - 3110.94 \dots\dots\dots \text{Eqn 2.4}$$

Daniel Teklu, (2003) studied about Examining the Swelling Pressure of Addis Ababa Expansive Soils using multiple regression analysis based on experimental results from 17 samples and he recommended the following two empirical equations (Daniel Tekle, 2003):-

$$\text{Log}P_s = -5.00 - 0.0002064 \cdot LL + 0.003477 \cdot PI + 0.005827 \cdot \gamma_d \dots\dots\dots \text{Eqn 2.5}$$

$$\text{Log}P_s = -9.384 + 0.02748 \cdot W + 0.006307 \cdot PI + 0.008359 \cdot \gamma_d \dots\dots\dots \text{Eqn 2.6}$$

Dagmawe Negussie, studied about In-depth investigation of relationship between Index property and Swelling characteristic of Expansive soil in Bahir Dar using the regression analysis based on experimental results from 21 samples and found out this empirical equation (Negussie, 2007):-

$$\text{Log}P_s = 7.042 - 1.926 \cdot \gamma_d - 0.046 \cdot w - 0.609 \cdot A_c \dots\dots\dots \text{Eqn 2.7}$$

In the above equations

Where: P_s = Swelling pressure (kPa) for all eqn.

W , LL , PI , and PL = Moisture content, Liquid Limit, Plasticity Index, and Plastic Limit respectively (%)

γ_d = Dry density (Kg/m³) for eqn. 2.4, 2.5, and 2.6

γ_d = Dry density (g/cm³) for eqn. 2.1 and 2.5 γ_d = Dry density (KN/m³) for eqn. 2.3

CEC = Cation Exchange Capacity (meq/100gm) for eqn. 2.5

In these equations index properties that are believed to have significance for swelling are used as independent variables. Obviously the proposed equations might have served their purpose in areas where they have been specifically developed.

3. MATERIAL AND METHOD

3.1 Descriptions of the Study Area

3.1.1 General

Arba Minch received its name for the abundant local forty springs which produce a groundwater forest located at the base of the western side of the great rift valley in Southern Nation Nationality and People Region (SNNPR) about 500km south of Addis Ababa. The town consists of the uptown administrative center of Shecha and 4km away from the downtown commercial and residential area of Sikela which are connected by a paved road.

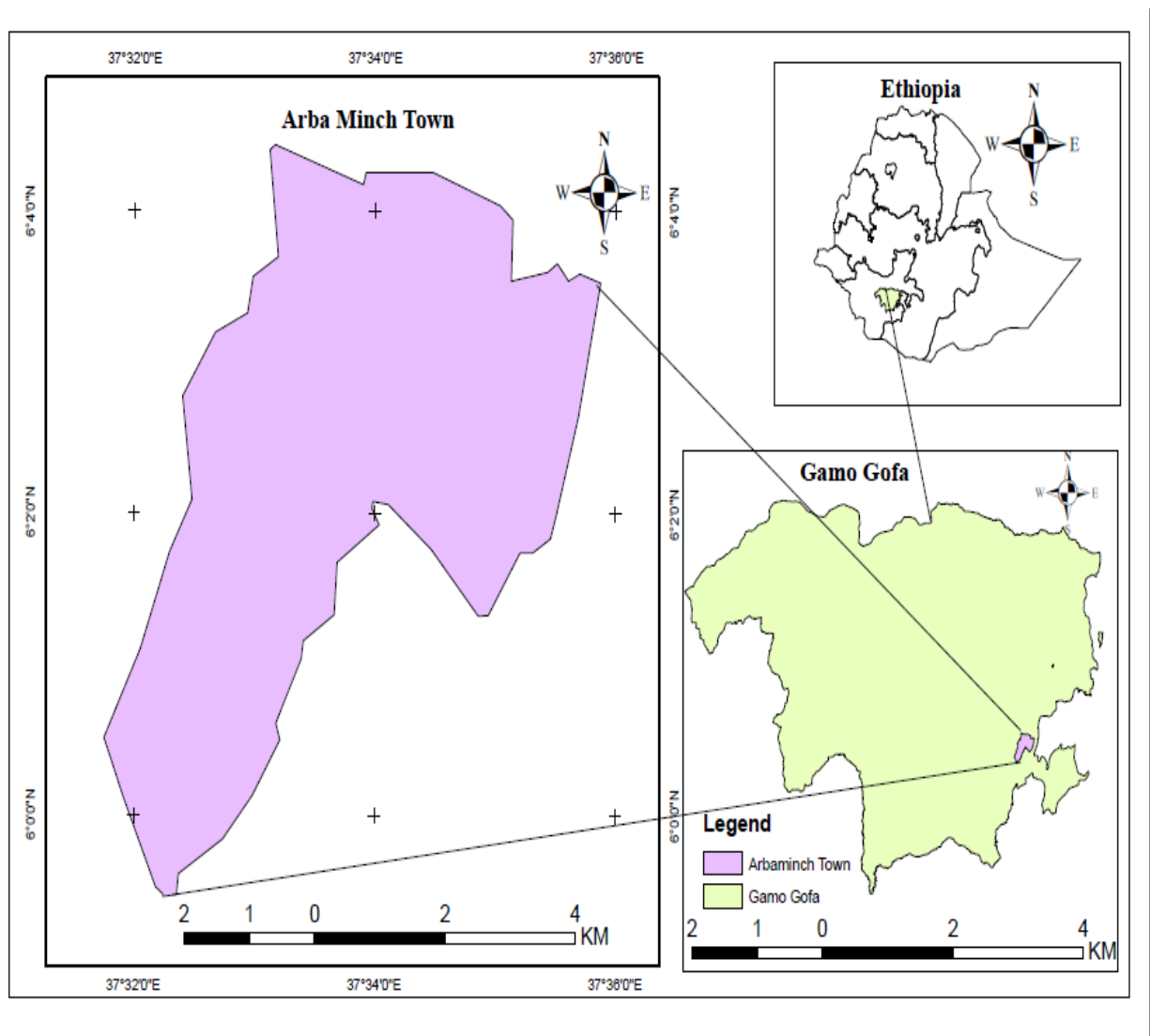


Figure 3. 1 Map of the study area

3.1.2 Topography and Climate

Arba Minch city has a coordinate $6^{\circ} 2' N 37^{\circ} 33'E$ with elevation of 1,285m. The climate here is tropical, in winter there is much less rainfall in Arba Minch than in summer, the average annual temperature is $21.8^{\circ}C$. With average precipitation of 818mm. The driest month is December, with 24mm of rainfall average of 128mm, the most precipitation falls in April. March is the warmest month of the year. The temperature in March is average $23.2^{\circ}C$, July has the lowest average temperature of the year. It is $20.8^{\circ}C$.

3.1.3 Geology

Geologically, the area belongs to category of rift valley system. The geological unit in the rift valley region mainly the result of volcanic activity during the tertiary period. The whole rift valley is underlain by ancient basement rock, which is defined as genesis grading in metamorphic granite, ignimbrites (consolidated hot-ash flows) and granodiorites.

3.2 Method and Procedure

3.2.1 Sample Site Selection

When selecting possible sampling sites, the major factor considered extremely important was that the site were to be certainly located in the expansive soil region. Sample sites were identified by visual investigation and field identification of expansive soil and information from residents and construction firms were collected. The collected information was showed some expansive characteristics that the study area have some polygonal cracks, Based on this information randomly ten sample sites were selected in Arba Minch town. The depth of the pits varied from 2.0m to 3.0m with 1m*1m width, as it is recurrent on the study area to place the foundation around these depths. The selected samples are not the overall characteristics of Arba Minch town, because there are different soil types found in the town. This thesis work is focused only on the expansive part of the town.

3.2.2 Sample Preparation

In order to accomplish the objective of this study different laboratory works are conducted by using disturbed and undisturbed soil sample. To collect undisturbed sample special care and attention is paid because soil is highly sensitive plus complex which can lose its in-situ characteristics easily, Actually we can't get 100% undisturbed sample but at least we can

minimize the degree of disturbance. The disturbed soil was placed in tight plastic bag with a reference tag to describe the location of the sample and the depth taken. This was done to avoid the possibility of contaminating the sample being collected.

3.2.3 Laboratory Testing

All engineering and index property test of soil specimen were examined in Arba Minch University soil laboratory and the testing procedure was undertaken according to American Society for Testing and Materials (ASTM) standard.

3.2.3.1 Particle Size

Since particle size analysis is one of the index property tests, the soil of the study area is examined for its grain size distribution. The normal method for separation of particles in a fine grained soil mass is the hydrometer analysis and for the coarse grained soils is sieve analysis. This test method can cover the quantitative determination of the distribution of particle sizes in soils. The laboratory test has been conducted in accordance with ASTM D 422 – 63 procedures.

3.2.3.2 Water Content

The consistency of a fine-grained soil largely depends on its water content. Natural moisture content of the study area was determined in laboratory by using undisturbed sample. The laboratory test procedures were conducted by referring ASTM D 2216-98 standard. A test specimen is first weighed in its natural or wet state and then dried to a constant mass for 24 hrs in oven at a temperature of 105°C and 50°C to evaluate whether the soil contain structural water or not. The loss of mass due to drying is considered to be water. The water content is calculated using the mass of water and the mass of the dry specimen.

3.2.3.3 Specific Gravity Test

The particular geotechnical term specific gravity of soil refers therefore to the ratio of the weight of the solid mater of a given soil sample to the weight of an equal volume (i.e. equal to the volume of solid matter) of water. According to ASTM D 854-98, two procedures for performing specific gravity are provided. These are Method-A, procedures for oven dried specimen and Method-B, procedure for moist specimen. In this research specific gravities were determined using Method-A due to high cohesive behavior of the soil specimens, it was not workable to sieve the sample in moist condition.

3.2.3.4 Atterberg's Limits Test

Atterberg's limits or consistency limits are water contents at which the soil changes from one state to the other. It usually applies to fine grained soils whose condition is affected by changes in moisture content. According to ASTM D 4318-98 the method adopted for these tests was the dry preparation method using a mechanical device. The sample that has been rubbed down and then sieved through a 425 μ m sieve, after the sample has been sieved, 200 grams soil was weighed and the liquid limit was determined by performing a trial which a portion of the sample is spread in a brass cup, divided in two by a grooving tool and then allowed to flow together from the shock.

3.2.3.5 Free Swell Test

The free swell test is the simplest test which gives a fair approximation of the degree of expansiveness of the soil sample. 10 grams of dry soil material passing through a 425 μ m (No. 40) was poured into each of the two graduate cylinders of 100ml of kerosene and distilled water. Kerosene was selected because it is non-polar and is unable to react with the soil to evaluate differential settlement. Both samples were then allowed to settle in the bottom of cylinders, 24hr was allowed for soil sample to attain equilibrium state of volume without any further change in the volume of the soils and the final volume of the soils in each of the cylinders was recorded.

3.2.3.6 Compaction

Compaction tests were done on 12 representative samples that were taken from ten different test pits. The test was conducted based on the procedure outlined on ASTM D 698-91 Standard procedure A.

In this standard test method, oven dried soil sample of 3000g passing through 4.75mm sieve soil is compacted by 2.5Kg hammer falling a distance of 30.5cm into a soil filled mold of having a volume of 944cm³. The mold was filled within three equal layers of soil, and each layer was subjected to 25 drops of the hammer. Using the test data the relationship between the moisture content and the dry density of a soil were plotted. From the curve optimum moisture content and the corresponding maximum dry density were obtained.

3.3.3.7 Unconfined Compressive test

This test method provides an approximate value of the strength of cohesive soil in terms of total strain and applicable to cohesive material which will not expel bleed water. According to ASTM

D 2166-98a the test were conducted. The soil specimen was remolded by using its MDD and OMC from standard compaction the mass is calculated. The specimen is size of 76mm height and 38mm diameter. Then, the specimen has been placed in the loading device so that it is centered on the bottom platen. The reading was started by making deformation dial zero.

3.3.3.8 Swelling Pressure

ASTM D4546-96 defines swelling pressure which prevents the specimen from swelling or that pressure which is required to return the specimen to its original state (void ratio, height) after swelling. There are different methods to determine the swelling pressure of expansive soils.

These are Different Pressure Method, Consolidation-swell Method, Constant volume Method and Double Oedometer Method. From these methods constant volume method is relatively easy and gives a reasonable swelling pressure result. A test procedure that applied for this particular laboratory test is ASTM D 4546-C as per ASTM D 2435 procedure which is constant volume test or swells-pressure test procedure.

Stress controlled tests use the conventional Oedometer. The samples were placed in the consolidation ring trimmed to the height of the ring. The samples were maintained at constant height (volume) by adjustments in vertical pressure after the specimen is inundated in free water to obtain swell pressure. The stress required to maintain the sample to its original height was the zero volume change or swelling pressure.

3.3 Analysis Method Used

3.3.1 Development of ANN for Prediction of Swelling Pressure

Artificial neural networks (ANNs) are computational model, which is based on the information processing system of the human brain. The network has been trained by dividing the samples into three sections which is, training, validation, and testing. The term training, that is presented to the network during training, and additionally, the network is adjusted in step with its error, however validation that is employed to measure network generalization and to close training when generalization stops improving. But, testing, does no effect training and so provides an independent measure of network performance during and after training.

An ANN model is designated to predict swelling pressure (P_s) from the soil index properties such as clay percent (C), Liquid limit (LL), plasticity index (PI), Plastic limit (PL), dry density

(Y_{dry}), water content (ω), and Activity (A_c). For this purpose, an ANN architecture with two up to four inputs and one output was constructed. Therefore, in total, 56% of the data were used for training, 24% for testing, and 20% for validation. During the design of optimal ANNs, the trials were formed. The optimal ANNs performance was obtained with the model having 10 hidden layers were chosen for better performance, 8 neurons in the hidden layers, 16 epochs, and a 0.001 momentum factor, a log-sigmoid transfer function in the neurons of the hidden layers and in the neuron of the output.

3.3.2 Development of MRA for Prediction of Swelling Pressure

Multiple regression analysis was performed to predict swelling pressure by using SPSS 22. Generally in this analysis procedures the value of swelling pressure (P_s) was considered as the dependent (target) variable whereas the liquid limit (LL), plastic limit (PL), plasticity index (PI), moisture content (ω) and dry density Y_{dry} values were the independent (input) variables.

The multiple regression equations take the form:

$$Y = b_1X_1 + b_2X_2 + \dots + c$$

The b 's are the regression coefficients, representing the amount the dependent variable changes when the independent changes 1 unit. The c is the constant, where the regression line intercepts the y axis; representing the amount the dependent y will be when all the independent variables are 0. To determine the strength of each correlation the R^2 value for the trend line was calculated. R^2 is the relative predictive power of a model and is a descriptive measure between 0 and 1. The closer it is to one the greater the ability for the equation to predict an outcome.

3.3.3 Choosing the right predictor variables

The key to a successful logistic regression model is to choose the correct variables to enter into the model. While it is tempting to include as many input variables as possible, this can dilute true associations and lead to large standard errors with wide and imprecise confidence intervals, or, conversely, identify false associations. In this study the conventional technique conducted was to first run the univariate analyses (i.e., relation of the outcome with each predictor, one at a time), the outcome is swelling-pressure whereas the predictor are index properties and then use only those variables which meet a preset cutoff for significance to run a multivariable model.

3.3.4 Avoiding the use of highly correlated variables

If input variables are highly correlated with one another (known as multicollinearity), then the effect of each on the regression model becomes less precise, because the effect will get split between two variables. During analysis of this study the predictors has been selected and their correlation was first examined. The developed regression model assigned to include less inter-related predictors.

3.3.5 Cross Validation

After developing new predictive model, cross validation is very essential. In this study there is twelve sample in total, ten samples were used to develop new swelling pressure predicting model and the rest two were kept to check (for cross validation). Once we are done with training our model, we just can't assume that it is going to work well on data that it has not seen before. In other words, we can't be sure that the model will have the desired accuracy. We need some kind of assurance of the accuracy of the predictions that our model is putting out. For this, we need to validate our model.

3.4 Previously Developed Equations

Attempts were made by different researchers to correlate swelling pressure with index properties. In general, previously developed empirical equations and equations to be developed in the future are not to be expected to determine swelling pressure precisely and accurately for all soils. The formation and development of soil structure has very erratic nature and the swell potential is dependent on the geology, environmental factors, soil characteristics and many other factors, which vary from place to place. Therefore equations developed for soils in one place may not work at all if tested on soils of other place of the same region. Hence specific models have to be developed for specific areas in order to give fair evaluations.

4. RESULT AND DISCUSSIONS

4.1 Laboratory Test Results

Laboratory test are valuable in providing trustworthy data for calculating index properties, swelling potential and other engineering characteristics of soil. A laboratory test for the study area is carried out in accordance with the ASTM standard testing methods. The actual test results are presented in the Appendices. In order to obtain the intended purpose of the research the following laboratory tests were carried out.

4.1.1 Index Properties of Soils

Soils occur naturally in a large variety. Engineers are frequently searching for simplified tests that will increase their knowledge of soils by employing a simple and rapid soil tests. These simplified tests which are indicative of the engineering properties of soils are called index properties, such as Moisture Content, Dry Density, Specific Gravity, particle size distribution and Atterberg's Limits.

4.1.1.1 Natural Moisture Content

From the test result both oven and air dried moisture content results were compared and less than 4% of moisture content was observed which indicates that there is no structural water found in the soil and other tests are conducted by using oven dry at 105°C . Moisture Contents of the study area falls in the range of 28% -43%. The result of the test is summarized in Table 4.1. The detailed Moisture Contents test results are attached in Appendix A.

Table 4. 1 Natural Moisture Content comparison for oven and air dried sample

Location	Depth	ω_i for Oven dried %	ω_i for Air dried %	Difference %
Gurba	2.6m	43	41	2.29
Medanialem sefer	2m	37	34	3.01
Bubu meda	3m	35	39	3.61
Secha H.s	3m	38	37	0.97
Edget ber	3m	30	34	3.4
Zuriya fird bet	2.5m	35	37	1.42
Wubet hotel	3m	33	31	1.83
Ajip	3m	31	32	0.75
Derik	2.8m	29	32	1.67
Doyisa	2m	28	31	3.25
Bubu Meda 2	2m	36.81	38.04	1.23
Doyisa 2	3m	24.19	25.41	1.2

4.1.1.2 Specific Gravity

Specific gravity of soil is the ratio of the unit weight of solids in the soil to the unit weight of water. The test results of specific gravity of study area are summarized in Table 4.2. The detailed Specific gravity test results are attached in Appendix B.

Table 4. 2 Specific Gravity and Free Swell test results.

Location	Depth	Gs	Free swell %
Gurba	2.6m	2.79	97.5
Medanialem sefer	2m	2.75	115
Bubu meda	3m	2.61	107.5
Secha H.s	3m	2.78	127.5
Edget ber	3m	2.72	117.5
Zuriya fird bet	2.5m	2.78	100
Wubet hotel	3m	2.75	120
Ajip	3m	2.65	140
Derik	2.8m	2.66	145
Doyisa	2m	2.75	142.5
Bubu Meda 2	2m	2.58	102.5
Doyisa 2	3m	2.83	155

4.1.1.3 Free Swell Test

The free swell test is one of the most commonly used simple tests for estimating soil swelling potential. Results of the free swell tests of the study area were given in Table 4.2. The test result revealed that the study area can be classified as highly expansive soil having greater than 100% free swell value except that of Gurba kebele, which can be classified as marginal as the result is between 50-100%. The free swell test result of study area is summarized in Table 4.2. The detailed free swell test results are attached in Appendix C.

4.1.1.4 Particle Size

For coarse-grained soils sieve analysis and for fine-grained soils hydrometer analysis is used. In this study, Hydrometer and sieve analysis were performed on all the samples and a plot of percent finer against size of soil particle was plotted. From the curve in Figure 4.1, the proportion and type of soil grains was determined, the results are given in Table 4.3. The detailed grain size analysis test results are attached in Appendix E.

Table 4. 3 Particle size result

Location	Depth in (m)	Gravel %	Sand %	Clay %	Silt %
Gurba	2.6m	3.3	8.32	39.26	49.12
Medanialem sefer	2m	2.11	8.6	43.11	46.17
Bubu meda	3m	1.25	9.12	41.77	47.86
Secha H.s	3m	1.1	9.15	43.45	46.3
Edget ber	3m	1.5	8.44	37.75	52.31
Zuriya fird bet	2.5m	2.8	6.84	35.68	54.67
Wubet hotel	3m	1.4	9.41	35.18	54.01
Ajip	3m	1.85	9.28	44.34	44.54
Derik	2.8m	2.5	8.96	48.94	39.6
Doyisa	2m	0.55	9.42	43.85	46.17
Bubu Meda 2	2m	1.51	10.35	46.31	41.83
Doyisa 2	3m	0.50	8.38	47.31	43.81

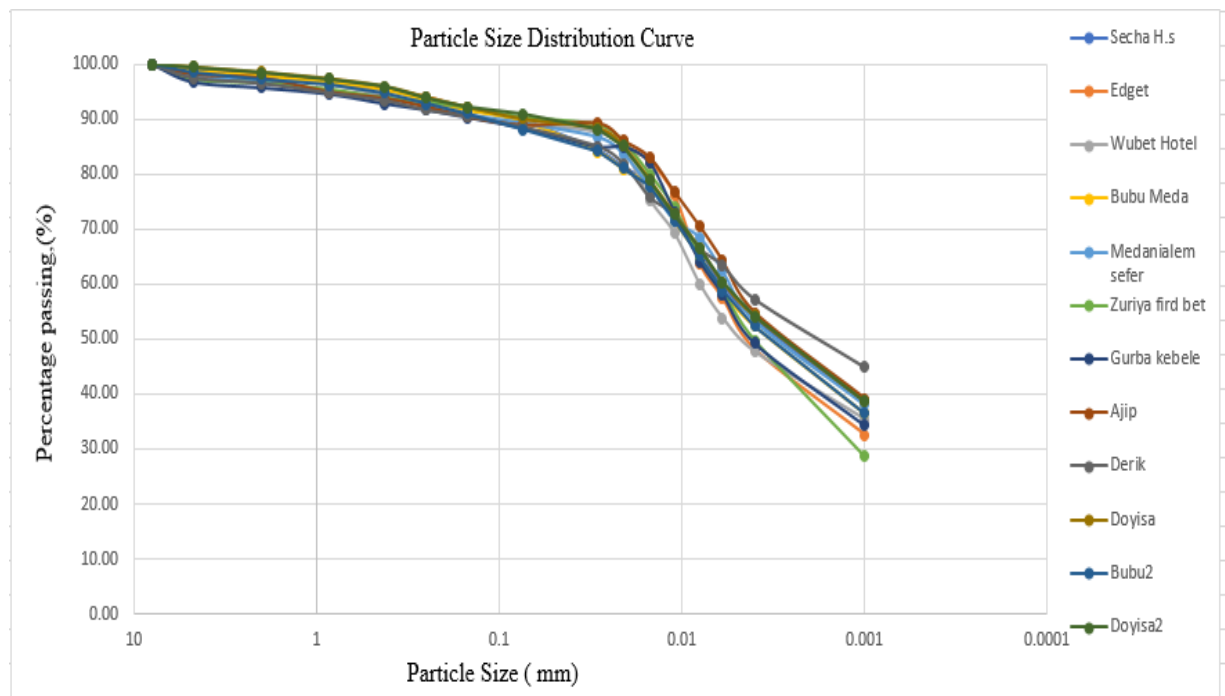


Figure 4. 1 Particle size distribution curve

4.1.1.5 Atterberg's Limit Test

Atterberg's limit test were determined for oven dried samples. From the test result it was observed that the soil under the study are fine grained soil having liquid limits ranging from 96%-120%, which indicates the study area is found to be highly plastic soil with high liquid limit and Plastic limit. The test results are given in Table 4.4 The detailed Atterberg's limit test results are attached in Appendix D.

Table 4. 4 Atterberg limit test results

Location	Depth	LL %	PL %	PI%
Gurba	2.6m	96	42	54
Medanialem sefer	2m	110	45	65
Bubu meda	3m	98	40	58
Secha H.s	3m	107	51	56
Edget ber	3m	101	48	53
Zuriya fird bet	2.5m	97	48	49
Wubet hotel	3m	104	48	56
Ajip	3m	116	46	70
Derik	2.8m	103	42	61
Doyisa	2m	120	43	77
Bubu Meda 2	2m	100	36	64
Doyisa 2	3m	113	39	74

4.1.2 Engineering Properties

4.1.2.1 Compaction

Standard compaction test was conducted according to ASTM D 698-91, MDD and OMC value are obtained from the graph. Summarized test result are given in Table 4.5.

Table 4. 5 Compaction test result

Location	Depth	OMC%	MDD
Gurba	2.6m	33	1.362
Edget ber	3m	32	1.32
Zuria fird bet	2.5m	32.5	1.35
Wubet hotel	3m	29	1.455
Secha H.S	3m	38	1.348
Bubu meda	3m	28	1.42
Medanialem	2m	28	1.4
Ajip	3m	28	1.385
Derik	2.8m	37	1.255
Doyisa	2m	30.5	1.385

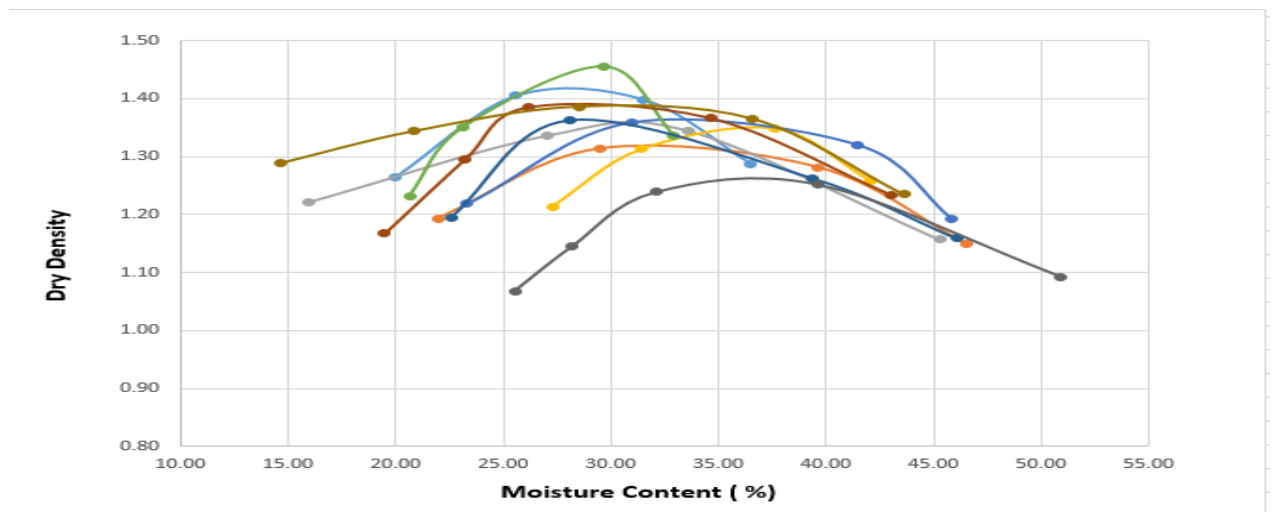


Figure 4. 2 Combined compaction results

4.1.2.2 Unconfined Compressive Strength Test

The unconfined compression test is one of the simplest and quickest tests used for the determination of the shear strength, this test conducted according to ASTM D 2166. The soil specimen was remolded by using its MDD and OMC from standard compaction the mass is also calculated. The unconfined compression test result is summarized in Table 4.6 Unconfined

compressive strength and Undrained shear strength of the study area ranged from 212.677 kPa to 365.282 kPa and 106.338 kPa to 182.641 kPa Therefore the consistency of the study area is Stiff this shows as the soil in the study area is expansive.

Table 4. 6 Unconfined Compressive Strength Test Results

Location	Depth (m)	qu (kPa)	Su (kPa)
Gurba	2.6m	212.67	106.34
Medanialem sefer	2m	278.62	139.31
Bubu meda	3m	270.93	135.46
Secha H.s	3m	265.59	132.80
Edget ber	3m	337.65	168.82
Zuriya fird bet	2.5m	328.49	164.25
Wubet hotel	3m	338.69	169.35
Ajip	3m	323.27	161.63
Derik	2.8m	343.96	171.98
Doyisa	2m	354.21	177.11
Bubu 2	2m	252.199	126.100
Doyisa 2	3m	365.282	182.641

4.1.2.3 Swelling Pressure Test

Using the ASTM procedures, water content, dry density and swelling pressure tests were conducted from soil samples. Swelling pressure for the study area falls in the range of 130.89 kPa to 502.82 kPa. The results of the test were given in Table 4.7. The detailed test results are attached in Appendix F.

Table 4. 7 Swelling Pressure Test Results

Location	Bulk density	Dry density (gm/cc)	Swelling Pressure kPa
Gurba	1.71	1.25	130.89
Medanialem sefer	1.63	1.26	219.46
Bubu meda	1.65	1.28	158.84
Secha H.s	1.64	1.30	200.83
Edget ber	1.75	1.40	487.29
Zuriya fird bet	1.7	1.35	212.73
Wubet hotel	1.78	1.41	350.53
Ajip	1.89	1.43	402.53
Derik	1.82	1.43	447.27
Doyisa	1.84	1.49	491.88
Bubu 2	1.6	1.15	155.476
Doyisa 2	1.86	1.54	502.82

4.2 Soil Classification

Soil classification is an important aspect of laboratory test, which tells the characteristic of the soil under interest. There are different methods of classification based on the identification tests performed on the soil. Unified Soil Classification System (USCS) and the American Association of State Highway Transport Officials (AASHTO) method are among the widely used schemes of soil classification. There are also other classification methods specifically proposed for expansive soil.

4.2.1 Classification according to USCS

The USCS uses symbols for particular size group. These symbols and their representations are G-gravel, S-sand, M-silt, and C-clay. These are combined with other symbols expressing gradation characteristics. W-for well graded and P-for poorly graded and plastic characteristics H- for high and L-for low and symbols O-for the presence of organic materials. Accordingly,

the soil under study is plotted on the USCS plasticity chart. The soil that found in around Bubu Meda, Derik, Medanilemm Sefer, and Gurba area are found on and near A-line, Bubu Meda 2, Doyisa kebele and Doyisa 2 are above A-line and the rest are below A-line directing the silt region. Because of this, the plasticity chart may not be abundantly effective for the soil, as the laboratory results of Free-swell and Atterberg's limit test exposed that the soil behaves primarily as clay but also displays some tendency toward silt behavior which indicates that further investigations need to be carried out.

4.2.2 Classifications of Soils Based on AASHTO Classification System

There are seven groups of inorganic soils, A-1 to A-7 with 12 subgroups in all. The system is based on Particle-Size Distribution, Liquid Limit and Plasticity Index. The AASHTO system uses similar techniques as that of USC but the dividing line has an equation of the form $PI = LL - 30$. It generally classifies a soil broadly into granular material and silt-clay material. The granular material is further divided into three groups which are called A-1, A-2 and A-3. The silt-clay material is in turn divided into four groups namely, A-4, A-5, A-6 and A-7. According to this the soil type of the study area falls in the region of A-2-7 and A-7-5, which indicates that the soil under concern is plastic clay that can easily exhibit volume change during moisture variation.

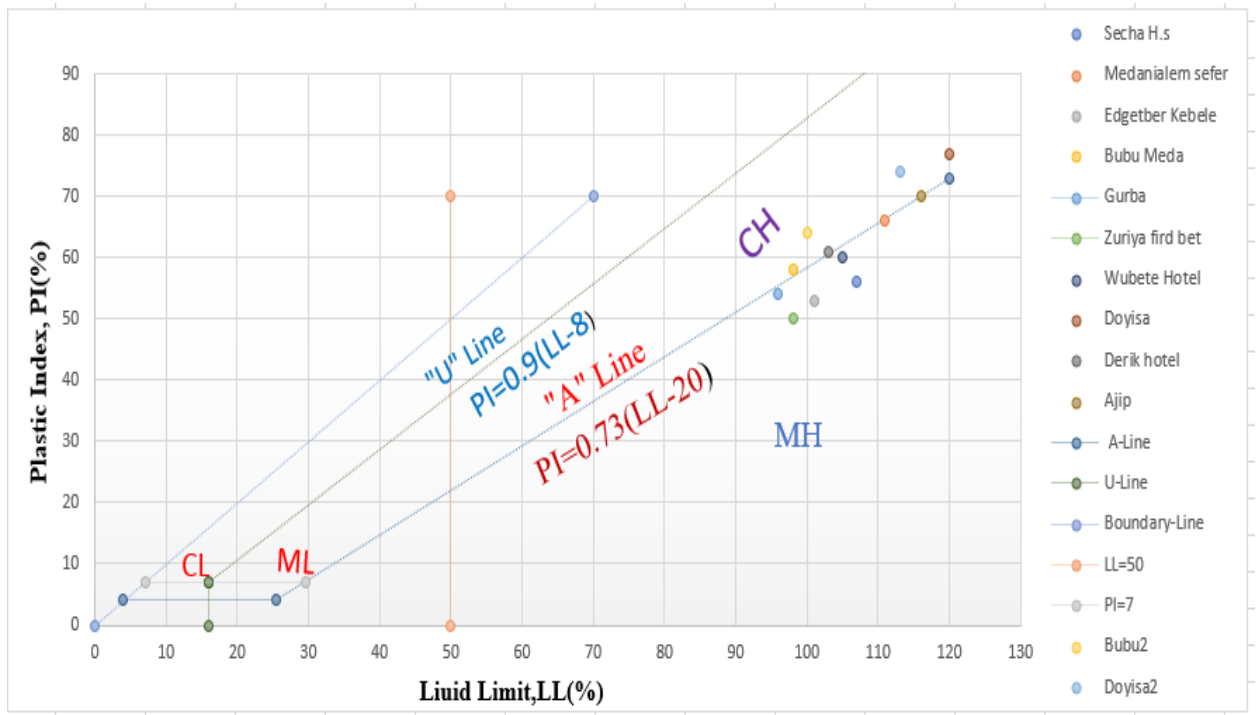


Figure 4. 3 Plasticity chart of the study area according to Unified Soil Classification System

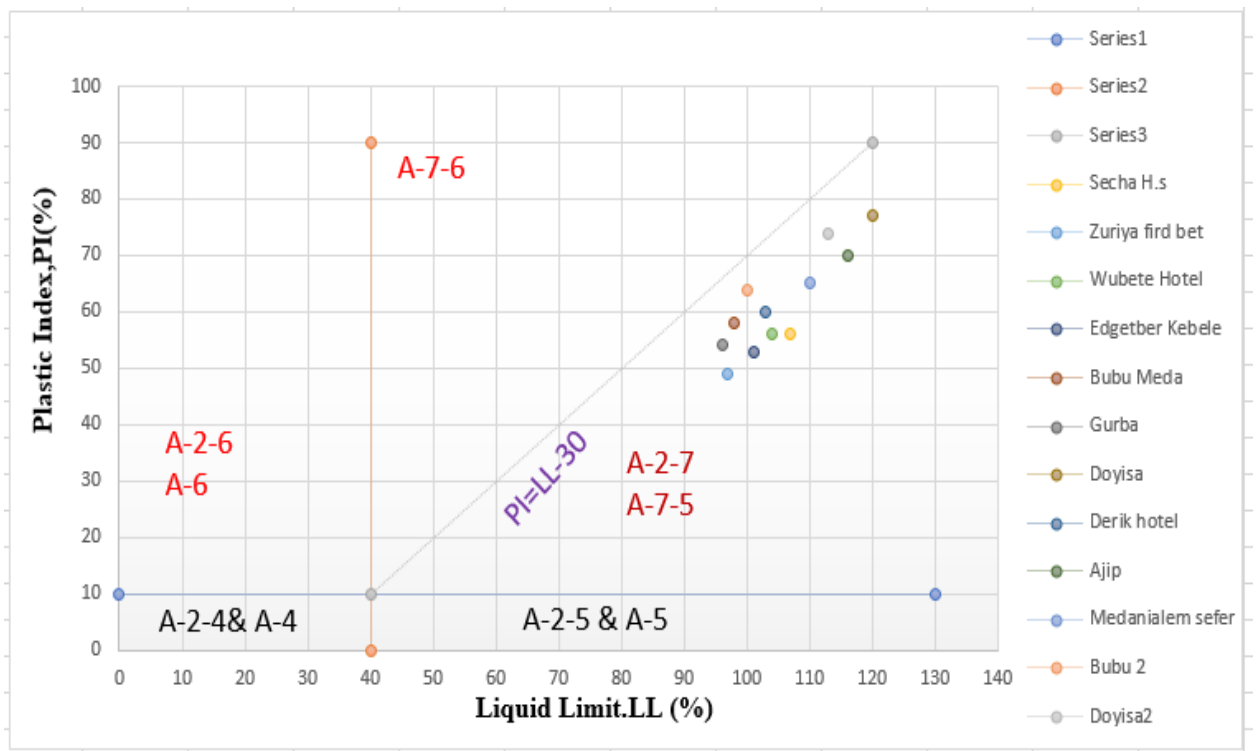


Figure 4. 4 Plasticity chart of the study area according to AASHTO Classification System

4.2.3 Classification Based on Indirect Predictions of Swell Potential

Seed, Woodward and Lundgreen

According to (Seed, 1962), plasticity index is a parameter which can be used as a preliminary indicator of the swelling characteristics of a soil and suggested different classes of clays according to their plasticity index.

Table 4. 8 Expansive soil classification based on plasticity index

Plasticity index	Swell potential
0-10	Low
10-35	Medium
20-55	High
55 and above	very high

Plasticity Index of the soil of the study area falls in the range of 49%-77%, with this result the soil reveals very high swelling potential.

Skempton's method (Mckeen, 1976)

According to (Skempton, 1953) the study areas have Active (highly active) potential expansion with having activity value of greater than 1.25 except that of Derik area which shows Ac value 1.25.

Table 4. 9 Activity test for the study area

Location	Depth(m)	PI (%)	Clay (%)	Ac
Gurba	2.6m	54	39.26	1.38
Medanialem sefer	2m	65	43.11	1.51
Bubu meda	3m	58	41.77	1.39
Secha H.s	3m	56	43.45	1.29
Edget ber	3m	53	37.75	1.40
Zuriya fird bet	2.5m	49	35.68	1.37
Wubet hotel	3m	56	35.18	1.59
Ajip	3m	70	44.34	1.58
Derik	2.8m	61	48.94	1.25
Bubu Meda 2	2m	64	46.31	1.38
Doyisa 2	3m	74	47.3	1.56
Doyisa	2m	77	43.85	1.76

4.3 Swelling Pressure Prediction

The formation and development of soil structure has very uneven nature and the swell potential is dependent on the geology, environmental factors, soil characteristics and many other factors which vary from place to place. Therefore equations developed for soils in one place may not work at all if tested on soils of other place of the same region. Hence specific models have to be developed for specific areas in order to give fair evaluations.

These models consist different soil parameters indifferent combinations. Index properties are the commonly used parameters for predicting swelling pressure, because these properties have significance in representing the swelling behavior of a soil. In general, equations going to be developed in the future and formerly developed empirical equations and are not expected to determine swelling pressure precisely and accurately for all soils.

4.3.1 Univariate Analysis

Univariate analysis is relation of the outcome with each predictor one at a time and its purpose is to identify potential predictor. Then only those variables which meet a preset cutoff for significance to run a multivariable model are used. Scatter plot for dependent and independent variables has been plotted to understand the effects of predictors by using the MS excel spreadsheet which is found to be the most powerful and manageable tool.

4.3.1.1 Swelling Pressure Vs Plastic Limit

The best fitting trend line for relationship between swelling pressure and plastic limit is $P_s = 15.53 * PL - 404.15$. As the strength of this correlation is 14.63% which is very weak and it is not reliable enough to be used as a predictor for the estimation of the swelling pressure of the study area.

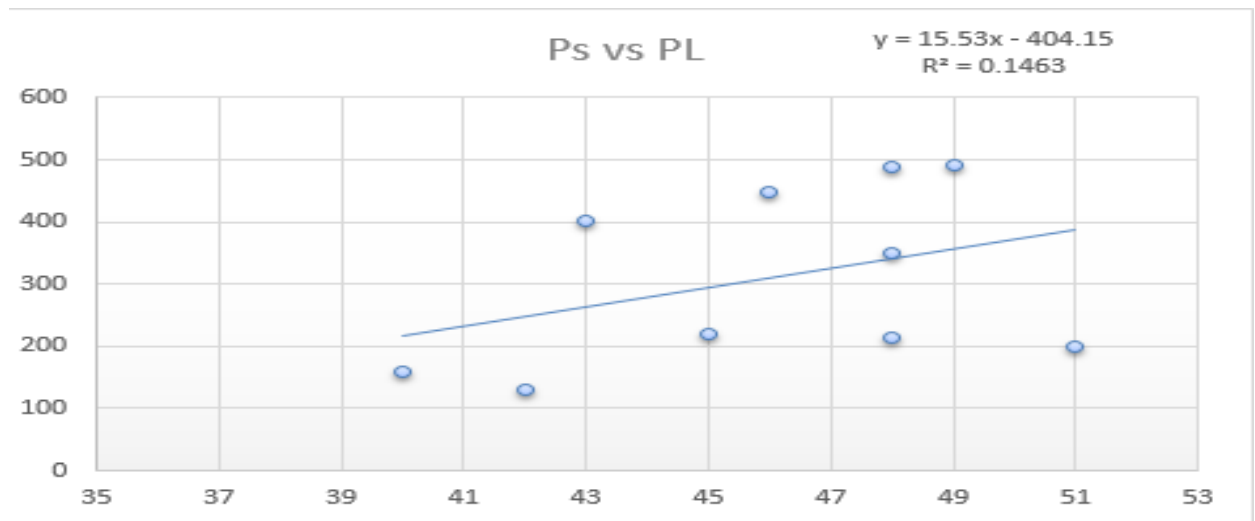


Figure 4. 5 Swelling Pressure Vs Plastic Limit

4.3.1.2 Swelling Pressure Vs Liquid Limit

The best fitting trend line for relationship between swelling pressure and liquid limit is $P_s = 9.3259 * LL - 670.86$. As the strength of this correlation is only 28.8 % it is not reliable enough to be used as a predictor for the estimation of the swelling pressure.

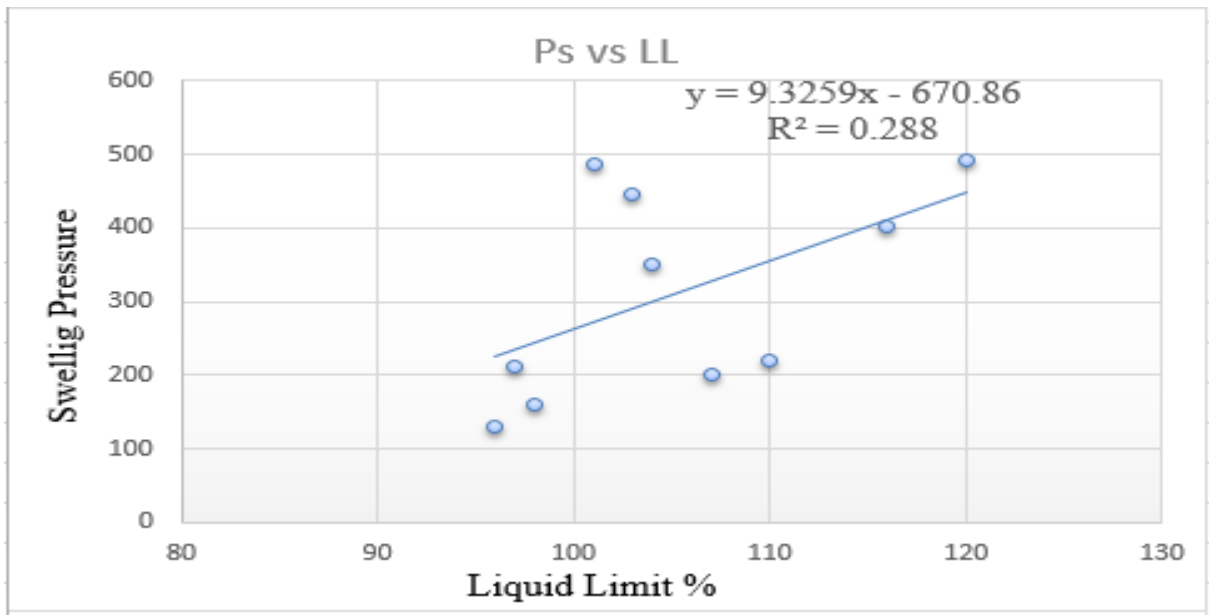


Figure 4.6 Swelling Pressure Vs Liquid Limit

4.3.1.3 Swelling Pressure Vs Dry density

The finest fitting trend line for this relationship is $P_s = 1547.6 \cdot \rho_{dry} - 1793.9$. The strength of this equation in predicting an effect from the dry density is around 85.06% or has an $R^2 = 0.8506$ it display that the relationship is strong. The result indicates that there is a trend of increase of swelling pressure as the dry density increases.

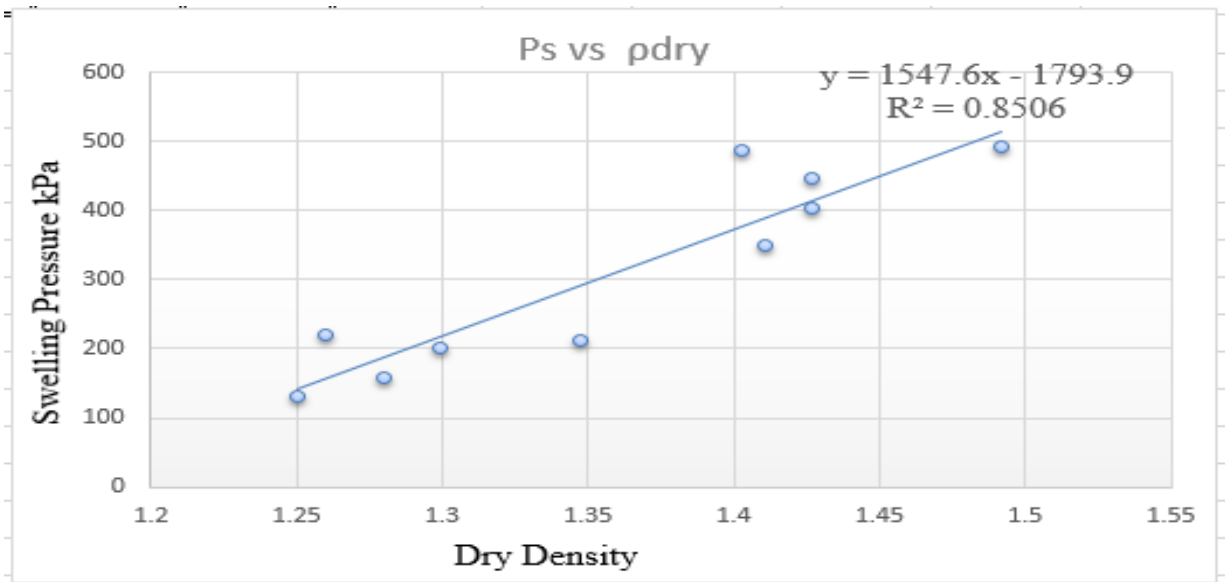


Figure 4. 7 Swelling Pressure Vs Dry density.

4.3.1.4 Swelling Pressure Vs Natural Moisture Content

The best fitting trend line for this relationship is $P_s = -25.867*\omega + 1182.2$. The strength of this equation in predicting an outcome from the natural moisture content is around 83.55 % or has $R^2 = 0.8355$. This indicates that swelling pressure is highly affected by Natural moisture content. When natural moisture content decrease swelling pressure increase.

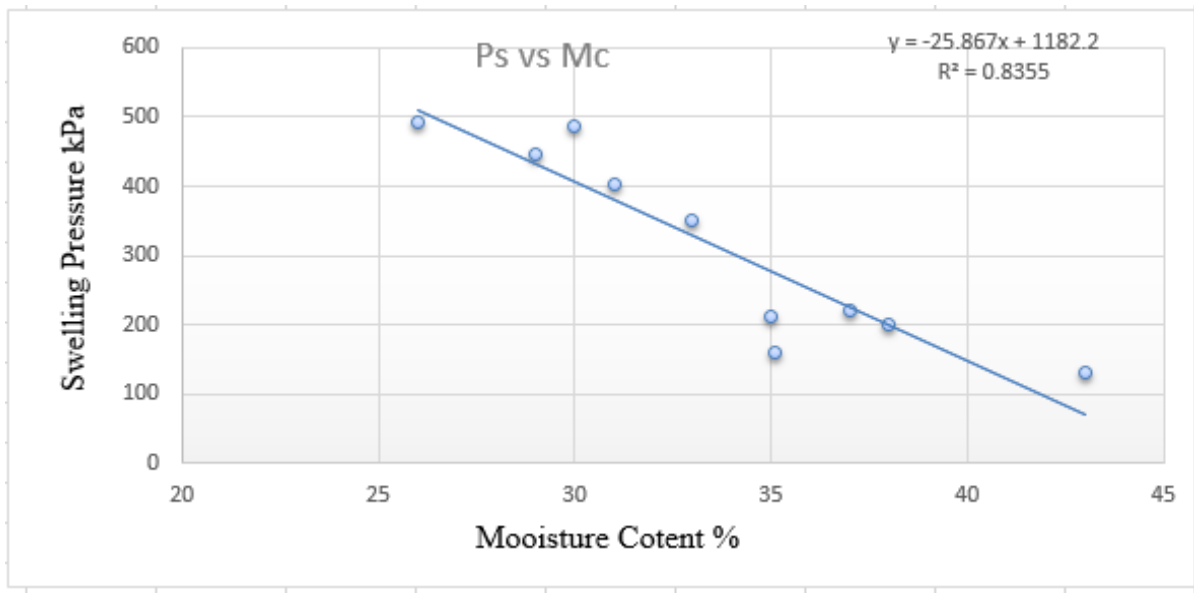


Figure 4. 8 Swelling Pressure Vs Natural moisture content

4.3.1.5 Swelling Pressure Vs Plastic Index

The best fitting trend line for this relationship is $P_s = 7.8894*PI - 162.35$. The strength of this equation in predicting an outcome from the Plastic index is around 22.96% or has $R^2 = 0.2296$.

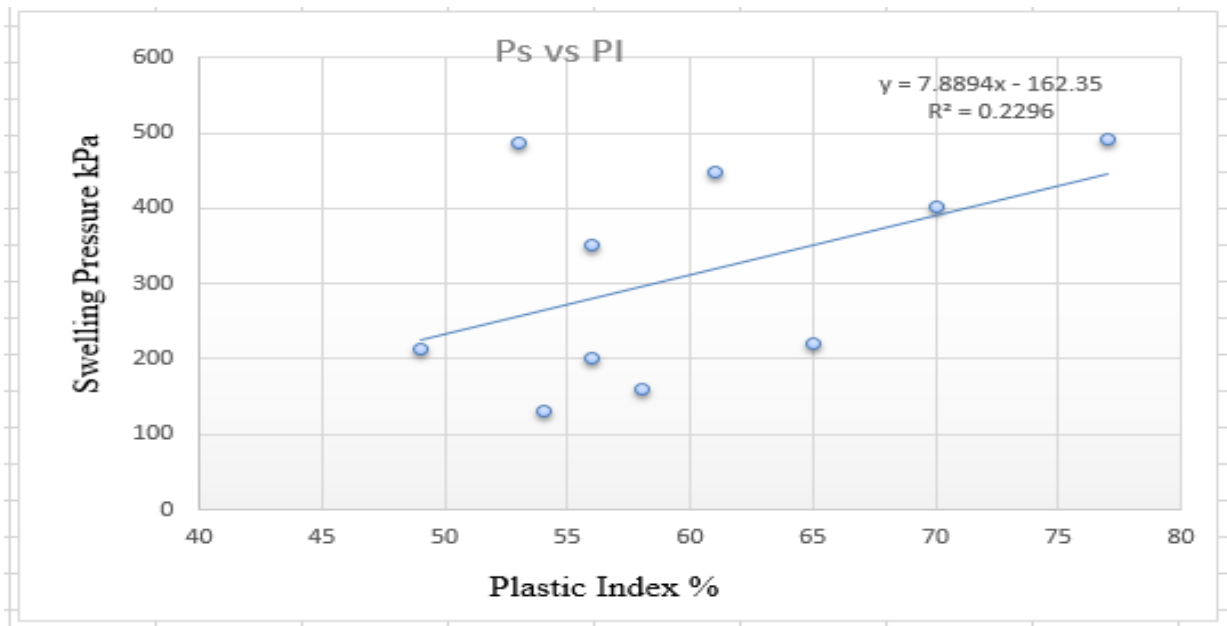


Figure 4. 9 Swelling Pressure Vs Plastic index

4.3.2 Multicollinearity Analysis

If input variables are highly correlated with one another, then the effect of each on the regression models becomes less precise. In order to develop strong correlation model multicollinearity analysis is very essential task. If two variables are highly correlated, the prediction model should include only one of the two or the most influential parameter.

4.3.2.1 Liquid Limit vs Plastic Index

The scatter plot indicates that liquid limit and plastic index are highly correlated with having R^2 value = 0.8336, there is inter-dependency between two parameters to avoid the effect of inter-dependency we can't use this two parameters at a time.

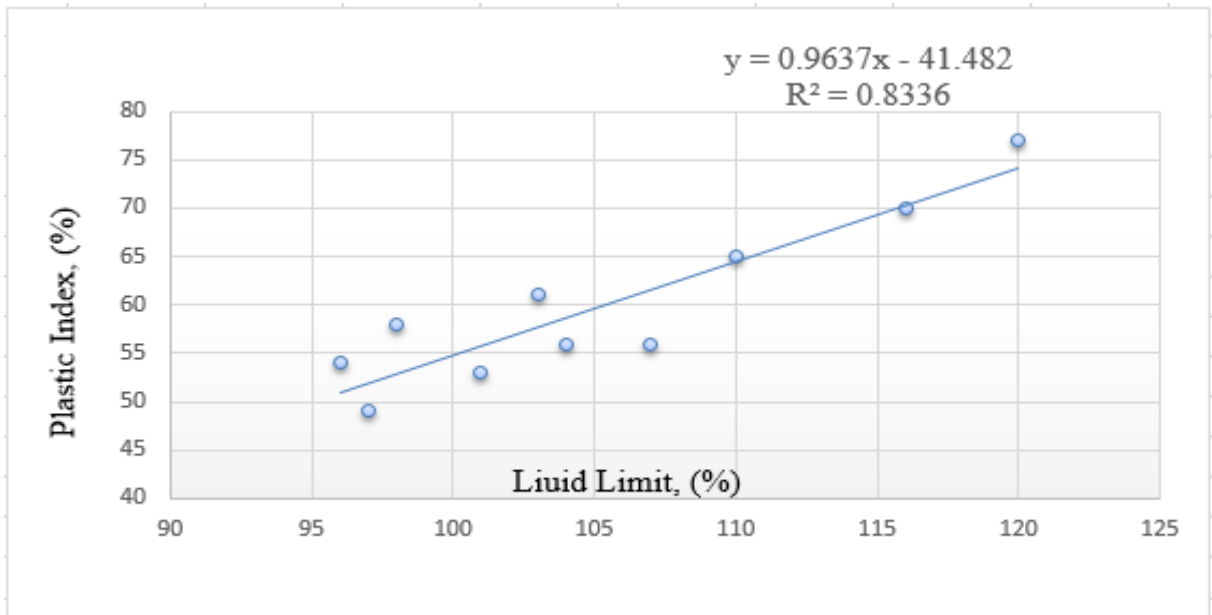


Figure 4.10 Liquid Limit vs Plastic Index

4.3.2.2 Dry Density vs Moisture Content

Dry density and moisture content are negatively correlated, when increasing value of dry density associated with decrease in moisture content value. There is inter dependency between two predictors with $R^2 = 0.847$, both dry density and moisture content can't be used in the same equation at a time.

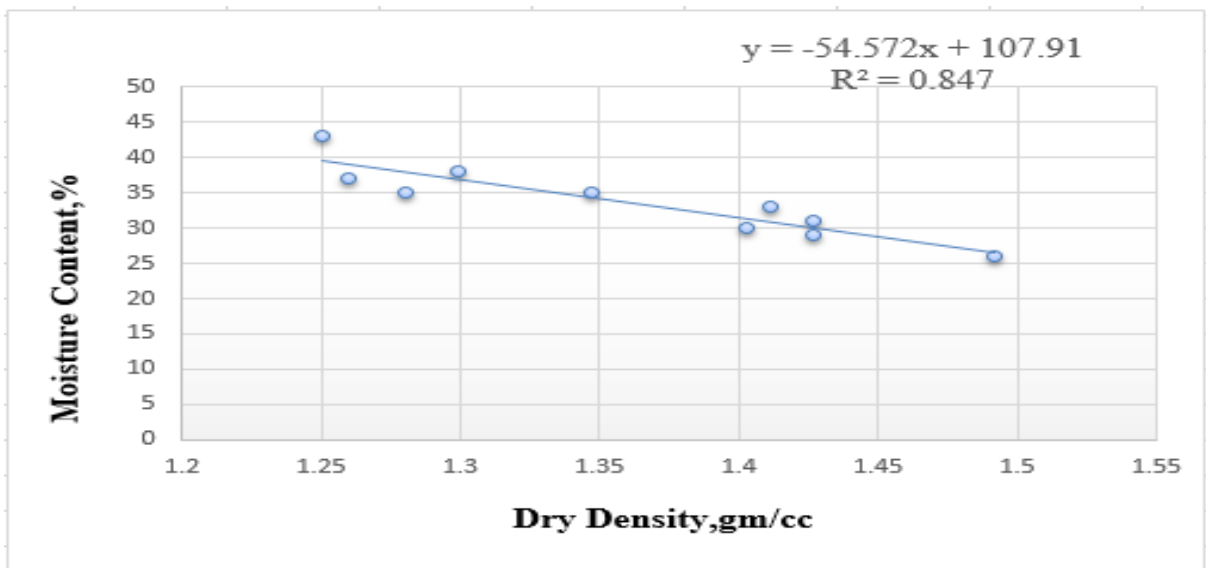


Figure 4.11 Dry Density vs moisture content

4.3.2.3 Liquid Limit vs Dry Density

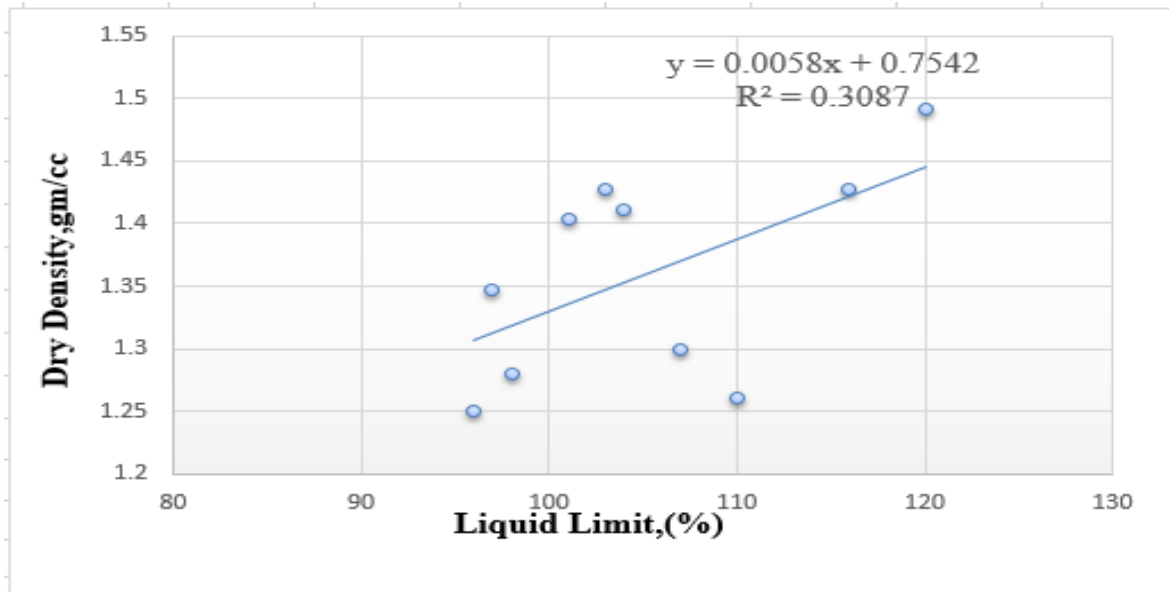


Figure 4.12 Liquid Limit vs Dry Density

4.3.2.4 Plastic Index vs Dry Density

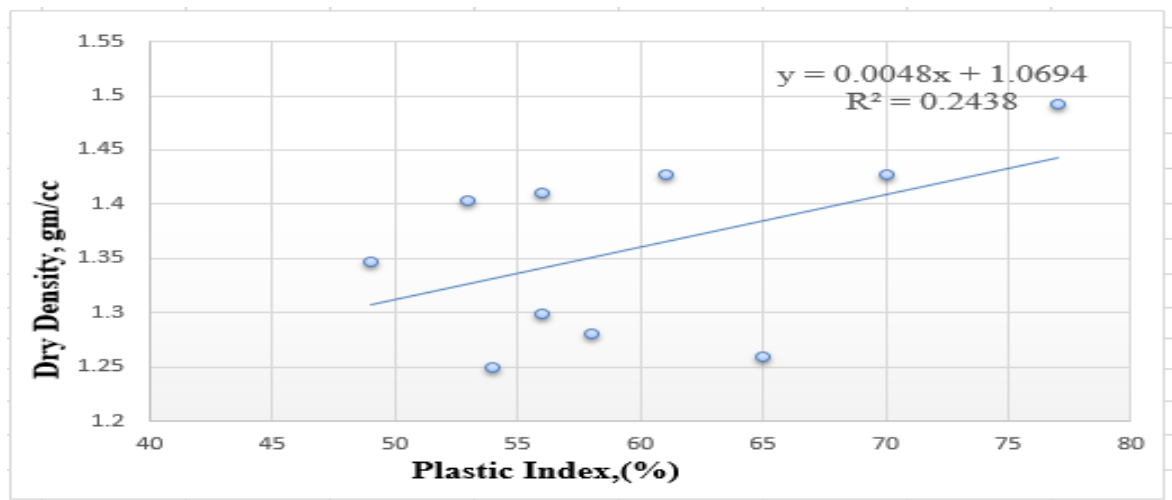


Figure 4.13 Plastic Index vs Dry Density

4.3.3 Development of ANN for Prediction of Swelling Pressure

In this paper, ANN has been adopted to predict swelling pressure by using index properties as input parameter and Swelling pressure as output (target) parameter. Both hidden and output layer has been created in MATLAB R2016a. The input parameters are varied depending on their inter-correlation degree.

Table 4. 10 Parameter used to develop ANN for prediction of swelling pressure

Trial	Input Parameter	Output (target)
1	ω , PI, C	Ps
2	PI, γ_{dry} , AC, C	Ps
3	LL, γ_{dry} , C, PL	Ps
4	LL, PI, ω , γ_{dry}	Ps
5	PI, γ_{dry}	Ps
6	γ_{dry} , ω , AC	Ps

Table 4. 11 Predicted Swelling Pressure by using ANN

Location	Depth	Ps kPa	Eqn 1	Eqn 2	Eqn 3	Eqn 4	Eqn 5	Eqn 6
Gurba	2.6m	130.89	130.95	135.22	136.43	130.89	130.89	131.02
Medanialem sefer	2m	219.46	294.86	208.654	203.10	491.88	130.89	218.22
Bubu meda	3m	158.84	177.77	159.0479	156.37	130.89	130.89	158.82
Secha H.s	3m	200.83	184.84	209.5668	200.98	130.89	491.88	200.35
Edget ber	3m	487.29	487.27	350.9831	383.97	130.89	491.88	430.15
Zuriya fird bet	2.5m	212.73	158.69	211.1988	227.46	130.89	491.88	198.97
Wubet hotel	3m	350.53	349.33	327.2855	409.96	491.88	491.88	349.28
Ajip	3m	402.53	402.53	412.1852	491.88	491.88	491.88	400.45
Derik	2.8m	447.29	443.82	472.1919	473.09	491.88	491.88	448.13
Doyisa	2.5m	491.88	491.75	475.4476	491.88	491.88	491.88	489.27

The above table showed the results of measured swelling pressure and predicted swelling pressure and the following graphs are plotted to examine the accuracy of the newly developed equations. The results of the best equations are compared with the actual measured value.

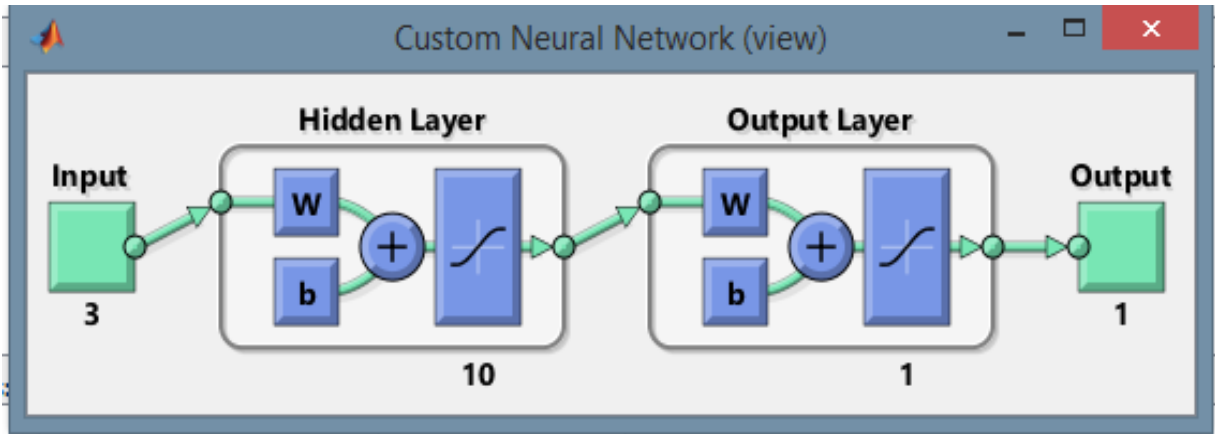


Figure 4. 14 Neural network view for trial 6

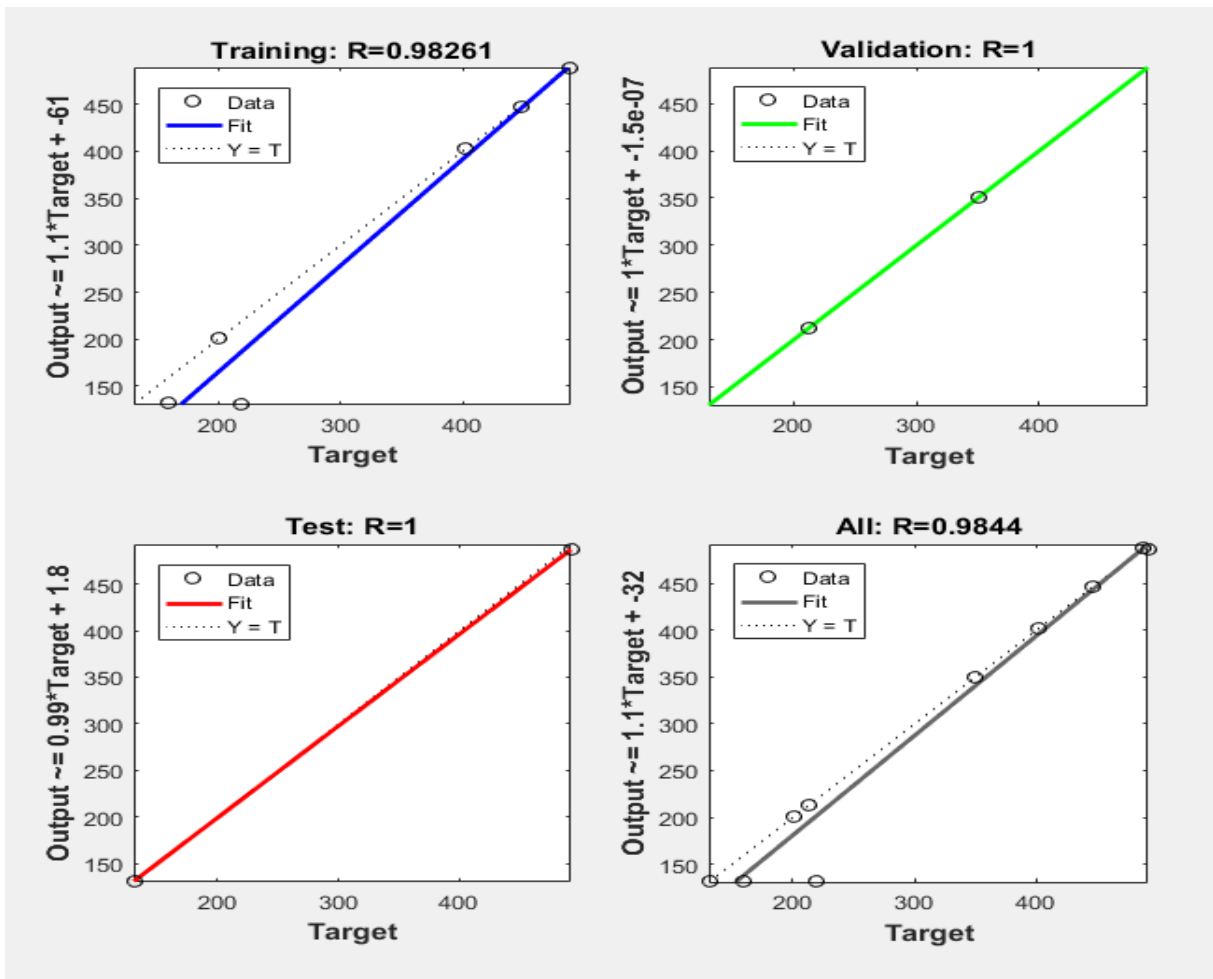


Figure 4. 15 Regression analysis for trial 6

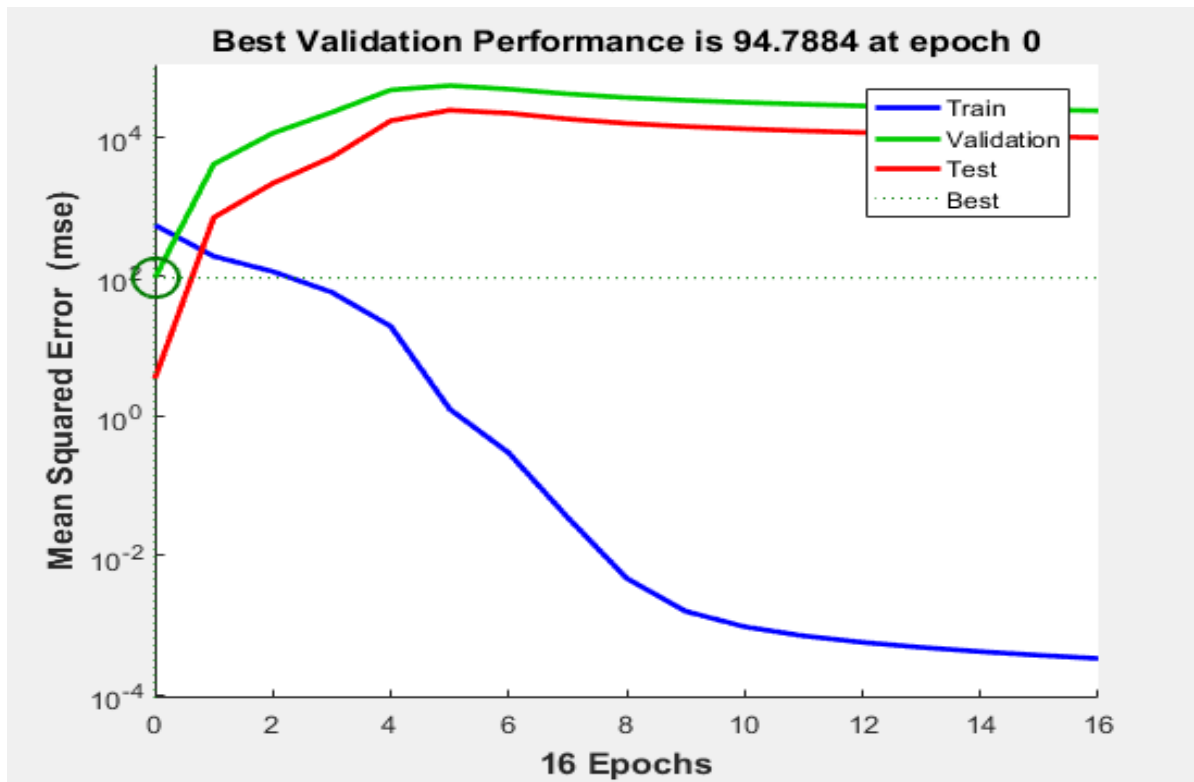


Figure 4. 16 Performance graph for trial 6

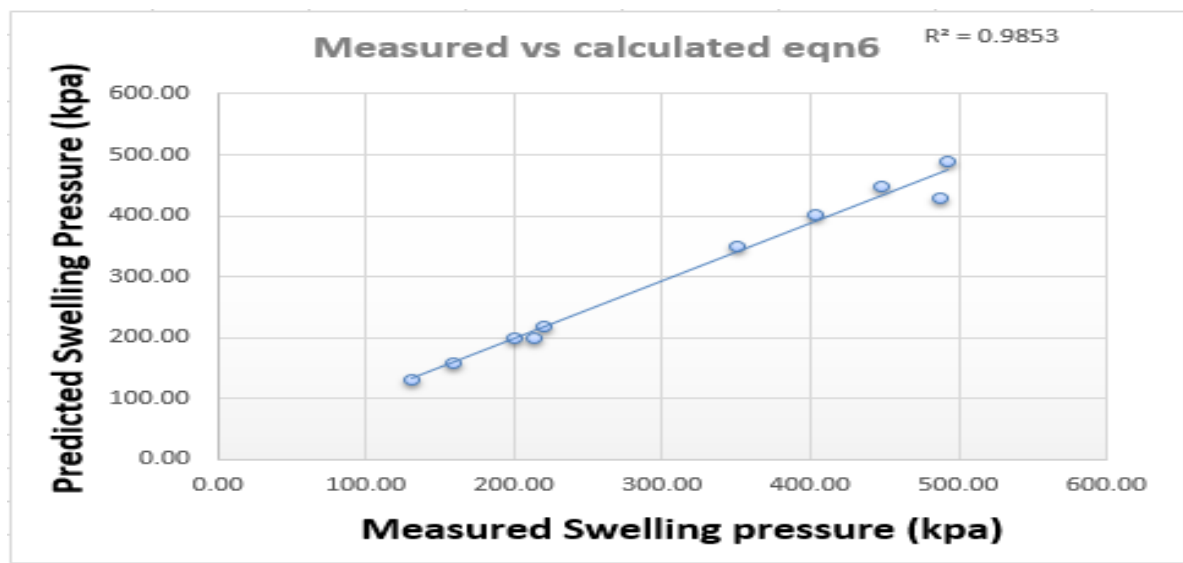


Figure 4. 17 Measured swelling pressure vs predicted swelling pressure using ANN

4.3.4 Multiple Regression Analysis using SPSS 22

Multiple regression analysis were carried out by using SPSS22.0 In order to take into account the combined effects of the soil properties on swelling parameter and to get predictive equations

with greater confidence of correlation than those obtained from simple regression, Out of these, equations with higher correlation coefficient were selected and using these equations the swelling pressure of the soil of the study area were calculated.

Table 4. 12 Data Used for Correlation

Location	Depth	LL%	PL%	PI%	Dry density (gm/c ³)	Bulk density	Mc	Ps(kPa)
Gurba	2.6m	95	42	53	1.25	1.708	43	130.89
Medanialem sefer	2m	110	45	65	1.26	1.548	37	219.46
Bubu Meda	3m	98	40	58	1.28	1.652	35	158.84
Secha H.s	3m	108	51	57	1.30	1.636	38	200.83
Edget Ber	3m	101	48	53	1.40	1.748	30	487.29
Zuriya Fird Bet	2.5m	97	48	49	1.35	1.7	35	212.73
Wubet Hotel	3m	105	48	57	1.41	1.178	33	350.53
Ajip	3m	120	43	77	1.43	1.892	31	402.53
Derik	2.8m	103	46	57	1.43	1.82	29	447.29
Doyisa	2.5m	117	49	68	1.49	1.836	26	491.88

4.3.4.1 Newly developed equations

To predict swelling pressure new empirical equation is developed by using SPSS 22, various empirical equations with different correlation coefficients obtained from the model and the one with relatively good R² value is selected.

Table 4. 13 Newly developed equations

Trial No.	Newly developed Equations	R ²
Eqn 1	$\text{LogPs} = -26.152 * \omega - 0.209 * \text{PI} - 0.496 * \text{C} + 1224.567$	0.833
Eqn 2	$\text{LogPs} = 3.829 * \text{PI} - 2.646 * \text{C} + 1559.48 * \gamma_{\text{dry}} - 203.706 * \text{Ac} - 1634.918$	0.843
Eqn 3	$\text{LogPs} = 4.147 * \text{C} + 1530.00 * \gamma_{\text{dry}} - 0.577 * \text{LL} + 2.108 * \text{PL} - 1976.795$	0.853
Eqn 4	$\text{LogPs} = 768.977 * \gamma_{\text{dry}} + 2.641 * \text{LL} - 2.501 * \text{PI} - 13.930 * \omega - 394.146$	0.877
Eqn 5	$\text{LogPs} = 1513.803 * \gamma_{\text{dry}} - 0.584 * \text{PI} - 1783.542$	0.847
Eqn 6	$\text{LogPs} = 911.041 * \gamma_{\text{dry}} - 12.429 * \omega - 48.958 * \text{Ac} - 438.845$	0.899

4.3.4.2 Predicted Swelling Pressure by using SPSS

The above anew developed equations are used to estimate the best equation, the swelling pressure were calculated. The results are shown in Table 4.14

Table 4. 14 Predicted Swelling Pressure by using SPSS

Measured Swelling Pressure Ps (kPa)	Predicted Swelling Swelling Pressure in kPa					
	Eqn 1	Eqn 2	Eqn 3	Eqn 4	Eqn 5	Eqn 6
130.89	64.38	137.13	147.63	86.51	140.25	98.17
219.46	220.46	157.70	155.62	187.24	161.81	175.38
158.84	270.77	189.92	189.57	214.90	188.00	223.05
200.83	196.12	227.76	212.99	217.89	215.59	209.20
487.29	402.98	370.09	360.67	400.96	371.28	397.74
212.73	271.89	279.16	275.22	287.70	284.17	286.08
350.53	323.06	362.58	407.09	365.74	385.14	358.54
402.53	377.13	419.57	439.51	402.57	417.53	398.62
447.29	433.77	440.63	417.47	418.62	412.28	439.75
491.88	505.62	512.93	327.37	515.25	520.02	511.30

4.3.4.3 Representation of Predicted and Measured Swelling Pressure

The following graphs are plotted to examine the accuracy of the newly developed equations. The results of the best equations are compared with the actual measured value.

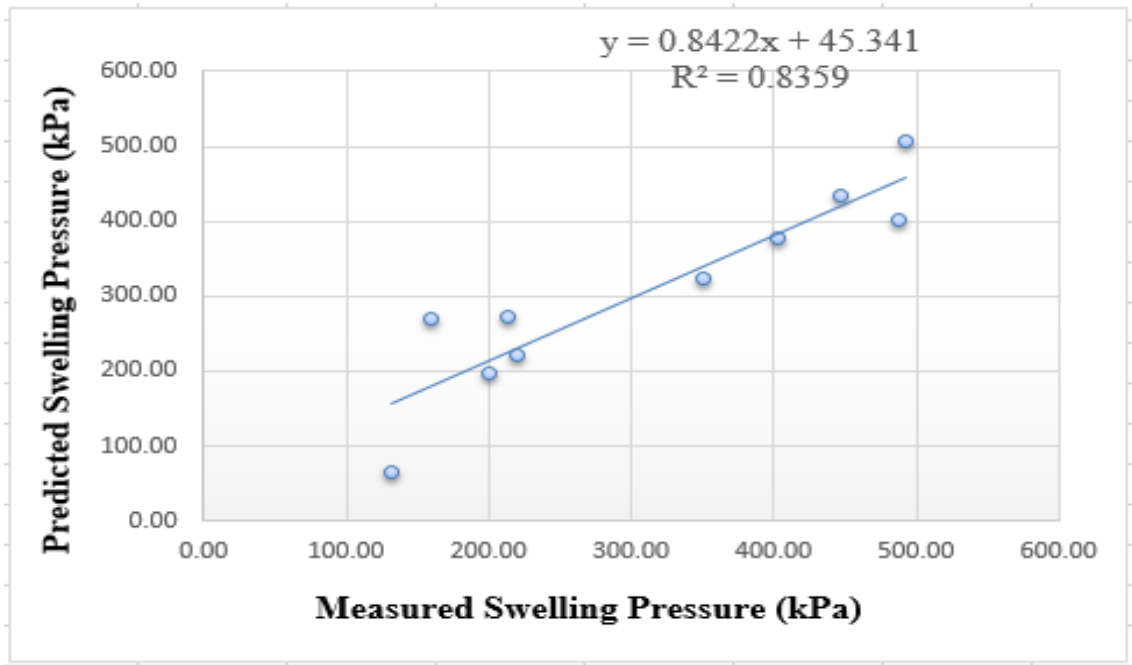


Figure 4. 18 Equation1 Predicted value vs Measured value

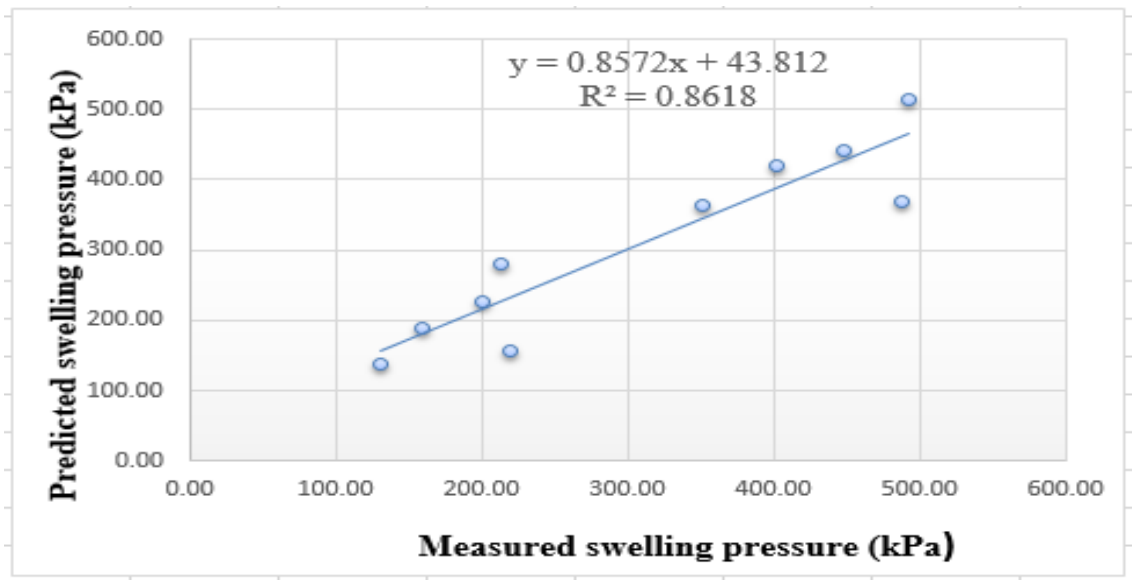


Figure 4. 19 Equation 2 Predicted vs Measured value

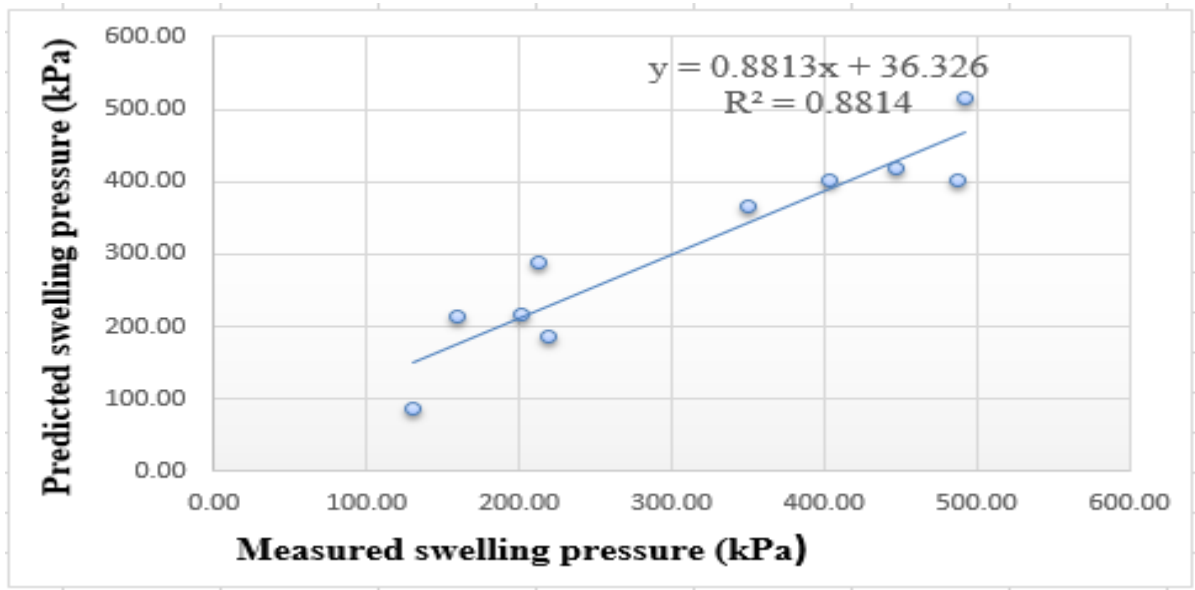


Figure 4.20 Equation3 Predicted vs Measured value

Among the above equations, the relation described by equation (trial) 6 is the closest to the measured swelling pressure with R^2 value 0.8814. And also it has parameters which could be easily determined in soil mechanics laboratories.

4.3.5 Comparison between ANN results and SPSS results

It is found that the values predicted from the ANN models match the experimental values much better than those obtained from MRA models with 0.9853 R^2 value. The performance level attained in the ANN models has also shown that the neural network is a useful tool to minimize the uncertainties encountered during the soil engineering projects. For this reason, the use of neural network may provide new approaches and methodologies.

4.3.6 Cross Validation

It's a model validation techniques for assessing how the results of a statistical analysis (model) will generalize to an independent data set. It is mainly used in settings where the goal is prediction, and one wants to estimate how accurately a predictive model will perform in practice. Newly developed equation to predict swelling pressure by using SPSS is $\text{LogPs} = 911.041 * \gamma_{\text{dry}} - 12.429 * \omega - 48.958$ with good correlation coefficient.

Table 4. 15 External data used for cross validation

Location	Depth	LL	PL	PI	Clay	Ac	Dry density	Bulk density	Mc	Ps
Bubu 2	2m	100	36	64	46.31	1.38	1.15	1.6	37	155.476
Doyisa 2	3m	113	39	74	47.3	1.56	1.45	1.86	28	520.82

Table 4.16 Cross validation by using eternal data

Location	Depth	Measured Swelling Pressure Ps (kPa)	Predicted Swelling Pressure by using eqn6 (kPa)	Difference
Bubu 2	2m	155.476	148.8662	6.60985
Doyisa 2	3m	520.82	534.0395	13.21945

4.3.7 Comparative study with previously developed equations

Attempts were made by different researchers to correlate swelling pressure with index properties. The following table show relation of previously developed equation with the study area.

Table 4. 17 Comparison of Measured Swelling Pressure with previously developed equation

Location	Depth	Measured swelling Ps kPa	Daniel Teklu		Komornik and David	Dagmawi
Gurba	2.6m	130.89	-482.477	-7.85133	297.2931	181.8854
Medanialem sefer	2m	219.46	-478.936	-7.94675	342.5538	199.5008
Bubu meda	3m	158.84	-481.11	-8.04295	322.7061	211.6489
Secha H.s	3m	200.83	-481.98	-7.97571	333.6264	200.7224
Edget ber	3m	487.29	-482.839	-8.2136	342.6733	210.4802
Zuriya fird bet	2.5m	212.73	-484.18	-8.1019	320.8996	200.1327
Wubet hotel	3m	350.53	-481.853	-8.11217	340.8438	183.7
Ajip	3m	402.53	-477.224	-8.0787	371.1849	190.6164
Derik	2.8m	447.29	-480.085	-8.19042	349.5249	220.0526
Doyisa	2.5m	491.88	-474.835	-8.17141	392.9592	190.3012

As it can be shown in Table 4.17 previously developed equation have overestimated and underestimated the properties of soil in the study area, its known that the characteristic and behavior of soil highly varied because of different factors. Equations developed for soils in one place may not work for soil in another place. Hence specific models have to be developed for specific areas in order to give fair evaluations.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this study soil found in Arba Minch town, from ten different test pit has been examined to characterize the soil type. The laboratory test result revealed that the study area is in the range of marginal expansion to highly expansive soil. Most of the soil samples in the study area have free swell value of greater than 50%. This indicated the soil in the study area is expansive with free swell value ranging from 97.5% to 155 %. The swelling pressure and swelling potential of the soils is medium to high which ranging from 130.89kPa to 502.82kPa and 5.16% to 18.75% respectively. The liquid limit of expansive soil in the research area ranged from 96 % - 120%, Plastic limit from 42%-51% and Plasticity index from 49%-77% High values of consistency limits indicated the presence of high clay content.

Efforts were made to develop artificial neural network (ANN) and multiple regression analysis (MRA) models that can be used for estimating swelling pressure. It is found that the values predicted from the ANN models match the experimental values much better than those obtained from MRA models with 0.9853 R^2 value. Therefore, swelling pressure of clay soils included in this study could be predicted using trained ANN structures as an inexpensive substitute for the laboratory testing, quite easily and efficiently. Similar ANN models can also be developed for other materials by using the same input parameters. ANN models have shown higher prediction performance than MRA models based on the performance indices. The performance level attained in the ANN models has also shown that the neural network is a useful tool to minimize the uncertainties encountered during the soil engineering projects. For this reason, the use of neural network may provide new approaches and methodologies.

5.2 Recommendation

Expansive soil characterization of the study area has to be carried out by conducting different mineralogical identification methods, to know the mineralogical composition of the area and classify soil according to mineralogical composition, because the soil classification showed that some of the study area is in the region of silt soil however, it behaves like highly clay soil.

In this thesis, different samples of soil were collected only from ten test pits, by increasing the number of sampling area and varying the depth of sampling further detailed investigation has to be carried out on disturbed and undisturbed soil samples.

Newly developed empirical equation is recommended for small projects and preliminary design only, for huge construction swelling pressure should be conducted in the laboratory to get reliable result about the area.

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APPENDIX

APPENDIX A: Analysis and Laboratory test results of Moisture Content

Table A.1: Determination of moisture content for test pit TP2 (Medaniale, sefer)

Gurba Kebele Oven Dry		
Depth	2.6m	
Container no	1K	6K
Mass of container(M1),gm	27	19
Mass of container+ wet soil(M2),gm	74	70
Mass of container + dry soil(M3),gm	56.5	59
Mass of water(M2-M3),gm	17.5	11
Mass of dry soil(M3-M1),gm	29.5	40
Moisture content	59.32	27.50
Average moisture content	43.41	
Gurba Kebele Air Dry		
Container no	EK	2K
Mass of container(M1),gm	27	27
Mass of container+ wet soil(M2),gm	78	70
Mass of container + dry soil(M3),gm	59	62
Mass of water(M2-M3),gm	19	8
Mass of dry soil(M3-M1),gm	32	35
Moisture content (%)	59.38	22.86
Average moisture content (%)	41.12	

Table A-2 Determination of moisture content for test pit TP2 (Medaniale, sefer)

Medanialem Sefer Oven Dry		
Depth	2m	
Container no	2	AK
Mass of container(M1),gm	27	19
Mass of container+ wet soil(M2),gm	166	119
Mass of container + dry soil(M3),gm	138	100
Mass of water(M2-M3),gm	28	19
Mass of dry soil(M3-M1),gm	111	81
Moisture content	25.23	23.46
Average moisture content	36.95	
Medanialem Sefer Air Dry		
Container no	T	4K
Mass of container(M1),gm	27	17
Mass of container+ wet soil(M2),gm	164	137
Mass of container + dry soil(M3),gm	136	120
Mass of water(M2-M3),gm	28	17
Mass of dry soil(M3-M1),gm	109	103
Moisture content (%)	25.69	16.50
Average moisture content (%)	33.94	
Total Moisture Difference (%)	3.01	

Table A. 3: Determination of moisture content for test pit TP3 (Bubu meda)

Bubu Meda Oven Dry		
Depth	3m	
Container no	LK	AK
Mass of container(M1),gm	27	19
Mass of container+ wet soil(M2),gm	162	130
Mass of container + dry soil(M3),gm	118	110
Mass of water(M2-M3),gm	44	20
Mass of dry soil(M3-M1),gm	91	91
Moisture content	48.35	21.98
Average moisture content	35.16	
Bubu Meda Air Dry		
Container no	F1	AK
Mass of container(M1),gm	28	19
Mass of container+ wet soil(M2),gm	158	128
Mass of container + dry soil(M3),gm	120	99
Mass of water(M2-M3),gm	38	29
Mass of dry soil(M3-M1),gm	92	80
Moisture content (%)	41.30	36.25
Average moisture content (%)	38.78	
Total Moisture Difference (%)	3.61	

Table A. 4 Determination of moisture content for test pit TP4 (Secha h.s)

Secha Oven Dry		
Depth	3m	
Container no	12K	KAA
Mass of container(M1),gm	28	26
Mass of container+ wet soil(M2),gm	157	140
Mass of container + dry soil(M3),gm	121	109
Mass of water(M2-M3),gm	36	31
Mass of dry soil(M3-M1),gm	93	83
Moisture content	38.71	37.35
Average moisture content	38.03	
Secha Air Dry		
Container no	wk	wa
Mass of container(M1),gm	27	27
Mass of container+ wet soil(M2),gm	154	160
Mass of container + dry soil(M3),gm	117	127
Mass of water(M2-M3),gm	37	33
Mass of dry soil(M3-M1),gm	90	100
Moisture content (%)	41.11	33.00
Average moisture content (%)	37.06	
Total Moisture Difference (%)	0.97	

Table A. 5 Determination of moisture content for test pit TP5 (Zuriya fird bet)

Zuriya Fird Bet Oven Dry		
Depth	2.5m	
Container no	wk	wa
Mass of container(M1),gm	28	27
Mass of container+ wet soil(M2),gm	165	176
Mass of container + dry soil(M3),gm	131	135
Mass of water(M2-M3),gm	34	41
Mass of dry soil(M3-M1),gm	103	108
Moisture content	33.01	37.96
Average moisture content	35.49	
Zuriya Fird Bet Air Dry		
Container no	wk	wa
Mass of container(M1),gm	28	28
Mass of container+ wet soil(M2),gm	109	136
Mass of container + dry soil(M3),gm	85	110
Mass of water(M2-M3),gm	24	26
Mass of dry soil(M3-M1),gm	57	82
Moisture content (%)	42.11	31.71
Average moisture content (%)	36.91	
Total Moisture Difference (%)	1.42	

Table A. 6 Determination of moisture content for test pit TP6 (Wubete hotel)

Wubet Oven dry		
Container no	12q	3r
Mass of container(M1),gm	27	28
Mass of container+ wet soil(M2),gm	143	140
Mass of container + dry soil(M3),gm	126	103
Mass of water(M2-M3),gm	17	37
Mass of dry soil(M3-M1),gm	99	75
Moisture content	17.17	49.33
Average moisture content	33.25	
Wubet Air Dry		
Depth	3m	
Container no	wk	wa
Mass of container(M1),gm	20	28
Mass of container+ wet soil(M2),gm	125	152
Mass of container + dry soil(M3),gm	102	120
Mass of water(M2-M3),gm	23	32
Mass of dry soil(M3-M1),gm	82	92
Moisture content (%)	28.05	34.78
Average moisture content (%)	31.42	
Total Moisture Difference (%)	1.83	

Table A. 7 Determination of moisture content for test pit TP7 (Edget ber)

Edget Oven Dry		
Depth	3m	
Container no	yy	wa
Mass of container(M1),gm	19	27
Mass of container+ wet soil(M2),gm	139	155
Mass of container + dry soil(M3),gm	121	117
Mass of water(M2-M3),gm	19	38
Mass of dry soil(M3-M1),gm	102	90
Moisture content	18.23	42.22
Average moisture content	30.22	
Edget Air Dry		
Container no	wk	wa
Mass of container(M1),gm	20	28
Mass of container+ wet soil(M2),gm	120	153
Mass of container + dry soil(M3),gm	96	120
Mass of water(M2-M3),gm	24	33
Mass of dry soil(M3-M1),gm	76	92
Moisture content (%)	31.58	35.87
Average moisture content (%)	33.72	
Total Moisture Difference (%)	3.5	

Table A. 8 Determination of moisture content for test pit TP8 (Ajip)

Ajip Oven		
Depth 3m		
Container no	1K	6K
Mass of container(M1),gm	28	26
Mass of container+ wet soil(M2),gm	149	140
Mass of container + dry soil(M3),gm	114	120
Mass of water(M2-M3),gm	35	20
Mass of dry soil(M3-M1),gm	86	94
Moisture content	41	21
Average moisture content	30.99	
Ajip Air Dry		
Container no	AW	AK
Mass of container(M1),gm	27	26
Mass of container+ wet soil(M2),gm	135	145
Mass of container + dry soil(M3),gm	100	129
Mass of water(M2-M3),gm	35	16
Mass of dry soil(M3-M1),gm	73	103
Moisture content (%)	48	16
Average moisture content (%)	31.74	
Total Moisture Difference (%)	0.75	

Table A. 9 Determination of moisture content for test pit TP9 (Derik)

Derik Oven Dry		
Depth	2.8m	
Container no	C1	7P
Mass of container(M1),gm	27.5	28
Mass of container+ wet soil(M2),gm	141	140
Mass of container + dry soil(M3),gm	117	113
Mass of water(M2-M3),gm	24	27
Mass of dry soil(M3-M1),gm	90	85
Moisture content (%)	26.82	31.76
Average moisture content (%)	29.29	
Derik Air Dry		
Container no	F1	6Z
Mass of container(M1),gm	30	28
Mass of container+ wet soil(M2),gm	145	128
Mass of container + dry soil(M3),gm	116	106
Mass of water(M2-M3),gm	29	22
Mass of dry soil(M3-M1),gm	86	78
Moisture content (%)	33.72	28.21
Average moisture content (%)	30.96	
Total Moisture Difference (%)	1.67	

Table A. 10 Determination of moisture content for test pit TP10 (Doyisa)

Doyisa Oven Dry		
Depth	2m	
Container no	ZZ	7Z
Mass of container(M1),gm	26	17
Mass of container+ wet soil(M2),gm	135	120
Mass of container + dry soil(M3),gm	116	95
Mass of water(M2-M3),gm	19	25
Mass of dry soil(M3-M1),gm	90	78
Moisture content	21.11	31.41
Average moisture content	26.26	
Doyisa Air Dry		
Container no	AA	KA1
Mass of container(M1),gm	27	17
Mass of container+ wet soil(M2),gm	146	143
Mass of container + dry soil(M3),gm	130	106
Mass of water(M2-M3),gm	16	37
Mass of dry soil(M3-M1),gm	103	89
Moisture content (%)	15.53	41.57
Average moisture content (%)	28.55	
Total Moisture Difference (%)	2.29	

APENDIX B: Analysis and Laboratory test results of Specific gravity

Table B. 1 Determination of specific gravity for test pit TP1 (Gurba kebele); Depth 2.6m

Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	90	90
Mass of Pycnometer, M_p (g)	25.0	25.0
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	21.8	21.9
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99782	0.99780
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	74.0	74.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	83.5	87.0
G (at Testing Temperature)	2.727	2.857
Correction Factor	0.99961	0.99959
G (at 20 $^{\circ}\text{C}$)	2.726	2.856
G_{avg} (at 20 $^{\circ}\text{C}$)	2.79	

Table B. 2 Determination of specific gravity for test pit TP2 (Medanialem sefer); Depth 2m

Test Data Medanialem		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	97	97
Mass of Pycnometer, M_p (g)	23.0	23.0
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	20.8	20.9
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99804	0.99802
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	73.0	73.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	83.0	85.0
G (at Testing Temperature)	3.000	2.500
Correction Factor	0.99983	0.99981
G (at 20 $^{\circ}\text{C}$)	2.999	2.500
G_{avg} (at 20 $^{\circ}\text{C}$)	2.75	

Table B. 3 Determination of specific gravity for test pit TP3 (Bubu meda); Depth 3m

Test Data Bubu Meda		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	90	90
Mass of Pycnometer, M_p (g)	25.0	25.0
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	21.1	21.2
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99797	0.99795
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	74.0	74.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	83.5	86.0
G (at Testing Temperature)	2.727	2.500
Correction Factor	0.99977	0.99974
G (at 20 $^{\circ}\text{C}$)	2.727	2.499
G_{avg} (at 20 $^{\circ}\text{C}$)	2.61	

Table B. 4 Determination of specific gravity for test pit TP4 (Secha H.s); Depth 3m

Test Data Secha .H.S		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	90	97
Mass of Pycnometer, M_p (g)	25.0	25.0
Mass of Soil Sample, M_s (g)	20.0	15.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	20.8	20.9
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99804	0.99802
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	73.5	73.5
Mass of Pycnometer + Water + Soil, M_{pws} (g)	84.5	84.0
G (at Testing Temperature)	2.222	3.333
Correction Factor	0.99983	0.99981
G (at 20 $^{\circ}\text{C}$)	2.222	3.333
G_{avg} (at 20 $^{\circ}\text{C}$)	2.78	

Table B. 5 Determination of specific gravity for test pit TP5 (Zuriya fird bet); Depth 2.5m

Test Data Zuriya fird bet		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	97	97
Mass of Pycnometer, M_p (g)	23.0	23.0
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	21.4	21.5
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99791	0.99789
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	73.0	73.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	83.5	84.0
G (at Testing Temperature)	3.333	2.222
Correction Factor	0.99970	0.99968
G (at 20 $^{\circ}\text{C}$)	3.332	2.222
G_{avg} (at 20 $^{\circ}\text{C}$)	2.78	

Table B. 6 Determination of specific gravity for test pit TP6 (Wubet hotel); Depth 3m

Test Data Wubet Hotel		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	90	90
Mass of Pycnometer, M_p (g)	25.0	25.0
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	20.7	20.8
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99806	0.99804
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	74.0	74.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	84.0	86.0
G (at Testing Temperature)	3.000	2.500
Correction Factor	0.99985	0.99983
G (at 20 $^{\circ}\text{C}$)	3.000	2.500
G_{avg} (at 20 $^{\circ}\text{C}$)	2.75	

Table B. 7 Determination of specific gravity for test pit TP7 (Edget ber kebele); Depth 3m

Test Data Eget Ber		
Testing Standard:	method a(oven dry)	
Test No.	1	2
Pycnometre No.	99	99
Mass of Pycnometer, M_p (g)	24.5	24.5
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	21.6	21.7
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99786	0.99784
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	73.0	73.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	83.5	83.5
G (at Testing Temperature)	3.333	2.105
Correction Factor	0.99966	0.99963
G (at 20 $^{\circ}\text{C}$)	3.332	2.104
G_{avg} (at 20 $^{\circ}\text{C}$)	2.72	

Table B. 8 Determination of specific gravity for test pit TP8 (Ajip); Depth 3m

Test Data Ajip		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	90	90
Mass of Pycnometer, M_p (g)	63.0	63.0
Mass of Soil Sample, M_s (g)	32.0	31.5
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	26.0	26.0
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99679	0.99679
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	162.0	162.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	182.5	181.0
G (at Testing Temperature)	2.783	2.520
Correction Factor	0.99858	0.99858
G (at 20 $^{\circ}\text{C}$)	2.779	2.516
G_{avg} (at 20 $^{\circ}\text{C}$)	2.65	

Table B. 9 Determination of specific gravity for test pit TP9 (Derik); Depth 2.8m

Test Data Derik		
Testing Standard:ASTM	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	A1	A8
Mass of Pycnometer, M_p (g)	65.0	65.0
Mass of Soil Sample, M_s (g)	32.0	32.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	26.0	26.0
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99679	0.99679
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	162.0	162.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	182.0	182.0
G (at Testing Temperature)	2.667	2.667
Correction Factor	0.99858	0.99858
G (at 20 $^{\circ}\text{C}$)	2.663	2.663
G_{avg} (at 20 $^{\circ}\text{C}$)	2.66	

Table B. 10 Determination of specific gravity for test pit TP10 (Doyisa kebele); Depth 2m

Test Data Doyisa		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	A1	A8
Mass of Pycnometer, M_p (g)	63.0	63.0
Mass of Soil Sample, M_s (g)	32.5	32.5
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	20.8	20.9
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99804	0.99802
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	162.0	162.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	182.0	183.0
G (at Testing Temperature)	2.600	2.826
Correction Factor	0.99983	0.99981
G (at 20 $^{\circ}\text{C}$)	2.600	2.826
G_{avg} (at 20 $^{\circ}\text{C}$)	2.71	

Table B.11 Determination of specific gravity for test pit TP3 (Bubu Meda 2); Depth 2m

Test Data Bubu 2		
Testing Standard:	Method A (Oven Dried Specimen)	
Test No.	1	2
Pycnometre No.	90	90
Mass of Pycnometer, M_p (g)	25.0	25.0
Mass of Soil Sample, M_s (g)	15.0	20.0
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	21.1	21.2
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99797	0.99795
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	74.0	74.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	83.0	86.5
G (at Testing Temperature)	2.500	2.667
Correction Factor	0.99977	0.99974
G (at 20 $^{\circ}\text{C}$)	2.499	2.666
G_{avg} (at 20 $^{\circ}\text{C}$)	2.58	

Table B.12 Determination of specific gravity for test pit TP10 (Doyisa Kebele 2); Depth 3m

Test Data Doyisa2		
Testing Standard:	Method A (Oven Dried Specimen)	
	1	2
Test No.	1	2
Pycnometre No.	90	90
Mass of Pycnometer, M_p (g)	63.0	64.0
Mass of Soil Sample, M_s (g)	32.5	32.5
Calibrated Volume of Pycnometer, V_p (ml)	99.930	99.930
Testing Temperature, T ($^{\circ}\text{C}$)	20.8	20.9
Density of Water at Testing Temperature, ρ_w (g/cm^3)	0.99804	0.99802
Calibrated Mass of Pycnometer + Water, M_{pw} (g)	162.0	162.0
Mass of Pycnometer + Water + Soil, M_{pws} (g)	182.5	183.5
G (at Testing Temperature)	2.708	2.955
Correction Factor	0.99983	0.99981
G (at 20 $^{\circ}\text{C}$)	2.708	2.954
G_{avg} (at 20 $^{\circ}\text{C}$)	2.83	

APENDIX C: Analysis and Laboratory test results of Free Swell

Formula used

$$Fs = \frac{(V-V_0)}{V_0} \times 100 (\%)$$

Where: Fs = Free Swell

V = Final Volume after swell

V₀ = Volume of dry soil, 10 cm³

Table C. 1 Free Swell test result for test pit TP1 (Gurba Kebele)

Test Pit Gurba		
Sample	1	2
Initial volume	10	10
Final volume	19.5	20
Free swell %	95	100
Average free swell%	97.5	

Table C. 2 Free Swell test result for test pit TP2 (Medanialem Sefer)

Test Pit Medanialem		
Sample	1	2
Initial volume	10	10
Final volume	22.5	20.5
Free swell %	125	105
Average free swell%	115	

Table C. 3 Free Swell test result for test pit TP3 (Bubu Meda)

Test Pit Bubu		
Sample	1	2
Initial volume	10	10
Final volume	21.5	20
Free swell %	115	100
Average free swell%	107.5	

Table C. 4 Free Swell test result for test pit TP4 (Secha H.s)

Test Pit Secha		
Sample	1	2
Initial volume	10	10
Final volume	22.5	23
Free swell %	125	130
Average free swell%	127.5	

Table C. 5 Free Swell test result for test pit TP5 (Zuria fird bet)

Test Pit Zuriya Fird Bet		
Sample	1	2
Initial volume	10	10
Final volume	19.5	20.5
Free swell %	95	105
Average free swell%	100	

Table C. 6 Free Swell test result for test pit TP6 (Wubet Hotel)

Test Pit Wubet Hotel		
Sample	1	2
Initial volume	10	10
Final volume	21	23
Free swell %	110	130
Average free swell%	120	

Table C. 7 Free Swell test result for test pit TP7 (Edet Ber Kebele)

Test pit Edget ber		
Sample	1	2
Initial volume	10	10
Final volume	21.5	22
Free swell %	115	120
Average free swell%	117.5	

Table C. 8 Free Swell test result for test pit TP8 (Ajip)

Test Pit Ajip		
Sample	1	2
Initial volume	10	10
Final volume	25	23
Free swell %	150	130
Average free swell%	140	

Table C. 9 Free Swell test result for test pit TP9 (Derik)

Test Pit Derik		
Sample	1	2
Initial volume	10	10
Final volume	25	24
Free swell %	150	140
Average free swell%	145	

Table C. 10 Free Swell test result for test pit TP10 (Doyisa Kebele)

Test Pit Doyisa		
Sample	1	2
Initial volume	10	10
Final volume	24.5	24
Free swell %	145	140
Average free swell%	142.5	

Table C. 11 Free Swell test result for test pit TP10 (Doyisa Kebele 2)

Test pit doyisa2		
Sample		
Initial volume	10	10
Final volume	25	26
Free swell %	150	160
Average free swell%	155	

Table C. 11 Free Swell test result for test pit TP3 (Bubu Meda 2)

Test Pit Bubu2		
Sample		
Initial volume	10	10
Final volume	20	20.5
Free swell %	100	105
Average free swell%	102.5	

APENDIX D: Analysis and Laboratory test results of Atterberg Limit

Table D. 1 Liquid limit and plastic limit for test pit TP1 (Gurba Kebele)

Test Type		Liquid Limit %				Plastic Limit %	
Trial		1	2	3	4	2	3
No.of Blows	N	32	27	24	15		
Can No.	n	DA4	Gt 24	Z10	Gt22	TA1	G8
Wt. Can + Wet Soil	g	67	63	67	67.5	30	29
Wt Can + Dry Soil	g	48	46	47	46.5	29	28
Wt. water	g	19	17	20	21	1	1
Wt. of Can	g	27	28	26	26	26	26
Wt. of Dry Soil	g	21	18	21	20.5	3	2
No.of Blows	N	32	27	24	15		
Moisture Content	%	90.48	94.44	95.24	102.44	33.33	50.00
Average %		96				42	

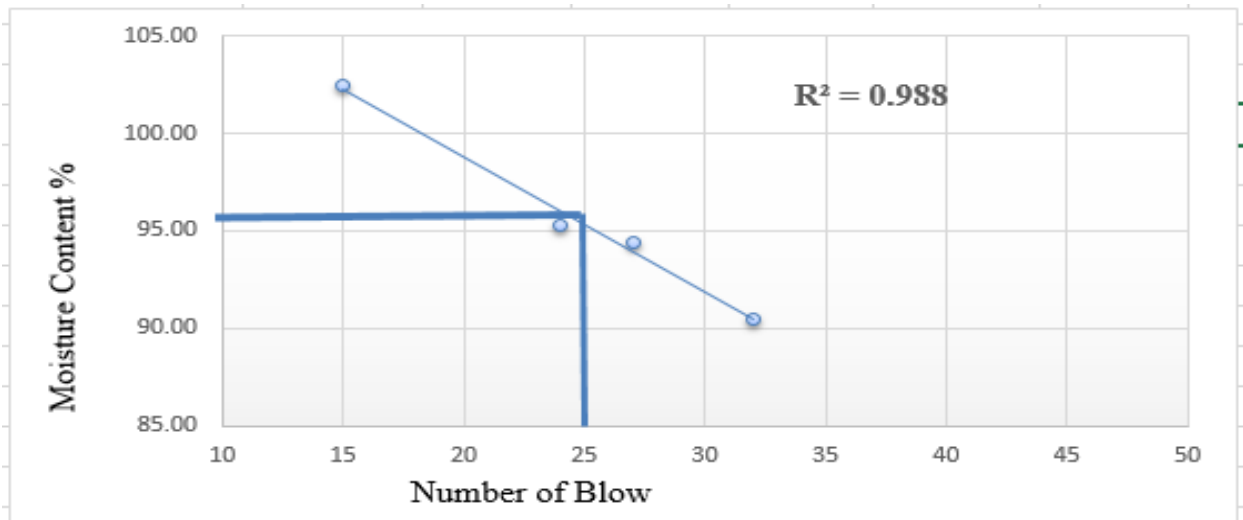


Figure D. 1 Water Content Vs log number of Blows for Test Pit TP1 (Gurba kebele)

Table D. 2 Liquid limit and plastic limit for test pit TP2 (Medanialem Sefer)

Test type	Liquid limit %				Plastic limit %	
	1	2	3	4	1	2
Trial						
No.of Blows N	33	27	24	16		
Can n	Z71	P32	D15	R30	29	35
Wt. Can + Wet Soil g	72.5	68	72	65	33	39
Wt Can + Dry Soil g	50	47.5	47.5	38	31.5	35
Wt. water g	22.5	20.5	24.5	27	1.5	4
Wt. of Can g	28	28	26	15	27	28
Wt. of Dry Soil g	22	19.5	21.5	23	4.5	7
No.of Blows N	33	27	24	16		
Moisture Content %						
	102.27	105.13	113.95	117.39	33.33	57.14
Average %	110				45	

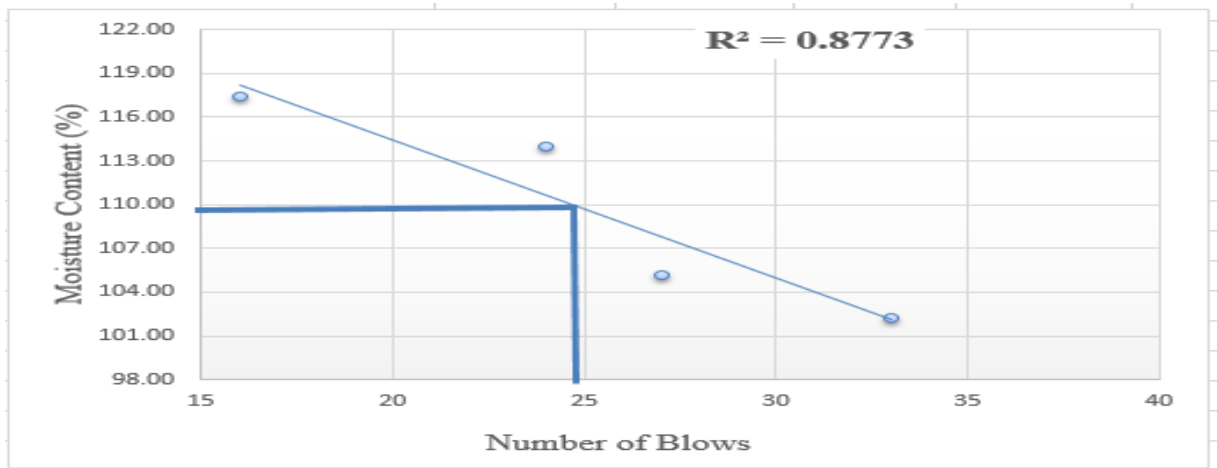


Figure D. 2 Water content Vs log number of blows for test pit TP2 (Medanialem Sefer)

Table D. 3 Liquid limit and plastic limit for test pit TP3 (Bubu meda)

Test type	Liquid limit				Plastic limit		
	1	2	3	4	1	2	
Trial number							
No.of Blows	N	34	29	21	17		
Can	n	P25	28k	Tca	R71	180	
Wt. Can + Wet Soil	g	61	63	55	50	28	
Wt Can + Dry Soil	g	40	43	35	32	25	
Wt. water	g	21	20	20	18	3	
Wt. of Can	g	17	22	15	15	19	
Wt. of Dry Soil	g	23	21	20	17	6	
No.of Blows	N	34	29	21	17		
Moisture Content	%	91.30	95.24	100.00	105.88	50.00	
Average (%)		98				40	

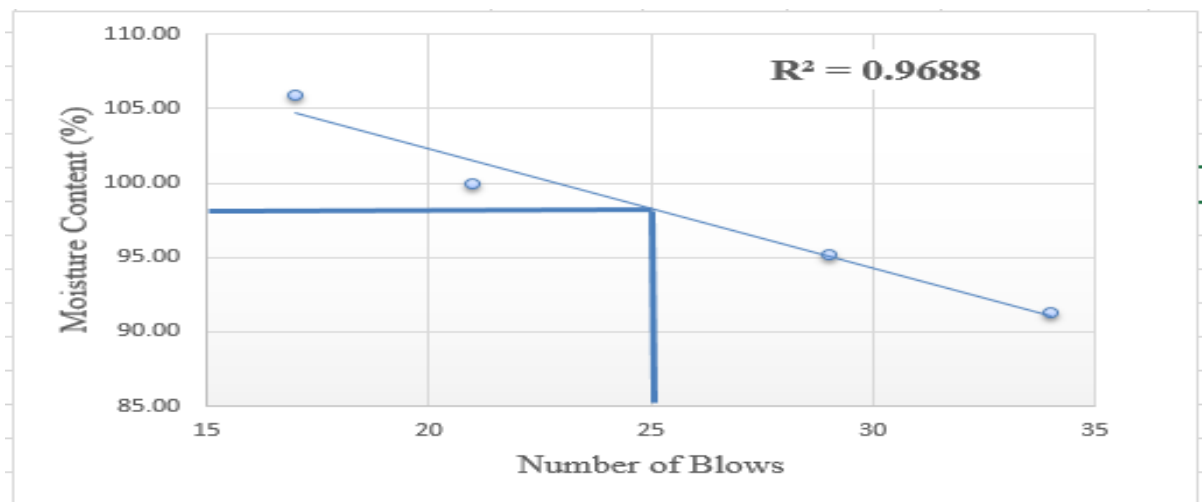


Figure D. 3 Water content Vs log Number of blows for test pit TP3 (Bubu Meda)

Table D. 4 Liquid limit and plastic limit for test pit TP4 (Secha H.s)

Test type	Liquid limit %				Plastic limit%		
	Trial	1	2	3	4	1	2
No.of Blows	N	32	29	23	19		
Can	n	Zst	Vc2	Yu5	Wq1	197	57
Wt. Can + Wet Soil	g	45	63	66.5	58	31	29
Wt Can + Dry Soil	g	30	44.5	46	42	28	25.5
Wt. water	g	15	18.5	20.5	16	3	3.5
Wt. of Can	g	15	27	27	28	20	20
Wt. of Dry Soil	g	15	17.5	19	14	8	5.5
No.of Blows	N	34	26	22	20		
Moisture Content	%	100	106	108	114	38	64
Average (%)		107				51	

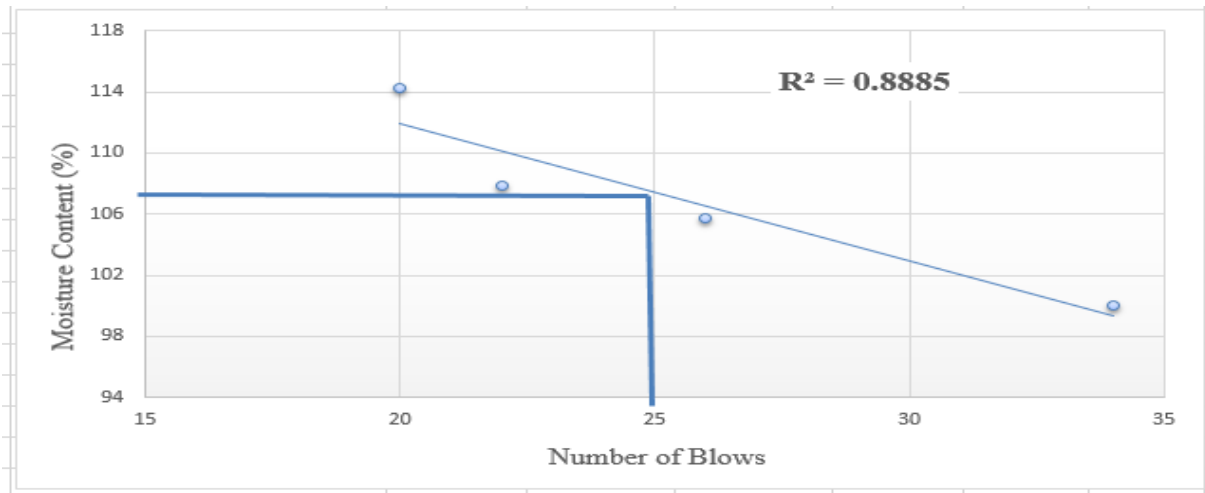


Figure D. 4 Water content Vs log number of blows for test pit TP4 (Secha H.s)

Table D. 5 Liquid limit and plastic limit for test pit TP5 (Zuriya Fird Bet)

Test type		Liquid limit %				Plastic limit %	
Trial		1	2	3	4	1	2
No.of Blows	N	33	27	23	18		
Can	n	Vs6	7zt	5st	28m	96	64
Wt. Can + Wet Soil	g	63	75.5	67	64	31	32.5
Wt Can + Dry Soil	g	46	52.5	47	46	30	30
Wt. water	g	17	23	20	18	1	2.5
Wt. of Can	g	28	28	27	28.5	27	26
Wt. of Dry Soil	g	18	24.5	20	17.5	3	4
No.of Blows	N	33	27	23	18		
Moisture Content	%	94.44	93.88	100.00	102.86	33.33	62.50
Average %		98				48	

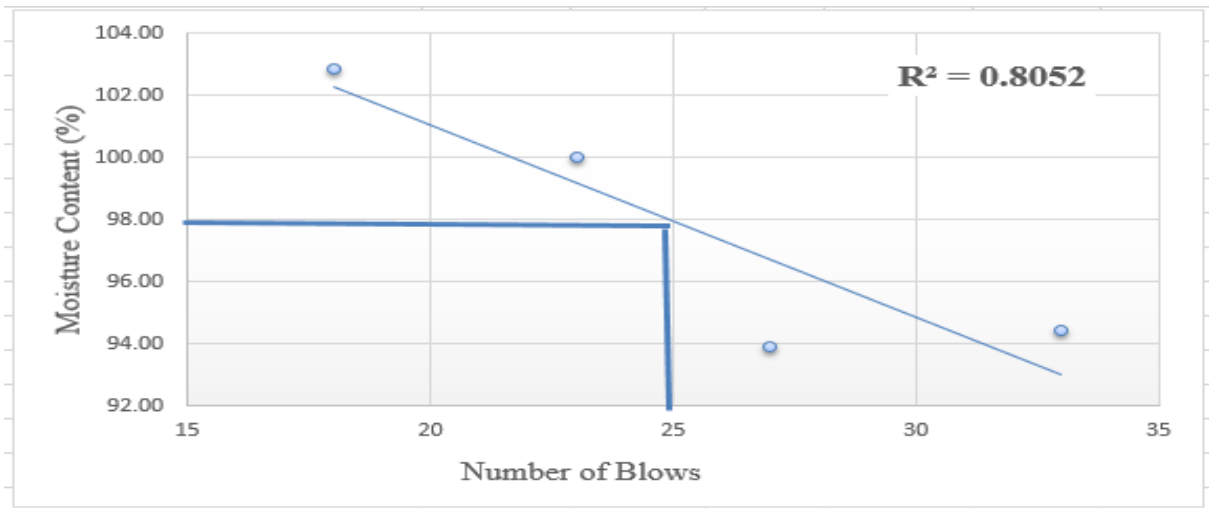


Figure D. 5 Water content Vs log number of blows for test pit TP5 (Zuriya fird bet)

Table D. 6 Liquid limit and plastic limit for test pit TP6 (Wubet Hotel)

Test type	Liquid limit %				Plastic limit %	
	1	2	3	4	1	2
Trial						
No. of Blows N	33	27	24	19		
Can n	P11	R65	D12	T39	114	118
Wt. Can + Wet Soil g	40	41	49	42	16	22
Wt Can + Dry Soil g	28.5	30	36	27.5	14	21
Wt. water g	11.5	11	13	14.5	2	1
Wt. of Can g	16	19	24	15	9	19
Wt. of Dry Soil g	12.5	11	12	12.5	5	2
No. of Blows N	33	27	24	19		
Moisture Content %	92.00	100.00	108.33	116.00	40.00	50.00
Average %	104				45	

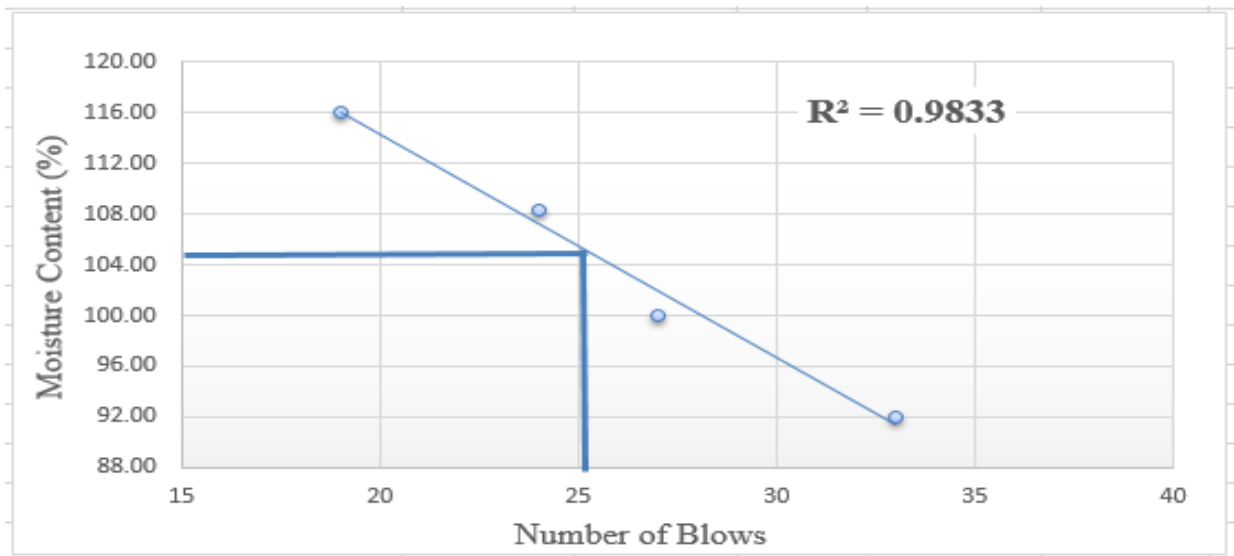


Figure D. 6 Water content Vs log number of blows for test pit TP5 (Wubet hotel)

Table D. 7 Liquid limit and Plastic Limit for test pit TP7 (Edget Ber)

Test type		Liquid Limit%				Plastic Limit%	
Trial number		1	2	3	4	1	2
No. of Blows	N	34	29	22	18		
Can	n	R20	5rm	4rx	A8t	38	45
Wt. Can + Wet Soil	g	70	71	45	35	34	34
Wt Can + Dry Soil	g	49.5	49.7	32.8	24.8	30.5	31
Wt. water	g	20.5	21.3	12.2	10.2	3.5	3
Wt. of Can	g	28	28	21	15	23	25
Wt. of Dry Soil	g	21.5	21.7	11.8	9.8	7.5	6
No. of Blows	N	34	29	22	18		
Moisture Content	%	95.35	98.16	103.39	104.08	46.67	50.00
Average (%)		101				48	

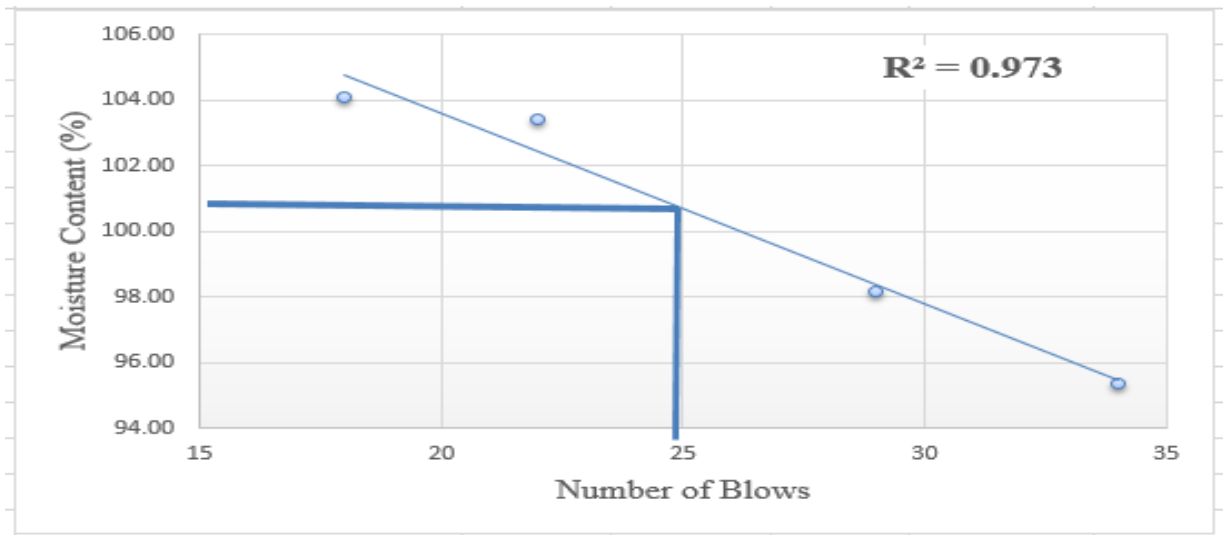


Figure D. 7 Water content Vs log number of blows for test pit TP7 (Edget Ber)

Table D. 8 Liquid limit and plastic limit for test pit TP8 (Ajip)

Test Type		Liquid limit %				Plastic limit %	
Trial Number		1	2	3	4	1	2
No.of Blows	N	34	28	22	18		
Can	n	Vs6	7zt	5st	28m	96	64
Wt. Can + Wet Soil	g	98	91.5	62	65	41	41
Wt Can + Dry Soil	g	65	58	43	42	36	37
Wt. water	g	33	33.5	19	23	5	4
Wt. of Can	g	27.5	27	27	26	27	26
Wt. of Dry Soil	g	37.5	31	16	16	9	11
No.of Blows	N	34	28	22	18		
Moisture Content	%	88.00	108.06	118.75	143.75	55.56	36.36
Average%		116				46	

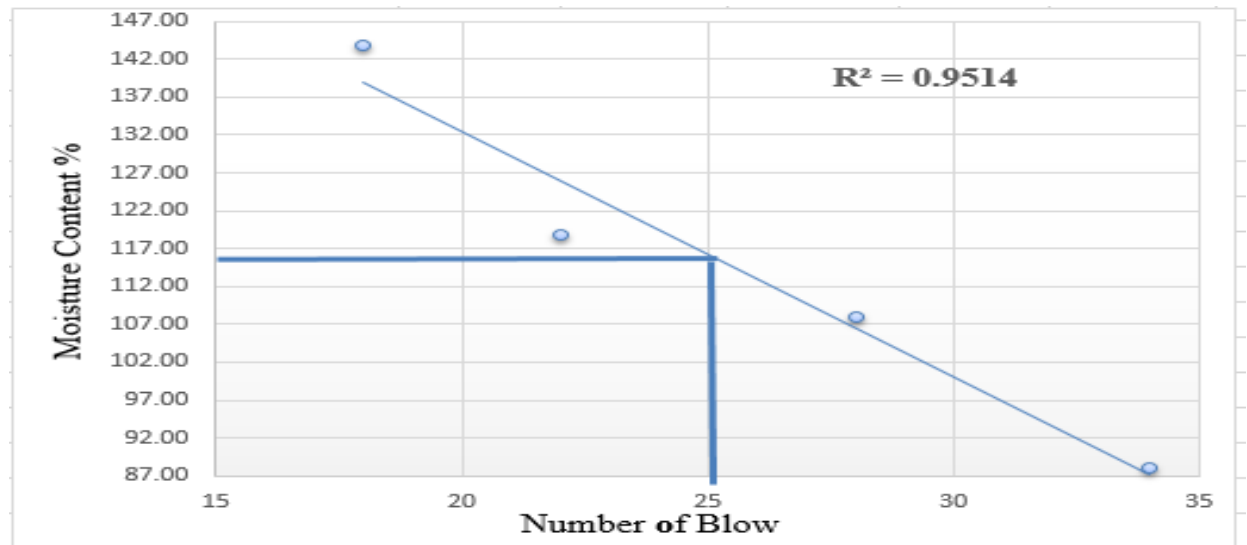


Figure D. 8 Water content Vs log number of blows for test pit TP8 (Ajip)

Table D. 9 Liquid limit and plastic limit for test pit TP9 (Derik)

Test type		Liquid limit%				Plastic limit%	
Trial		1	2	3	4	1	2
No.of Blows	N	33	26	23	19		
Can	n	Z8	F2	Z3	B6	A4	W11
Wt. Can + Wet Soil	g	83	91.5	73.5	60	66	58
Wt Can + Dry Soil	g	54.5	59	50	43	60	54.5
Wt. water	g	28.5	32.5	23.5	17	6	3.5
Wt. of Can	g	26	27	27	27	46	46
Wt. of Dry Soil	g	28.5	32	23	16	14	8.5
No.of Blows	N	33	26	23	19		
Moisture Content	%	100.00	101.56	102.17	106.25	42.86	41.18
Average (%)		103				42	

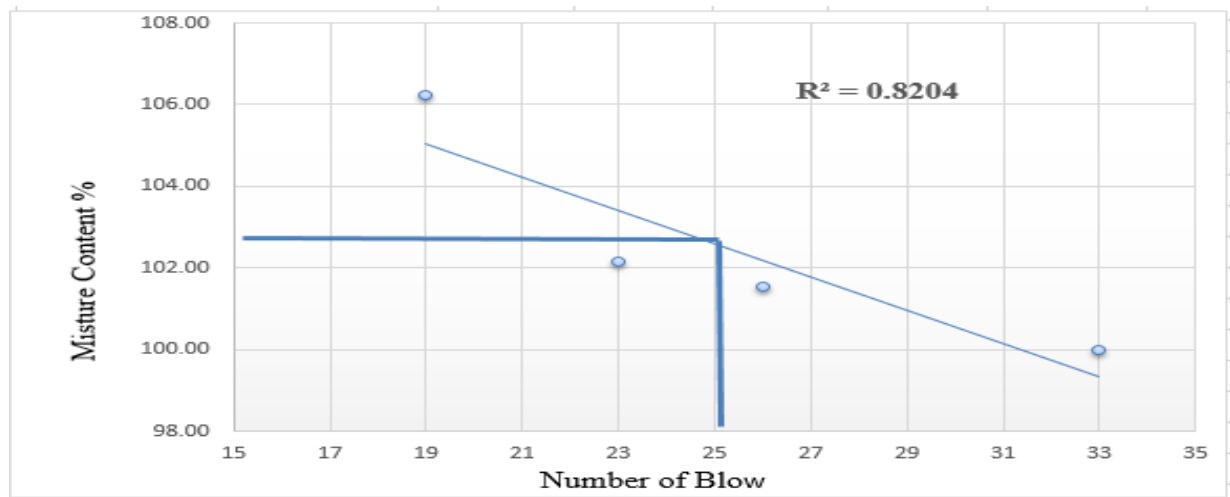


Figure D. 9 Water content Vs log number of blows for test pit TP9 (Derik)

Table D. 10 Liquid limit and plastic limit for test pit TP10 (Doyisa)

Test type		Liquid limit%				Plastic limit%	
Trial		1	2	3	4	1	2
No.of Blows	N	31	28	23	18		
Can No.	n	D1	G2	A3	G10	G3	G4
Wt. Can + Wet Soil	g	48	47	66	49	39	42.5
Wt Can + Dry Soil	g	34	33	44	32	35.5	38
Wt. water	g	14	14	22	17	3.5	4.5
Wt. of Can	g	20	20	27	20	27.5	27.5
Wt. of Dry Soil	g	14	13	17	12	8	10.5
No.of Blows	N	31	28	23	18		
Moisture Content	%	100.00	107.69	129.41	141.67	43.75	42.86
		120				43	

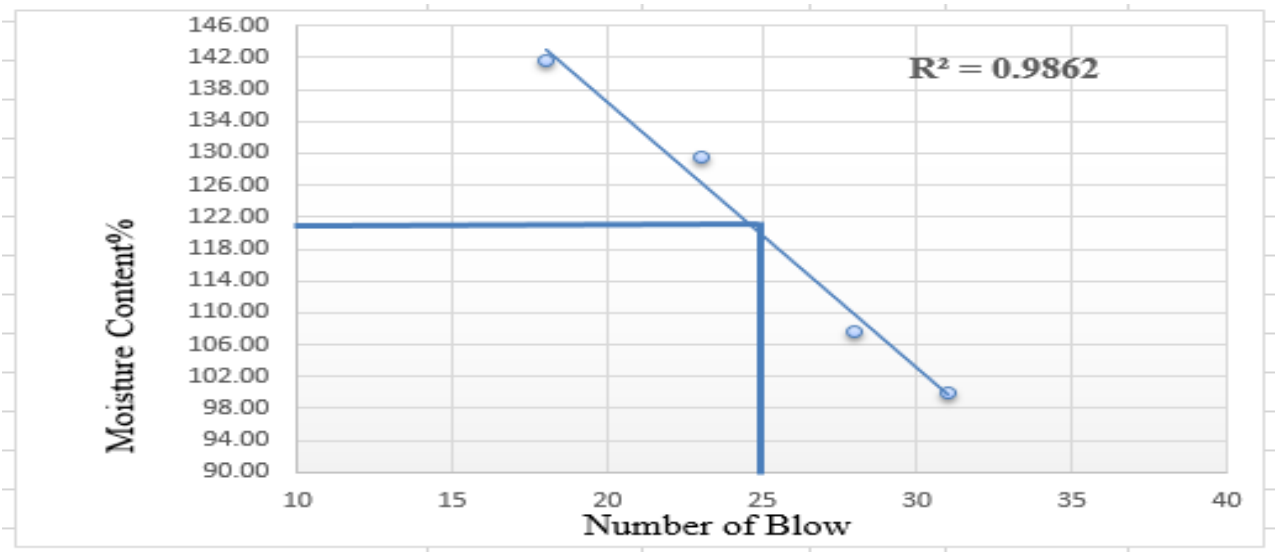


Figure D. 10 Water content Vs log number of blows for test pit TP10 (Doyisa)

APPENDIX E: Analysis and Laboratory test results of Particle-size Distribution

Formula used

For Sieve Analysis

Mass of retained = Mass of sieve +retained - Mass of sieve

Percentage retained = (Mass of retained / Total mass used in sieve analysis)*100%

Cumulative percentage retained = Summation of Percentage retained at each sieve
Percentage finer = 100 - Cumulative percentage retained

For Hydrometer Analysis

Corrected Hydrometer reading (RC) = Actual Hydrometer reading (RA) - Composition correction

Table E.1 Sieve Analysis for Bubu Meda, Depth 3m

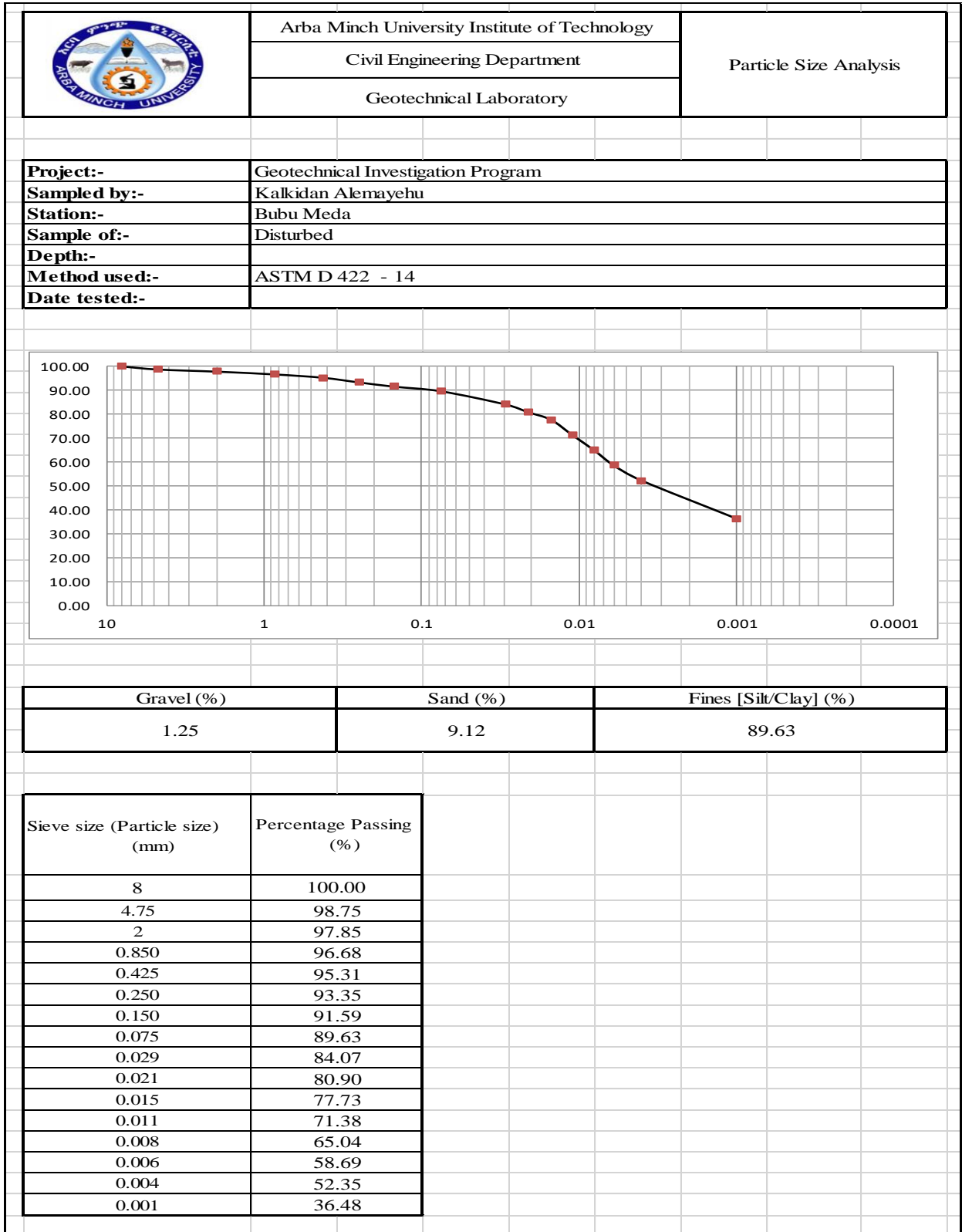
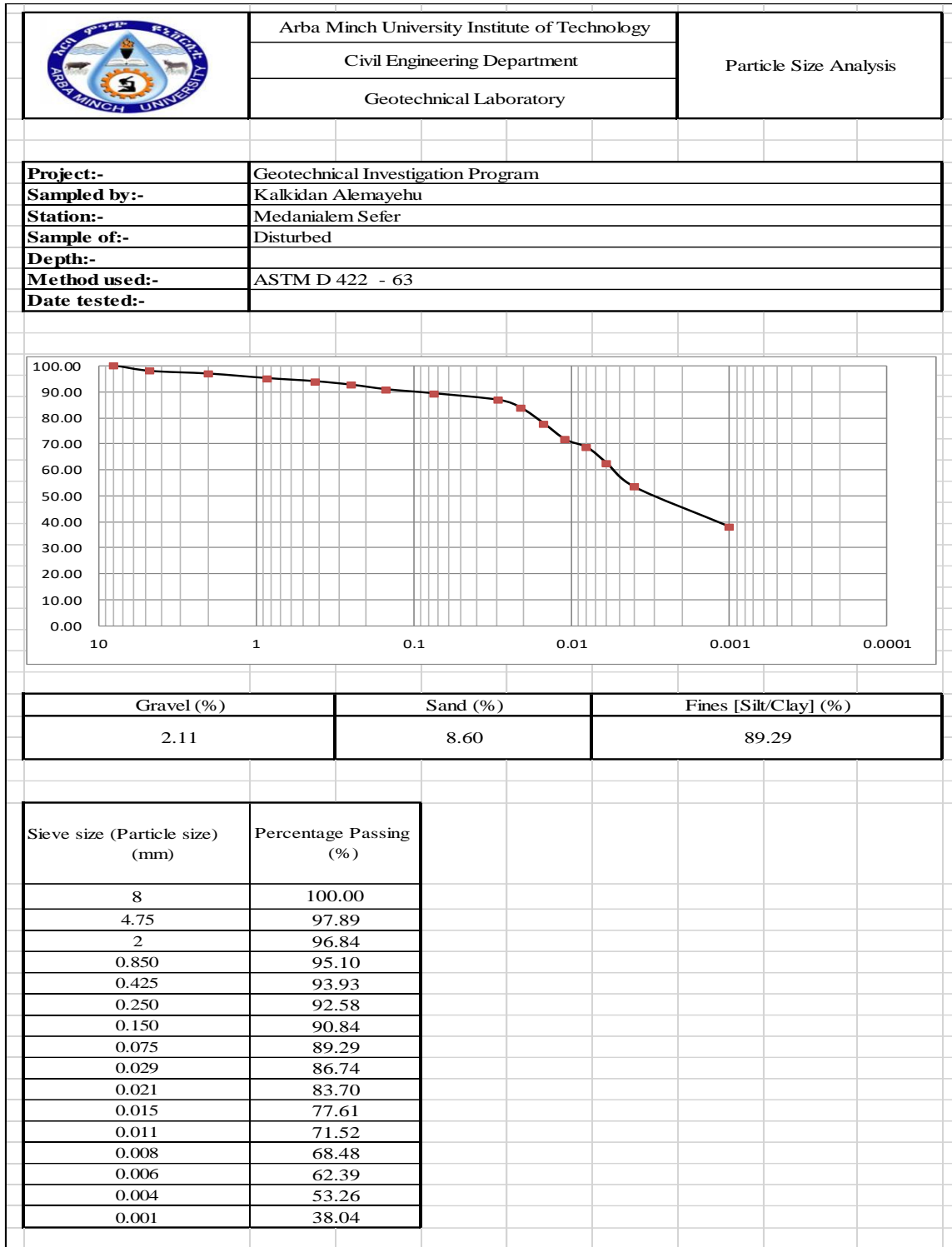


Table E.2 Sieve Analysis for Medanialem Sefer



APPENDIX F: Analysis and Laboratory test results of Swelling Pressure

Formula used

Mass of soil= (Mass of ring + soil) – Mass of ring

Volume of the ring = $(\Pi * D^2 / 4) * H$

Where: - D= Diameter of ring=63mm

H= Height of ring=20mm

Bulk density = Mass of soil / Volume of the ring

Dry density = Bulk density / (1+ water content in decimal)

Table F. 1 Swelling Pressure Calculation table for test pit 1(Gurba)

Calculation table					
Applied pressure(kPa)	final Dial Reading(mm)	Change in specimen height(mm)	final specimen height(mm)	void height(mm),Hv	Void Ratio
Loading					
7	6.889	0.000	20.000	10.571	1.121
7	5.872	-1.017	21.017	11.588	1.229
50	6.146	-0.743	20.743	11.314	1.200
100	6.599	-0.29	20.290	10.861	1.152
200	7.551	0.662	19.338	9.909	1.051
400	9.116	2.227	17.773	8.344	0.885
800	11.645	4.756	15.244	5.815	0.617
1600	13.851	6.962	13.038	3.609	0.383

A In the beginning of the test	
Sample type :	
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	1.34
Initial moisture content, %	36.54
Specific Gravity:	2.79
Wet density,g/cm3	1.71
B In the end of the test	
Final Moisture Content, %	30.97
Dry specimen wt (ms), gm:	78
Dry density,g/cm3	1.25
Height of Solids(Hs), mm	8.97
Final Void Ratio, ef:	0.45

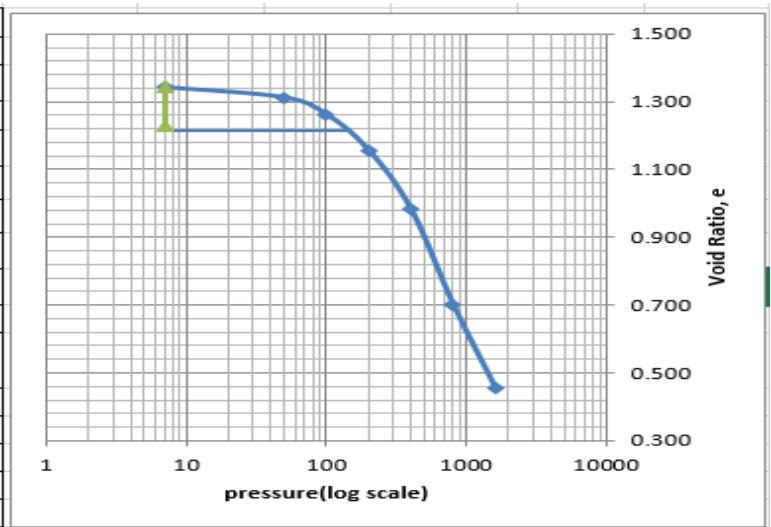


Figure F. 1 Determination of swelling pressure from e-logp curve for test pit 1(Gurba)

Table F. 2 Swelling pressure calculation table for test pit 2 (Medanialem)

Calculation table					
Applied Pressure(kPa)	Final Dial Reading (mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height (mm),Hv	Void Ratio,E
Loading					
7	5.168	0.000	20.000	11.250	1.286
7	3.270	-1.898	21.898	13.148	1.503
50	3.684	-1.484	21.484	12.734	1.455
100	4.362	-0.806	20.806	12.056	1.378
200	5.029	-0.139	20.139	11.389	1.302
400	6.457	1.289	18.711	9.961	1.138
800	9.209	4.041	15.959	7.209	0.824
1600	12.509	7.341	12.659	3.909	0.447

[A] In the beginning of the test	
Sample type :	Disturbed
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	1.50
Initial moisture content,%	22.28
Specific Gravity:	2.75
Wet density,g/cm3	1.67
[B] In the end of the test	
Final Moisture Content,%	29.91
Dry specimen wt (ms), gm:	75
Dry density,g/cm3	1.20
Height of Solids(Hs), mm	8.75
Final Void Ratio, ef:	0.45

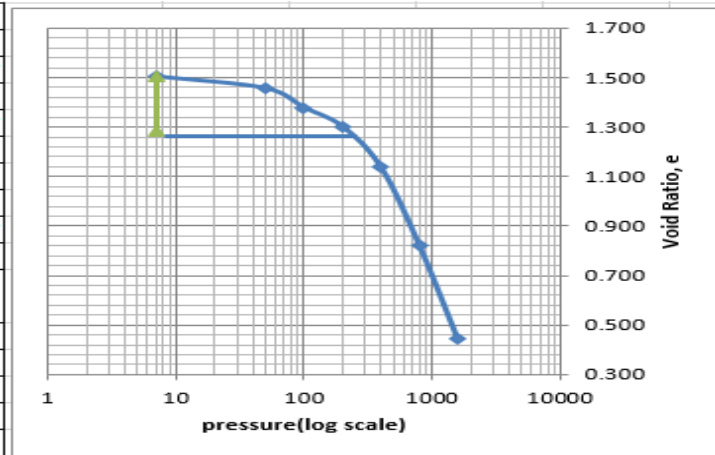


Figure F. 2 Determination of swelling pressure from e-logp curve for test pit2 (Medanialem)

Table F. 3 Swelling pressure calculation table for test pit 3 (Bubu meda)

Calculation table:					
Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	3.912	0.000	20.000	10.166	1.034
7	2.880	-1.032	21.032	11.198	1.139
50	2.998	-0.914	20.914	11.080	1.127
100	3.522	-0.39	20.390	10.556	1.074
200	4.189	0.277	19.723	9.889	1.006
400	5.626	1.714	18.286	8.452	0.860
800	7.843	3.931	16.069	6.235	0.634
1600	9.868	5.956	14.044	4.210	0.428

[A] In the beginning of the test	
Sample type :	Disturbed
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	1.14
Initial moisture content,%	23.00
Specific Gravity:	2.61
Wet density,g/cm3	1.65
[B] In the end of the test	
Final Moisture Content,%	24.53
Dry specimen wt (ms), gm:	80
Dry density,g/cm3	1.28
Height of Solids(Hs), mm	9.83
Final Void Ratio, ef:	0.43

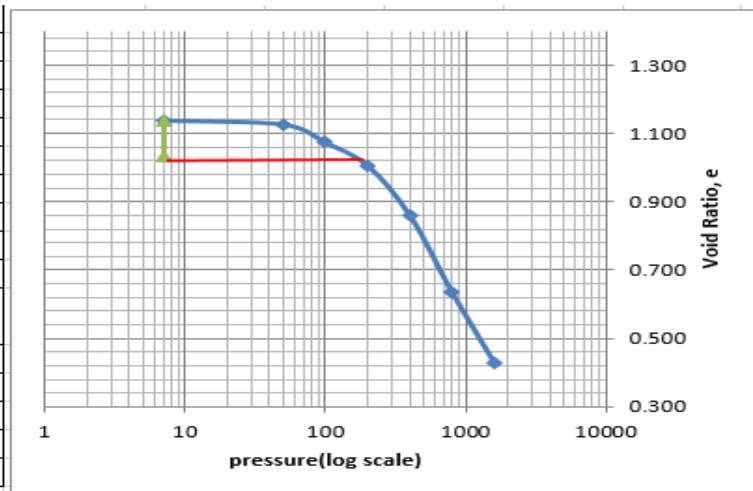


Figure F. 3 Determination of swelling pressure from e-logp curve for test pit 3 (Bubu meda)

Table F. 4 Swelling pressure calculation table for test pit 4 (Secha)

Calculation table:					
Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	8.721	0.000	20.000	10.652	1.140
7	6.418	-2.303	22.303	12.955	1.386
50	6.614	-2.107	22.107	12.759	1.365
100	7.408	-1.313	21.313	11.965	1.280
200	8.715	-0.006	20.006	10.658	1.140
400	10.152	1.431	18.569	9.221	0.986
800	11.799	3.078	16.922	7.574	0.810
1600	12.959	4.238	15.762	6.414	0.686

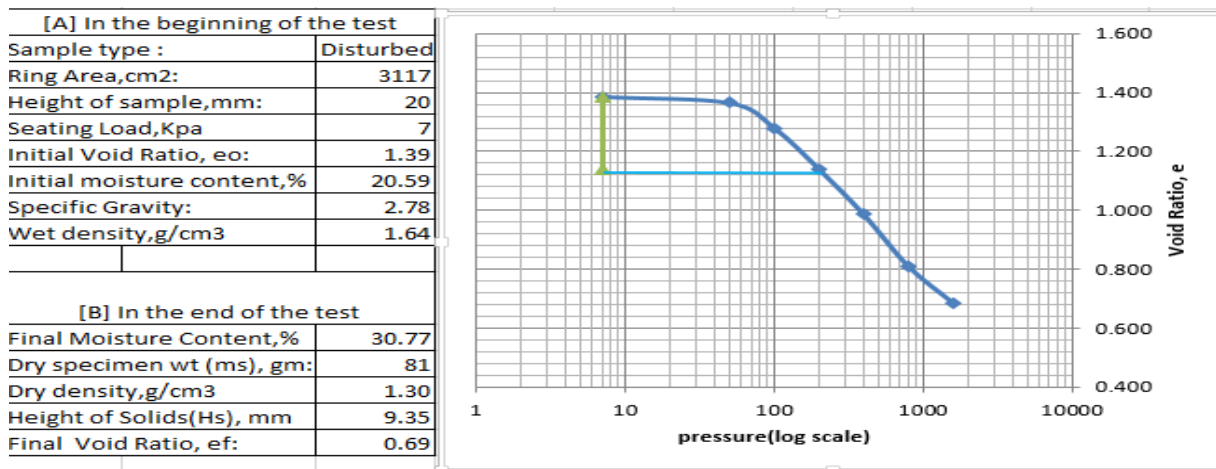


Figure F. 4 Determination of swelling pressure from e-logp curve for test pit 4 (Secha)

Table F. 5 Swelling pressure calculation table for test pit 5 (Edget)

[C] Calculation table:					
Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	4.911	0.000	20.000	9.267	0.863
7	0.900	-4.011	24.011	13.278	1.237
50	1.704	-3.207	23.207	12.474	1.162
100	2.491	-2.420	22.420	11.687	1.089
200	3.209	-1.702	21.702	10.969	1.022
400	4.346	-0.565	20.565	9.832	0.916
800	6.935	2.024	17.976	7.243	0.675
1600	9.715	4.804	15.196	4.463	0.416

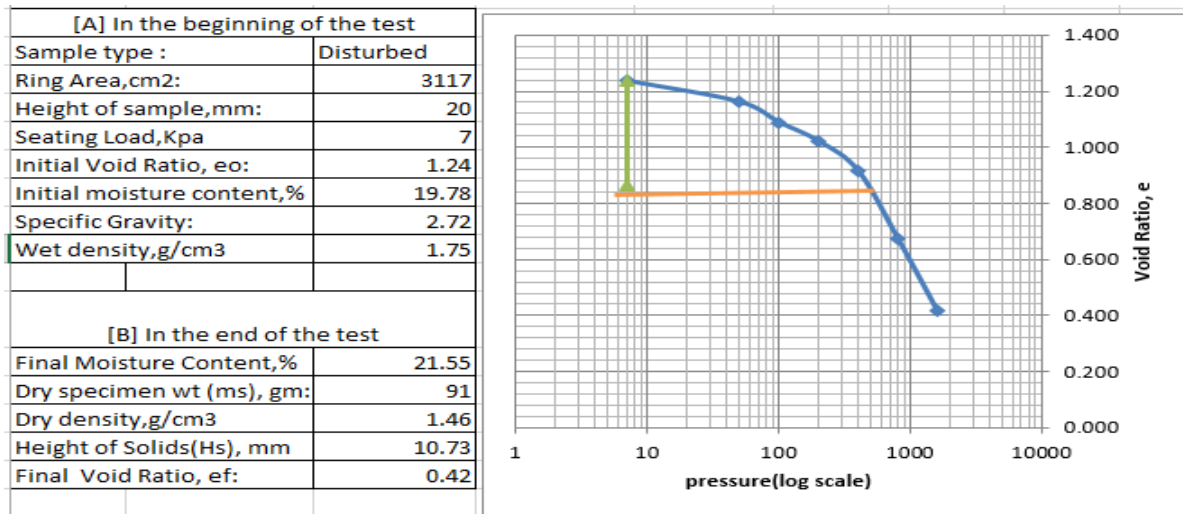


Figure F. 5 Determination of swelling pressure from e-log curve for test pit 5 Edget)

Table F. 6 Swelling pressure calculation table for test pit 6 (Zuriya)

[C] Calculation table:					
Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	4.301	0.000	20.000	11.460	1.342
7	2.266	-2.035	22.035	13.495	1.580
50	2.730	-1.571	21.571	13.031	1.526
100	3.468	-0.833	20.833	12.293	1.440
200	4.235	-0.066	20.066	11.526	1.350
400	5.272	0.971	19.029	10.489	1.228
800	7.639	3.338	16.662	8.122	0.951
1600	9.977	5.676	14.324	5.784	0.677

[A] In the beginning of the test	
Sample type :	Disturbed
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	1.58
Initial moisture content,%	28.85
Specific Gravity:	2.78
Wet density,g/cm3	1.70
[B] In the end of the test	
Final Moisture Content,%	30.19
Dry specimen wt (ms), gm:	74
Dry density,g/cm3	1.19
Height of Solids(Hs), mm	8.54
Final Void Ratio, ef:	0.68

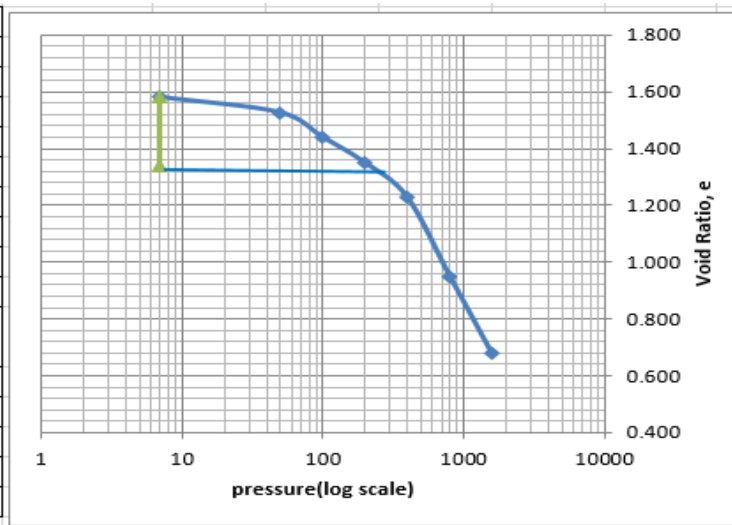


Figure F. 6 Determination of swelling pressure from e-log curve for test pit 6

Table F. 7 Swelling pressure calculation table for test pit 7 (Wubet)

Calculation table:					
Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	3.863	0.000	20.000	9.384	0.884
7	1.702	-2.161	22.161	11.545	1.087
50	2.098	-1.765	21.765	11.149	1.050
100	2.398	-1.465	21.465	10.849	1.022
200	3.294	-0.569	20.569	9.953	0.937
400	4.050	0.187	19.813	9.197	0.866
800	4.934	1.071	18.929	8.313	0.783
1600	5.987	2.124	17.876	7.260	0.684

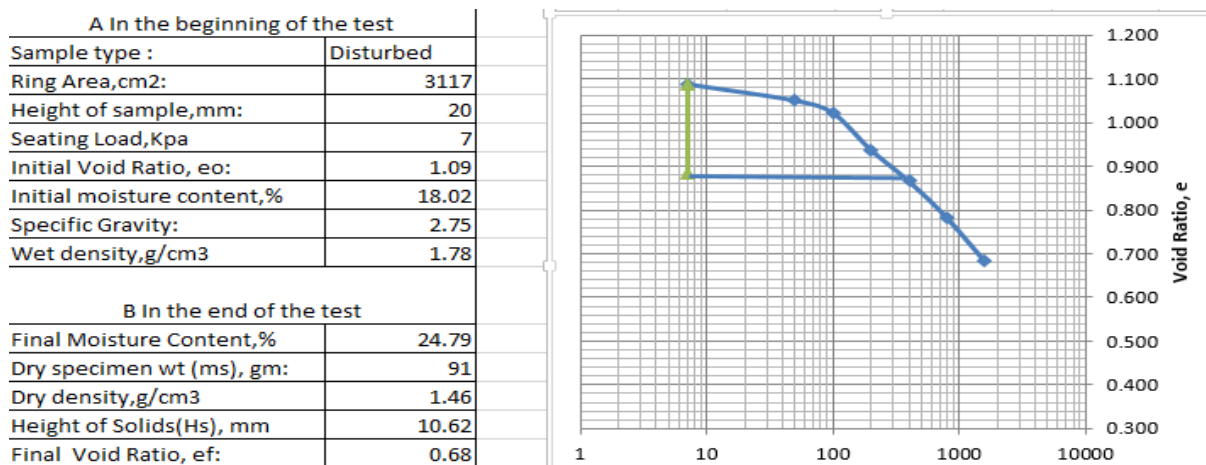


Figure F. 7 Determination of swelling pressure from e-logp curve for test pit 7(Wubet)

Table F. 8 Swelling pressure calculation table for test pit 8 (Ajip)

Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	4.498	0.000	20.000	8.378	0.721
7	1.366	-3.132	23.132	11.510	0.990
50	1.902	-2.596	22.596	10.974	0.944
100	2.698	-1.8	21.800	10.178	0.876
200	3.447	-1.051	21.051	9.429	0.811
400	4.484	-0.014	20.014	8.392	0.722
800	6.701	2.203	17.797	6.175	0.531
1600	10.935	6.437	13.563	1.941	0.167

[A] In the beginning of the test	
Sample type :	Disturbed
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	0.99
Initial moisture content, %	27.97
Specific Gravity:	2.65
Wet density,g/cm3	1.89
[B] In the end of the test	
Final Moisture Content, %	27.97
Dry specimen wt (ms), gm:	96
Dry density,g/cm3	1.36
Height of Solids(Hs), mm	11.62
Final Void Ratio, ef:	0.17

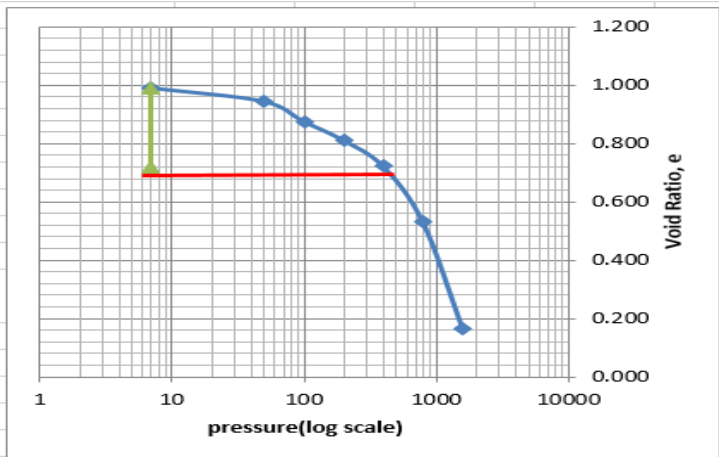


Figure F. 8 Determination of swelling pressure from e-logp curve for test pit 8(Ajip)

Table F. 9 Swelling pressure calculation table for test pit 9 (Derik)

Calculation table:					
Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	10.434	0.000	20.000	10.532	1.112
7	6.683	-3.751	23.751	14.283	1.509
50	6.934	-3.5	23.500	14.032	1.482
100	7.468	-2.966	22.966	13.498	1.426
200	8.135	-2.299	22.299	12.831	1.355
400	10.172	-0.262	20.262	10.794	1.140
800	12.389	1.955	18.045	8.577	0.906
1600	13.981	3.547	16.453	6.985	0.738

[A] In the beginning of the test	
Sample type :	Disturbed
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	1.51
Initial moisture content,%	44.59
Specific Gravity:	2.66
Wet density,g/cm3	1.82
[B] In the end of the test	
Final Moisture Content,%	32.91
Dry specimen wt (ms), gm:	78.5
Dry density,g/cm3	1.79
Height of Solids(Hs), mm	9.47
Final Void Ratio, ef:	0.74

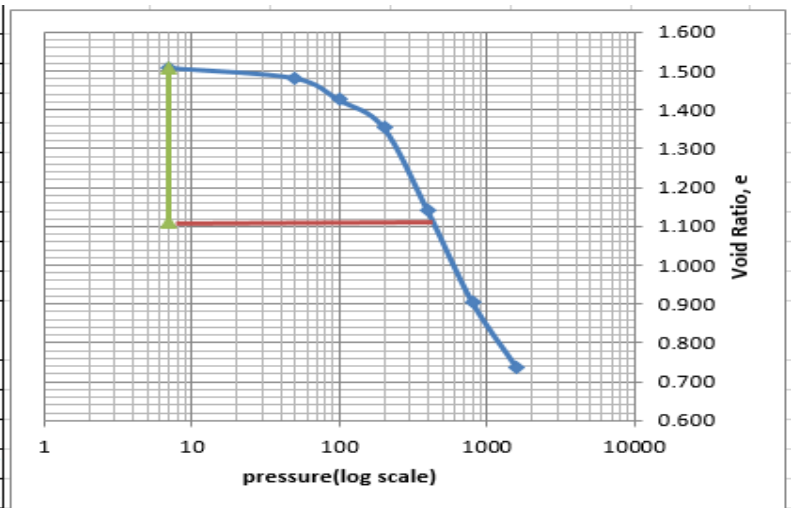


Figure F. 9 Determination of swelling pressure from e-log p curve for test pit 9(Derik)

Table F. 10 Swelling pressure calculation table for test pit 10 (Doyisa)

Applied Pressure(kPa)	Final Dial Reading(mm)	Change in specimen height(mm)	Final specimen height(mm)	Void height(mm),Hv	Void Ratio,E
Loading					
7	6.938	0.000	20.000	10.842	1.184
7	5.502	-1.436	21.436	12.278	1.341
50	5.795	-1.143	21.143	11.985	1.309
100	6.002	-0.936	20.936	11.778	1.286
200	6.210	-0.728	20.728	11.570	1.263
400	6.686	-0.252	20.252	11.094	1.211
800	7.783	0.845	19.155	9.997	1.092
1600	8.853	1.915	18.085	8.927	0.975

A In the beginning of the test	
Sample type :	Disturbed
Ring Area,cm2:	3117
Height of sample,mm:	20
Seating Load,Kpa	7
Initial Void Ratio, eo:	1.34
Initial moisture content,%	31.44
Specific Gravity:	2.75
Wet density,g/cm3	1.84
B In the end of the test	
Final Moisture Content,%	32.91
Dry specimen wt (ms), gm:	78.5
Dry density,g/cm3	1.26
Height of Solids(Hs), mm	9.16
Final Void Ratio, ef:	0.97

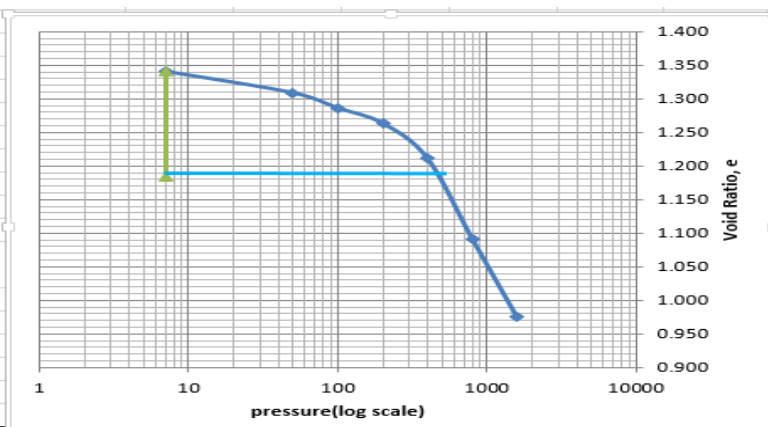


Figure F.10 Determination of swelling pressure from e-log p curve for test pit 10(Doyisa)

Appendix G: SPSS 22 Regression Analysis Output

For equation 1

Descriptive Statistics

	Mean	Std. Deviation	N
Ps	310.2270	140.66167	10
Mc	33.7000	4.96767	10
PI	59.9000	8.54335	10
C	41.3330	4.32082	10

Correlations

		Ps	Mc	PI	C
Pearson Correlation	Ps	1.000	-.912	.479	.248
	Mc	-.912	1.000	-.543	-.294
	PI	.479	-.543	1.000	.615
	C	.248	-.294	.615	1.000
Sig. (1-tailed)	Ps	.	.000	.081	.244
	Mc	.000	.	.053	.205
	PI	.081	.053	.	.029
	C	.244	.205	.029	.
N	Ps	10	10	10	10
	Mc	10	10	10	10
	PI	10	10	10	10
	C	10	10	10	10

Variables Entered/Removed^a

Model	Variables Entered	Variables Removed	Method
1	C, Mc, PI ^b	.	Enter

a. Dependent Variable: Ps

b. All requested variables entered.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.912 ^a	.833	.749	70.47584	.833	9.951	3	6	.010

a. Predictors: (Constant), C, Mc, PI

ANOVA^a

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	148270.296	3	49423.432	9.951	.010 ^b
	Residual	29801.064	6	4966.844		
	Total	178071.360	9			

a. Dependent Variable: Ps

b. Predictors: (Constant), C, Mc, PI

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	1224.567	366.950		3.337	.016	326.672	2122.461
	Mc	-26.152	5.641	-.924	-4.636	.004	-39.954	-12.350
	PI	-.209	3.976	-.013	-.053	.960	-9.937	9.519
	C	-.496	6.908	-.015	-.072	.945	-17.398	16.407

a. Dependent Variable: Ps