Jimma University

Jimma Institute of Technology

School of Graduate Studies

Faculty of Civil and Environmental Engineering

Geotechnical Engineering Stream

Prediction of Swelling Pressure from Index Properties of Expansive Soils found in Burayu Town

A Research thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirement of Degree of Master of Science in Civil Engineering.

By:
Chala Lechu Kistana

March, 14/2020
Jimma, Oromia, Ethiopia

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Main Advisor: Prof. Emer T. Quezon (P.Eng)

Co Advisor: Mr. Worku Firomsa (Msc.)

March, 14/2020

Jimma, Oromia, Ethiopia

Declaration

I, the undersigned, declare that this Research thesis entitled "**Prediction of Swelling Pressure from Index properties of Expansive soils found in Burayu town**" is my original work, and has not been presented by any other person for an award of a degree in this or any other University. In addition, all sources of material used for this Research thesis duly acknowledged.

Candidate:

Mr. Chala Lechu Kistana

______________________ ______________

Signature Date

As Master's Research Advisors, I hereby certify that I have read and evaluated this MSc. Research thesis prepared under my guidance by **Chala Lechu** entitled: "**Prediction of Swelling Pressure from Index properties of Expansive soils found in Burayu town**".

Prof. Emer T. Quezon, P.Eng	________________	15/03/2020
Main Advisor	Signature	Date
Mr. Worku Firomsa (MSc.)	________________	___________
Co- Advisor	Signature	Date

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Abstract

Expansive soils are recognized as problematic soils that impose several challenges for civil engineers. Such soils undergo significant volume change in case water penetrates into them, and they shrink as they lose moisture. Lightly-loaded engineering structures such as pavements, single story buildings, railways and walkways may experience severe damages when they are founded on such soils. A considerable surface area of Burayu town covered by expansive soils, which have a tendency to undergo volume change due to change in water content variation.

Reconnaissance study of the area carried by visiting the entire part and the surrounding part of the town. For this study thirty-(30) samples collected from 10(ten) test pits for different laboratory tests and each samples are determined according to American Society of Testing Materials (ASTM) and their result and discussions was stated.

This Research study is aimed to predict the swelling pressure from index properties of expansive soils found in Burayu town including classification of soil using AASHTO (American Association of State Highway and transportation officials) and Unified soil classification systems (USCS) to know the expansiveness of the soils the study area. The study also carried out on examining the nature and mechanism of swell-shrink behavior of expansive soils.

The statistical analysis conducted using Computer program Software (SPSS 20) and Microsoft-Excel to develop Empirical between soil index properties and swelling pressure of expansive soil of the study area. The outcome of this study is Modelling of swelling pressure from index properties of expansive soils in the study area. Based on both single and multiple linear regression analysis relatively good correlation is obtained by combining Swelling pressure (Sp) with soil index properties. From the analysis the equations developed are $S_P = 4.134*PI - 2.406*NMC - 95.564*\gamma d - 247.366*Ac + 381.831$ *with coefficient of determination* (R^2) *of 0.869 for multiple linear regression and* $Sp = 387.51 - 158.1*\gamma d$ *with coefficient of determination* R^2 *of 0.829 for single linear regression. The Results on the validity of the newly developed correlation with control test results shows that, the correlation of swelling pressure value with soil index properties is valid only for preliminary design purposes and estimation of swelling pressure of the soils the study area.*

Key words: *- Expansive, Swell Pressure, Regression, Correlation, Swell-Shrink behavior.*

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Abbreviations

AASHTO	American Association State Highway and Transportation Officials
Ac	Activity of Clay
ASTM	American Society of Testing Materials
CH	High plasticity inorganic clays
CL	Low plasticity inorganic clays
GM	Salty gravels
GP	Poorly graded gravels
Gs	Specific gravity
GW	Well graded gravels
LI	Liquid Index
LL	Liquid Limit
MH	High plasticity inorganic silts
ML	Low plasticity inorganic silts
OH	highly plastic organic soil
OL	low plastic organic soil
PI	Plastic Index
PL	Plastic Limit
Ps	Swelling pressure
Pt.	Highly organic soils
SC	Clayey sands
SL	Shrinkage Limit
SM	Salty sands
SP	Poorly graded sands
SPSS	Statically Package For Social Science Software
SW	Well graded sands
USCS	Unified Soil Classification system
W	Moisture content
γd	Dry density

CHAPTER ONE

INTRODUCTION

1.1 Back Ground of the Study

Expansive soils are mostly found in the arid and semi-arid regions of the world, which exhibit significant volume changes because of soil moisture variation. Expansive soils swell if its moisture content increases and shrinks when its moisture content decreases. The magnitude of the expansion depends upon the kind and amount of clay minerals present, their exchangeable ions, the electrolyte content of the aqueous phase, and the internal structure. The three most important groups of clay minerals are Montmorillonite, Illite, and Kaolinite[1].

The Swelling tendencies of expansive soils quantified by the potential swelling parameters. Determination of swelling potential of expansive soils, namely, swell percent and swelling pressure, is important for the design of foundations. The swell percent or volume change of expansive soil is the percentage of heave of a soil for a given surcharge load, while the swelling pressure of a soil is the external pressure that needs to be placed over a swelling soil to prevent volume increase. These swelling parameters directly measured in the laboratory or indirectly estimated from empirical correlations [2].

As investment in infrastructure development forms a significant portion of the global economy, expansive soils are a prime focus of research in geotechnical engineering and soil science. The road network in Ethiopia has been identified as a serious bottleneck for the economic development of the country, as it provides the dominant mode of freight and passenger transport and thus plays a vital role in the economy of the country. The network comprises a huge national asset that requires adherence to appropriate standards for design, construction and maintenance in order to provide a high level of service. As the length of the road network is increasing, appropriate choice of methods to preserve this investment becomes increasingly important [3]. Most of the roads constructed, lightly loaded residential and commercial buildings, airfield and proposed as well as substantial amount of the newly planned railway routes in the country pass through in the heart of expansive soils [4, 5, 6].

1.2 Statement of the Problem

Potentially expansive soils can be found almost anywhere in the world. In the underdeveloped nations, much of the expansive soil problems may not be recognized. The volume change behavior of expansive soil generates serious damage to civil infrastructures many countries over the world. In general, the annual damage in Sudan exceeds six million dollars and most of the annual damage reported occurs in residential and commercial buildings [7], [8]. Previous studies indicated a continual increase in annual damage caused by expansive soil as the population continues to grow due to the need of new developments to the expanding residential buildings and commercial markets [9], [8]. Rosen balm and Zapata [10],[8] stated that in the United States alone, the cost to repair structures damaged by expansive soils has been estimated to be twice the combined damages of natural disasters. Expansive soils have reportedly inflicted billions of dollars in damages and repairs annually to structures [45], [46].

Expansive soils widely occur in Ethiopia and are notorious for posing a wide range of problems in the construction sector. Two foremost topics in expansive soil research are characterization and treatment or stabilization [12], [13]. While the first deals with identification and quantitative analysis of expansive soils, and the second strives to improve their geotechnical characteristics (such as reducing their swelling and shrinkage potential). Site characterization is a prerequisite at the onset of any construction, also to promote a better land-use planning [14, 5].

Ethiopian researchers have shown that substantial damage has been occurring on structures that are constructed on expansive soils. ***A***mong many researchers, two authors from Ethiopia found out damage of structures founded on expansive soils [13], [15].

The study area of this research is nearest to city of Finfinne. Burayu town is one of the town surrounding the Finfinne city in which the Engineering properties of their soils are almost similar. Many researchers studied that the engineering properties of Finfinne area covered by expansive soils, which will be almost similar to the soils of Burayu town [25].

In Burayu town, expansive soil may cause significant damage in the structures to build upon it during future urban development [16]. In order to determine its swelling pressure of those soils for design purpose, their laboratory tests will take time to analysis their results. In order to reduce cost, time, and its complex procedure, it is better to use simple index tests and correlating with swelling characteristics. This gives the required solution to the geotechnical problems, which used for the design projects around the study area.

1.3 Research questions

The research questions that this research study attempted to answer during the study are:

1. What are the swelling pressure and index property of expansive soils in Burayu town?
2. How swelling pressure could be correlated with index property of expansive soils in Burayu town?
3. How much deviation of the values as a result from the developed equations with the existing correlation approaches related to the study?

1.4 Objectives of the study

1.4.1 General Objective

The general objective of this study is to predict the swelling pressure from Index Properties of Expansive soils found in Burayu town.

1.4.2 Specific Objective

- To determine swelling pressure and index property of expansive soils in Burayu town.
- To analyze and establish correlations betweeen swelling pressure and index property of expansive soils in Burayu town.
- To validate and evaluate the developed equations and compare with the existing correlation approaches related to the study.

1.5 Scope of the Study

This research address to cover as defined in the objective and provides correlations between the swelling pressure and index property of expansive soils in Burayu town. Collections of samples are limited to ten (10) test pits which is selected from representative locations. From each test pit, disturbed and undisturbed samples collected at a depth ranging from 1m to 3m depending on stratification of soil layer.

For the intended purpose, the analysis of Atterberg limits, grain size analysis, natural moisture contents, dry density, specific gravity, free swell test and swell-consolidation tests are conducted on disturbed and undisturbed samples. At the last this study covers the statistical analysis by using Statistical Package for Social Science Software (SPSS 20) and Microsoft-Excel for the purpose of Modelling of swelling pressure from index properties of expansive soils in the study area based on correlation and regression analysis.

1.6 Significance of the study

The guidance and information provided in this study can significantly reduce the risk of undesirable and severe damages to many structures for numerous expansive soil conditions. This research thesis predicts the swelling pressure for selecting economical foundations on expansive soil to minimize structural distress to within tolerable levels and guidance for minimizing problems that may occur in structures on expansive soils. The most obvious way in which expansive soils can damage foundations is by uplift as they swell with moisture increases. Swelling soils lift up and crack lightly-loaded, continuous strip footings, and frequently cause distress in floor slabs because of that predicting swelling pressure will benefits the designers to determine the amount of vertical heave and uplift pressure of expansive soils.

In addition, the finding of this study will benefit any construction sectors as the source of information to avoid the potential hazards posed due to the presence of swelling soils during the operational face of any construction in the town. And also, different construction Owners, contractors and consultants will benefit from this study as a source of information to determine the techniques of soil stabilization that reduce the anticipated heave of the foundations by examining the swelling pressure from index properties of expansive soils found in the town.

Finally, other researchers will use the findings as a reference for further research on the prediction of swelling pressure from index properties of expansive soils.

1.7 Organization of the Thesis

This thesis is organized into five Chapters. In the first Chapter back ground of the thesis, objectives of the research, significance and scope of the study are given. The second Chapter deals with literature review. The third Chapter addresses material sampling and testing methodology including description of the study area. The fourth Chapter describes laboratory test result, soil classification, and analysis of correlation and regression results including their discussions. At the end the study the last Chapter contains conclusion and recommendation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Expansive Soil

The response of expansive soils in the form of swelling and shrinkage due to changes in water content is frequently expressed superficially as heaving and settlement of lightly loaded structures such as pavements, walkways, railways, roadways, foundations, channel linings, etc. [17, 18].

Swelling soils recognized as problematic soils that undergo significant volume changes when their moisture content is changed. Principally, swelling occurs when water infiltrates between the clay particles, causing them to separate [19, 18].

Many lightly loaded structures had undergone severe damages when they founded over such soils due to differential heave of the underlying soils. Volume change of these soils is a major cause of concern since it causes extensive damage to the structures and the allied services. [20, 18].

Even when mitigating measures such as drain systems provided to prevent these soils from reacting to changes in their moisture condition, the soils still exhibit inherent low shear strength and undergo large secondary compression. Expansive or swelling soils are highly plastic soils that typically contain clay minerals such as Montmorillonite that attract and absorb a significant amount of water [21].

The type and amount of mineral and the percentage of clay fraction play a vital role in controlling the index properties such as liquid limit, plasticity index, and activity as well as the swelling characteristics including swell potential and swell pressure of such soils. Based on the mineral present, the swell potential of the soil varies; the Montmorillonite group minerals have the maximum swell potential, and the Kaolinite family minerals have the least swelling properties. Many empirical models proposed by various researchers to predict the swelling properties of such soils based on physical and index properties. The evaluation of swelling parameters (swell potential and swell pressure) of such soils includes both direct as well as indirect measurements. The direct methods involve the physical measurements of swell potential and swell pressure through laboratory test; however, the indirect methods involve the use of empirical models and correlations formulated based on basic soil properties. Nevertheless, these models provide an initial prediction of the swelling characteristics, which may not be as accurate as the direct evaluations. A number of correlations between index properties and the swelling characteristics developed in the past for a variety of expansive soils. No special considerations made in these correlations to incorporate the remolding or natural moisture content of the expansive soils, which certainly has a significant influence on soils exhibiting certain degree of swell potentials. The role and significance of natural moisture content identified and incorporated in the prediction models presented in this study [22, 18**].**

Expansive soils or swelling soils are those soils, which have the tendency to increase in volume when water is available and to decrease in volume if water removed. Foundations constructed on these expansive soils subjected to large uplift forces caused by swelling and inducing heaving, cracking and break up building foundations and slabs on grade members. The engineering behavior of a soil mass greatly influenced by physical properties of particles, the type of clay mineral, the proportion of the soil grains forming the soil mass and index properties. Clay soils containing montmorillonite mineral swell considerably upon imbibing water from outside. Clay soils containing other clay minerals do not exhibit the volume change characteristic to the same degree as those of containing montmorillonite mineral. Swelling pressure, defined as maximum force per unit area that placed over a swelling soil to prevent volume increase. The objective of this study was to establish a correlation among Free Swell (FS), Plasticity Index (PI) and Swelling Pressure (SP) to obtain an approximate value of Swelling Pressure in short time [23].

2.2 Description of Expansive Soil

Most soil in the Front Range can be classified as a swelling soil. This means that the soil contains a high percentage of certain types of clay that absorb vast quantities of water. Expansive soils sometimes called shrink-swell soils, swelling soils, adobe, clay, or caliche soils. This can cause the soil to expand 10% or more as moisture enters it, usually during winter snowmelt and spring runoff. The soil then exerts tremendous pressure on foundations, slabs, and other structures [35].

2.3 Field Identification of Expansive Soils

Soil that cracks or fractures when it dries often a sign that it is expansive; however, a lack of cracks does not necessarily indicate that the soil is not expansive. Soils containing expansive clays become very sticky when wet and usually characterized by surface cracks or a "popcorn" texture. Expansive soils are often becoming very sticky when wet, hard, and brittle when dry [24].

2.4 Experimental Identification of Expansive soils

Generally, there are three different method of identifying Expansive soils for the purpose of experimental study to know their engineering properties. [41]

2.4.1 Indirect methods

Indirect methods are used to investigate the swelling potential of a soil by examining other parameters, which indirectly yield excellent indices of expansive properties. Such tests are easy and can be performed in average soil mechanics laboratory. The commonly used test here is the index property tests (consist of Grain size analysis, liquid limit, plastic limit, shrinkage limit, free swell and vertical swell).

2.4.1.1 Grain Size Analysis Test

Grain size analyses, known as soil gradation test, are performed on essentially all geotechnical materials ranging from clay to boulders. Since, Grain size analysis is one of the index property tests, in which the soil of the study area examined for its grain size distribution. Grain size divides soil into two distinctive groups, namely cohesion less and cohesive soil. Soil particles, which are coarser than 0.075 mm, are generally termed as cohesion less, and the finer ones like silt and clay considered as fine-grained [29].

A sieve analysis test consists of shaking the soil through a stack of wire screens with openings of known size. The steady fall of soil particles through a liquid at rest called sedimentation. The hydrometer method is based on Stokes equation that relates the velocity of a free-falling spherical particle through a liquid to the diameter of the particle, the specific gravity of the particle and the viscosity of the liquid. The hydrometer analysis assumes that the soil particles are spheres, the soil suspension is sufficiently low concentration to permit individual settling of grains without interference by others. That means small spheres in a liquid settle at a different rate according to the size of the sphere [26].

2.4.1.2 Natural Moisture Content Test

Moisture content (w) is defined as the ratio, expressed as a percentage, of the weight of water in a given soil mass to the weight of solid particles. The change in water content in a soil's environment plays a major role in determining the degree of swelling and shrinking behavior expansive soils.

Generally, natural moisture content has an influence on the swelling potential of expansive soils. The natural moisture content of a soil affected by climate, vegetation cover of the area, and other artificial factors. Hence, the same soil could have different moisture contents in different seasons of a year and at different times. Since such type of moisture content is likely to fluctuate any time, it may not indicate the general property of the soil [26].

2.4.1.3 Atterberg limit Test

The Swedish soil scientist Albert Atterberg originally defined six "limits of consistency" to classify fine-grained soils, but in current engineering practice only two of the limits, the liquid and plastic limits, are commonly used. (A third limit, called linear shrinkage limit, used occasionally.) The Atterberg limits determined based on the moisture content of the soil [26].

These test methods are used as an integral part of several engineering classification systems to characterize the fine grained fractions of soils (ASTM D 2487 and D 3282) and to specify the fine-grained fraction of construction materials (ASTM D 1241). The liquid limit, plastic limit, and plasticity index of soils used extensively, either individually or together, with other soil properties to correlate with engineering behavior such as compressibility, hydraulic conductivity (permeability), compatibility, shrink-swell, and shear strength parameters of soils.

a) Liquid Limit

The liquid limit is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow on the application of a very small shearing force. When soil becomes a viscous fluid, the soil will begin to flow under its own weight and a minimal amount of energy input. The liquid limit is primarily used by civil and geotechnical engineers as a physical property of soil.

The liquid limit of a soil also defined as the water content at the boundary between the liquid and plastic states. The water content at this boundary arbitrarily defined as the water content at which, two halves of a soil pat placed in a brass cup, cut with standard groove, and dropped from a height of 1cm will undergo a groove closure of about 1.3 cm when the cup dropped 25 times at the rate of 2 drops per sec.

b) Plastic Limit (PL)

The plastic limit of a soil is the water content at the boundary between the plastic and semisolid state. The water content at this boundary arbitrarily defined as the water content at which soil begins to crumble when rolled into threads of specified size 3.2mm.

c) Plasticity Index

Plasticity index (PI) is the range of water content over which the soil behaves plastically. From the Atterberg limit values, it is possible to determine plasticity index using the formula: Plasticity index, PI = LL – PL.

d) Linear Shrinkage Limit

The swell potential is presumed to be related to the opposite property of linear shrinkage measured in a very simple test. Altmeyer (1955) suggested the values given Table 2-10 as a guide to the determination of potential expansiveness based on shrinkage limits and linear shrinkage.

The linear shrinkage of a soil for the moisture content equivalent to the liquid limit, that decrease in one dimension, expressed as a percentage of the original dimension of the soil mass, when the moisture content is reduced from the liquid limit to an oven-dry state.

2.4.1.4 Activity of clay

Activity which is defined as the ratio of the plastic index to the percent of clay fraction finer than 0.002mm is one means of classifying expansive soils based on their index property. They used to estimate the swelling potential of given clay.

2.4.1.5 Specific Gravity Test

Specific gravity is referred as the ratio of the density of a substance to the density of a reference substance such as water. Samples are oven-dried at 105 for a period of 16 to 24 hours. To perform the test, it is necessary to have empty weight of pycnometer and weight of pycnometer with oven dry soil. Then add water to cover the soil in the pycnometer and screw on the cap. To remove entrapped air it is necessary to shake the pycnometer well and connect it to the vacuum pump for about 10 to 20 minutes, finally fill the pycnometer with water.

2.4.2 Direct measurement

As the name indicates, 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 in-situ 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. The method quantitatively evaluates the volume change characteristics of Expansive soil.

2.4.2.1 Free Swell Test

The free swell of expansive soil, also termed as a free swell index, is the increase in the volume of soil without any external constraint when subjected to submergence in water. Such soils can damage the structure when the water table reaches the influence zone.

The free swell test is one of the most commonly used simple tests for estimating swelling soil potential. This test is performed by pouring 10cc of dry soil, passing through sieve no 40 (0.425mm diameter), into a 100 cc graduated cylinder. The two cylinder then filled with distilled water and kerosene, and the swelled volume of the soil for two cylinders measured after the material settles within 24 hours.

2.4.2.2 Swelling pressure Test

Swelling Pressure is the amount of pressure a soil exerts upon the structure or the pressure required recompressing the fully swollen sample back to its initial volume. Most of the structural damages occur when the swelling pressure is greater than the foundation pressure; assessing the swelling pressure is an important task in dealing with expansive soil. The available techniques for quantitative measurement swelling pressure of expansive soils can be odometer test [27].

2.5 Measurement of swelling pressure using Oedometer tests

The oedometer tests are capable of simulating some of the factors, which affect the swelling characteristics of expansive soils. It should note, however, that the odometer tests have limitation. The odometer tests consider moisture as well as volume change in one dimension only. In the in-situ, the volume changes take place in three directions. For simplicity, the odometer testing techniques are popular and extensively used. The different types of techniques under these methods are Constant Volume Method and Swell-Consolidation Method. [27]

2.5.1 Constant Volume Method

The specimen in the constant volume method is allowed to absorb water without any increase in volume by increasing the applied pressure as the test proceeds until the sample reaches equilibrium. The more load is added to keep the volume of the sample constant while the sample absorbs water. The swelling pressure can be determined by plotting the applied pressure against change in volume. This method does not represent the in-situ condition where the applied load after the structure is in service, does not change with time. Information such as the amount of heave which could be expected under application of a certain load or load which could be applied to limit the heave within tolerable limit cannot be furnished by this method. The method needs uninterrupted monitoring for a long period.

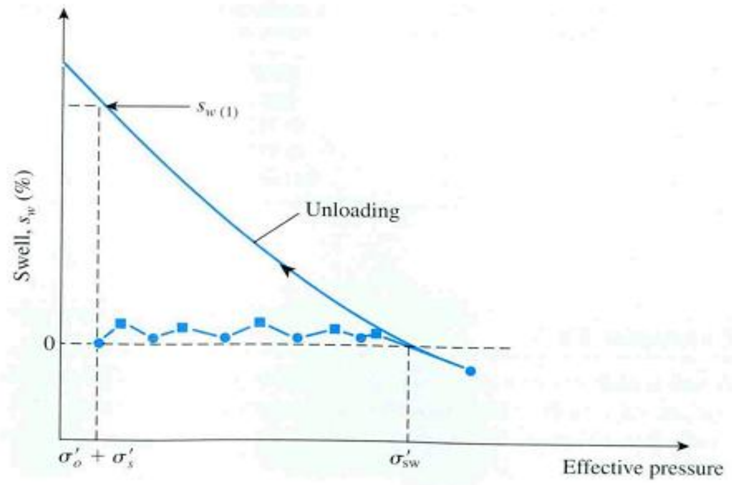


Figure 2-1: Graph of swelling pressure by Constant Volume Methods [27]

2.5.2 Swell-Consolidation Method

In this method, an undisturbed sample allowed to absorb water under a load of 1psi (7kpa) and putted aside to expand and reach equilibrium fully. Then it will 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 corresponds to zero volume change is taken as swelling pressure.

This method is quite popular, and many investigators have used this method to evaluate swelling pressure and to establish a relationship between swelling pressure and index properties of soils. The most serious drawback of this method is that it does not represent the normal sequence of load submersion. In the field, the soils are first subjected to the structural load and then swell later following exposure to moisture but not vice versa.

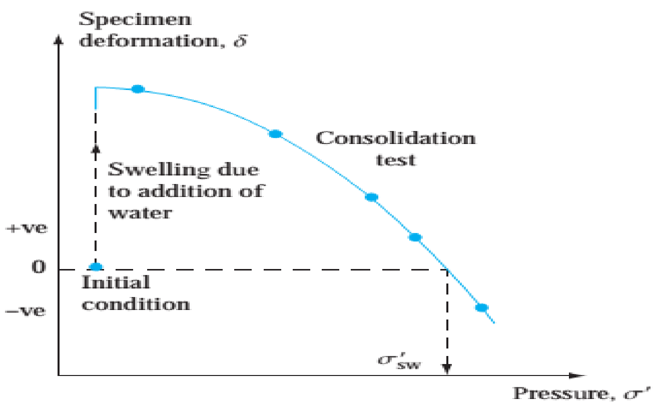


Figure 2-2: Graph of swelling pressure by swell-consolidation method [27].

2.6 Mineralogical identification

Type of clay mineral is a fundamental factor, which determines the expansive behavior of a soil. This method is used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and charge deficiency and surface activity of clay particle. These properties are a fundamental factor controlling Expansive soil behavior. [1]

The various techniques under this method are X-ray diffraction, Differential thermal analysis, Dye absorption, Electron microscope Base Exchange capacity, Infrared spectroscopy and Radio frequency electrical dispersion. But these methods are not suitable for routine tests because, they are time consuming, require expensive test equipment and, the results are interpreted by specially trained technicians.

2.6.1 Structure of Clay Minerals

An initial study of the crystal structure of clay minerals leads to a better understanding of the behavior of clays under different conditions of loading. Clay mineral is composed of two structural units of a silicon–oxygen tetrahedron unit and an aluminum or magnesium octahedron unit. [29]

2.6.2 Clay Minerals 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. [29]

2.7 Classification methods of Expansive Soils

The key to all Expansive soil classification systems is the method of measuring swell potential, since soils are rated by their measured swell potential. Swell potential may be measured directly in swell test or indirectly determined by correlation with other test results of swell test data. In almost every case swell potential is evaluated in the laboratory in a consolidation test device. This may yield swell potentials different from those for in-situ soils. Thus an accurate correlation between swell potential and other test results for a purpose of prediction of in-situ heave is difficult. These procedures, however, do provide good indicators of swell potential when the soil is subjected to the conditions used in the laboratory test [25]. There are two category of Soil classification systems are:

- General classification systems
- Classification Specific to Expansive soil

2.7.1 General Soil Classification Systems

2.7.1.1 Unified Soil Classification System

The basis for USCS is liquid limit and plasticity index of 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 consists 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:-

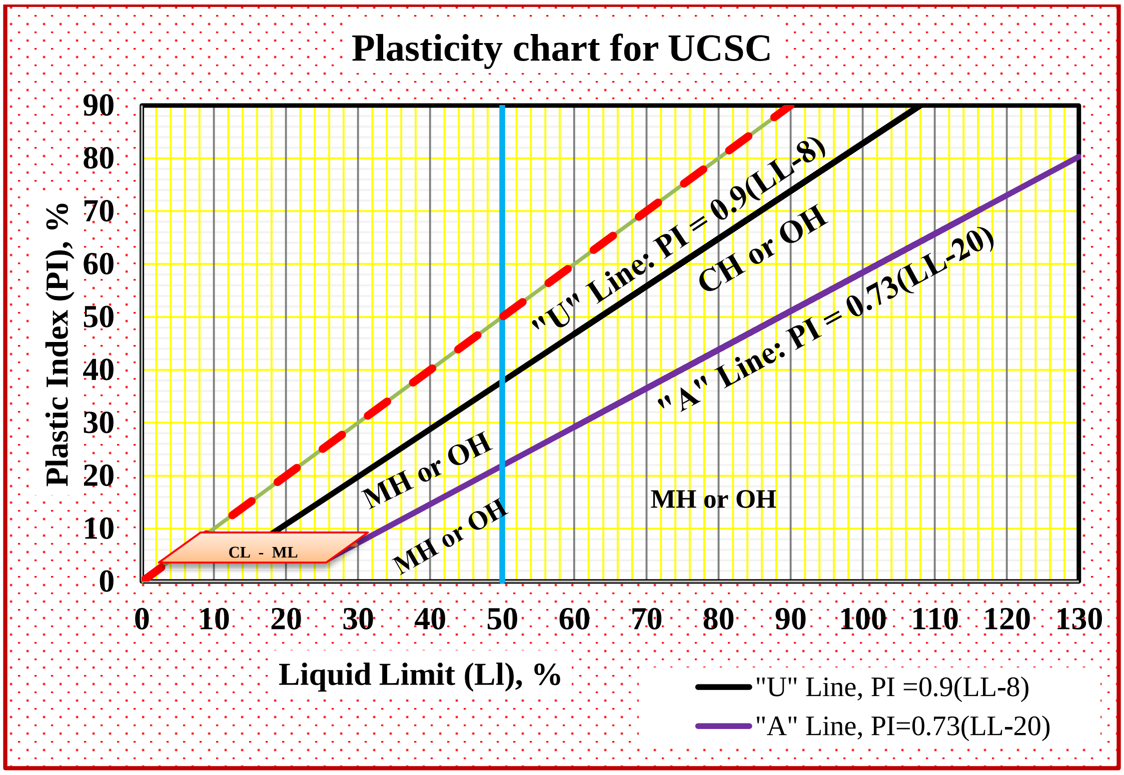


Figure 2-3: Casagrande Plasticity Chart (ASTM D2487-11) [25].

Table 2-1: Soil Classification in Unified System

Symbol	Category	soil classification
1	Little or no expansion	GW, GP, GM, SW, SP, SM
2	Moderate expansion	GW, SC, ML, MH
3	High volume change	CL, OL, CH, OH
4	No rating	PT (Organic peat)

2.7.1.2 AASHTO Soil Classification system

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 sieve classified under groups A-4, A-5, A-6 and A-7. 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 which have high plasticity indexes in relation to liquid limit and which are subject to extremely high volume change [26].

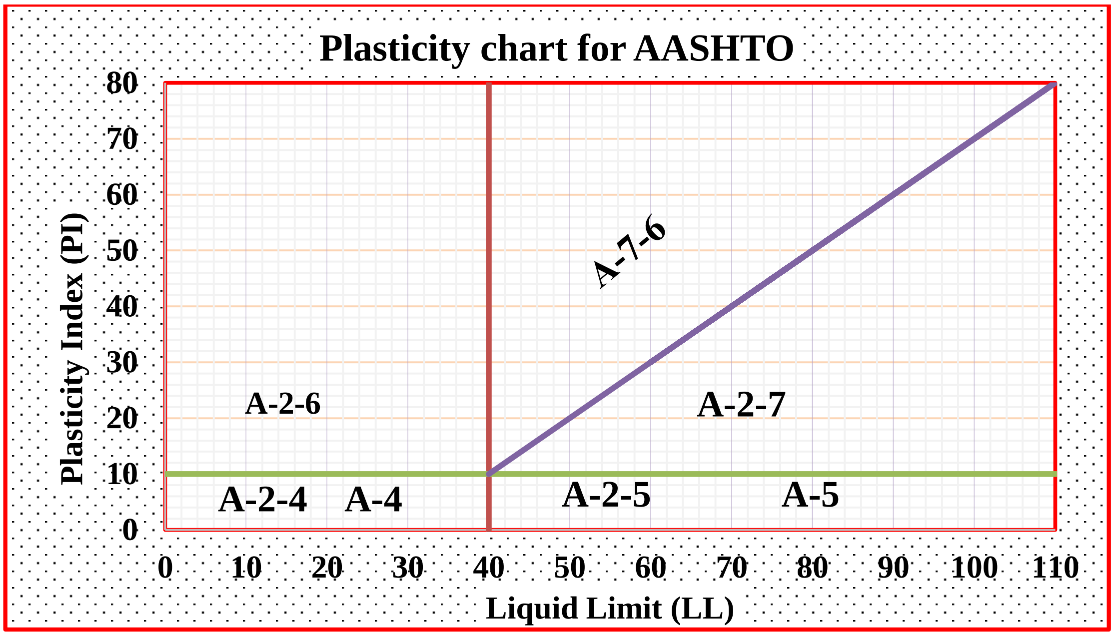


Figure 2-4: Liquid limit vs Plasticity Index chart for AASHTO classification [26].

2.7.2 Classification specific to Expansive soils

The above classification system may give an initial alert that the soil may have expansive character but does not 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 [11].

Hence, it is very important to emphasize that design decision has to be based on predicting testing and analysis, which provide reliable information. An indirect prediction of swell potential includes correlations based on index properties, swell, physical indicator and a combination of them. Some of such classification methods are:

Skempton‘s method [28]

Skempton classifies clays according to their activities. Following his classification, three degree of colloidal activity (Activity, Ac = PI/ percentage by weight finer than 2μm) have been established as indicated in table below.

Table 2-2: Degree of colloidal activity (Skempton's method)

Degree of activity	Activity
Inactive clay	<0.75
Normal clay	0.75-1.25
Active clay	>1.25

Following this classification:-

- montmorillonitic clay (expansive clay) is defined as active
- Illitic clay as normal and
- Kaolinitic clay as inactive.

U.S.B.R Classification Method

This method was developed by Holtz and Gibbs [42] to establish degree of expansion based on simultaneous consideration of shrinkage limit (SL), plasticity index (PI), percent smaller than 0.001mm (1µm), free swell (FS) and percent swell under a pressure of 1psi. The relationship between degree of swell and indicative clay properties as established by Holtz and Gibbs are presented in table below.

Table 2-3: U.S.B.R Classification method

Degree of Expansiveness	Swell in oedometer under a pressure of 1psi (%)	SL, %	PI, %	Percent smaller than 1µm	FS, %
Very high	> 30	< 10	> 32	> 27	> 200
High	20 - 30	6 - 12	23 - 45	18 - 37	100 - 200
Medium	10 - 20	8 - 18	12 - 34	12 - 27	50 - 100
Low	< 10	> 13	< 20	< 17	< 50

Altmeyer [28]

He suggested rating for degree of expansion based on volumetric shrinkage limit (SL) and linear shrinkage (LS) as shown in Table below.

Table 2-4: Altmeyer classification of expansive soil based on SL, % and LS, %

Volumetric SL, %	LS, %	Degree of expansion
<10	>8	Critical
10 - 12	5 - 8	Marginal
>12	<5	non critical

Seed, Woodward and Lundgreen [43]

According to Seed, Woodward and Lundgreen, Plasticity Index is a parameter which can be used as a preliminary indicator of the swelling characteristics of a soil.

Table 2-5: Seed, Woodward and Lundgreen classification of expansive soil.

Swell Potential	Plasticity Index
Low	0-15
Medium	10_35
High	20-55
Very High	35 and above

Chen Method [1]

In this method, a correlation is made between swell data and percent passing less than number 200 sieve, liquid limit, and standard penetration resistance and their degree of expansiveness stated.

Table 2-6: Chen method of classification of Expansive soil

Percent passing < No. 200 sieve, %	LL, %	SPR	Probable Expansion, %	Degree of expansiveness
< 30	< 30	< 10	< 1	Low
30 - 60	30 - 40	10 - 20	1 - 5	Medium
60 - 95	60	20 - 30	3 - 10	High
> 95	> 60	> 30	> 10	Very high

2.7.3 Other Expansive soil classification based on different index properties

The indirect methods of characterizing the soil swell potential suffer from the following limitations: [41]

Indirect Methods:

1. **Atterberg limit related properties**

Table 2-7: Expansive soil classification based on liquid limit

Swell Potential	Liquid limit, LL (%)		
	Chen (1965)	Snethan et al. (1977)	IS: 1498 (1970)
Low	< 30	< 50	20 - 35
Medium/marginal	30 - 40	50 - 60	35 - 50
High	40 - 60	> 60	50 - 70
Very high	> 60	--	70 - 90

Table 2-8: Expansive soil classification based on plasticity Index

Swell Potential	Liquid limit, LL (%)		
	Holtz and Gibbs (1956)	Chen (1988)	IS: 1498 (1970)
Low	< 18	0 - 15	< 12
Medium	15 - 28	10 - 35	12 - 23
High	25 - 41	20 - 55	23 - 32
Very high	> 35	> 35	> 32

2. **Shrinkage limit related properties**

Table 2-9: Expansive soil classification based on shrinkage limit (Holtz and Gibbs1956)

Swell Potential	Shrinkage limit, SL (%)
Low	> 15
Medium	10 - 16
High	7 - 12
Very high	< 11

Table 2-10: Expansive soil classification based on shrinkage limit (Altmeyer, 1956)

Volume Change	Shrinkage limit, SL (%)
Non-critical	> 12
Marginal	10 - 12
Critical	< 10

Table 2-11: Expansive soil classification based on shrinkage index (IS: 1498)

Degree of expansiveness/swell potential	Shrinkage Index, SI (%)
Low	< 15
Medium	15 - 30
High	30 - 60
Very high	> 60

3. Particle size composition related properties

Table 2-12: Expansive soil classification based on particle size composition

Swell Potential	Percent clay size fraction (Chen 1965)	Colloid content (Holtz and Gibbs1956)
Low	< 30	< 15
Medium	30 - 60	13 - 23
High	60 - 95	20 - 31
Very high	> 95	> 28

Table 2-13: Expansive soil classification based on the activity

Activity (A_c)	Nature of the soil	Probable Degree of swell potential
< 0.75	Inactive	Low
0.75 – 1.25	Normal	Marginal
> 1.25	Active	High

Direct methods:

1. **Oedometer Tests**

Table 2-14: Expansive soil classification based on oedometer swell tests

Swell Potential	% Expansion in Oedometer (Holtz and Gibbs 1956)	% Expansion in Oedometer (Seed et al. 1962)
Low	< 10	0 - 1.5
Medium	10 - 20	1.5 - 5
High	20 - 30	5 - 25
Very high	> 30	> 25

2. Free swell test

Table 2-15: Expansive soil classification based on Free Swell Index (FSI, %)(IS 1498:1970)

swell potential	FSI (%)
Low	< 50
Medium	50 - 100
High	100 - 200
Very high	> 200

Table 2-16: Expansive soil classification based on FSR (Sridharan and Prakash 2000b)

Free Swell Ratio	Clay type	Swell potential	Dominant clay mineral type
≤ 1.0	Non-swelling	Negligible	Kaolinitic
1.0 - 1.5	Mixture of swelling and non-swelling	Low	Mixture of Kaolinitic and Montmorillonitic
1.5 - 2.0	Swelling	Moderate	Montmorillonitic
2.0 - 4.0	Swelling	High	Montmorillonitic
> 4.0	Swelling	Very high	Montmorillonitic

2.8 Mechanics of Swell

Soil volume change results from an imbalance in internal energy of the system (soil, water, air). Energy imbalances are important in engineering result from moisture movement caused by loads, desiccation, and temperature changes. Response to a specific set of conditions determined by the composition, structures, and geologic history of the soil. The largest component of volume change is that of the clay micelle which surrounds the individual clay particles in the soil. Water is forced out of the micelle by loads, desiccation, or temperature along energy gradient and reduction in volume results. When these influences removed or reduced, the energy gradients reversed, the available water forced into the clay micelle, and swell is produced [28].

Swelling in expansive soils will take place if there is change in the environment. Environmental change can consist of pressure release due to excavation, desiccation caused by temperature increase, and volume increase because of the introduction of moisture. By far the most important element for swelling is the effect of water on expansive soils. With the introduction of water, volumetric expansion takes place. If pressure applied to prevent expansion, the pressure required to maintain the initial volume is the swelling pressure [1].

2.8.1 Moisture Transfer

The pattern of moisture migration depends on the geological formation, climatic condition, topographic features, soil types and ground water level. The most common method of moisture transfer is by gravity. The moisture migration can occur in all direction. Moisture migration will caused by different reasons. Fractures and fissures, shrinkage cracks, capillary force, vapor transfer, thermal gradients, etc. are some of the sources that cause moisture migration and swelling on expansive soils [1].

2.8.2 Moisture Equilibrium

In natural ground, the moisture content of the partially saturated soil is in general equilibrium with the applied stress, the forces due to evaporation and transpiration at ground surface and the capillary forces. When building or pavement covers the area, the evaporation and transpiration forces are eliminated and a new set of equilibrium must be established. The new equilibrium requires the flow of moisture compatible with the new condition. The force causing the moisture change or flow is termed soil suction [1].

2.8.3 Depth of Moisture Fluctuation

In covered area, there is no gain or loss of moisture to the atmosphere. The moisture content of the soil decreases with depth as shown in curve 1 of Fig 2.10. In uncovered natural conditions evaporation and transpiration causes loss of moisture content in the soil near the ground surface. Hence, the moisture content will increase with depth. However the influence of evaporation decreases with depth and at some depth, Had, the moisture content equilibrium remains the same as the covered condition. The value of H_D depends on the climatic condition, type of soil, and the location of the water table. This depth represents the total thickness of the material, which has a potential to expand because of change of moisture content. The maximum depth of H_d is equal to the depth of the water table, and the minimum depth is equal to the depth of the seasonal moisture contents fluctuation (H_s). During wet months with heavier precipitation and higher humidity, the moisture content of near surface soil increases and the moisture profile represented by curve 2 alters its shape to curve three. The watering of lawns, planting of trees and shrubs, discharge of roof chains, formation of drainage channels and swales, and the possibility of utility line leakage will all increase the value of Hs. When areas are covered by structures such as buildings, pavements, sidewalks or aprons evaporation is blocked or partially retarded. The moisture content beneath the covered area decreases due to gravitational migration, capillary action, and vapor and liquid thermal transfer and, in course of several years, the depth of seasonal moisture content fluctuation Hs can approach to the depth of desiccation Hd [1].

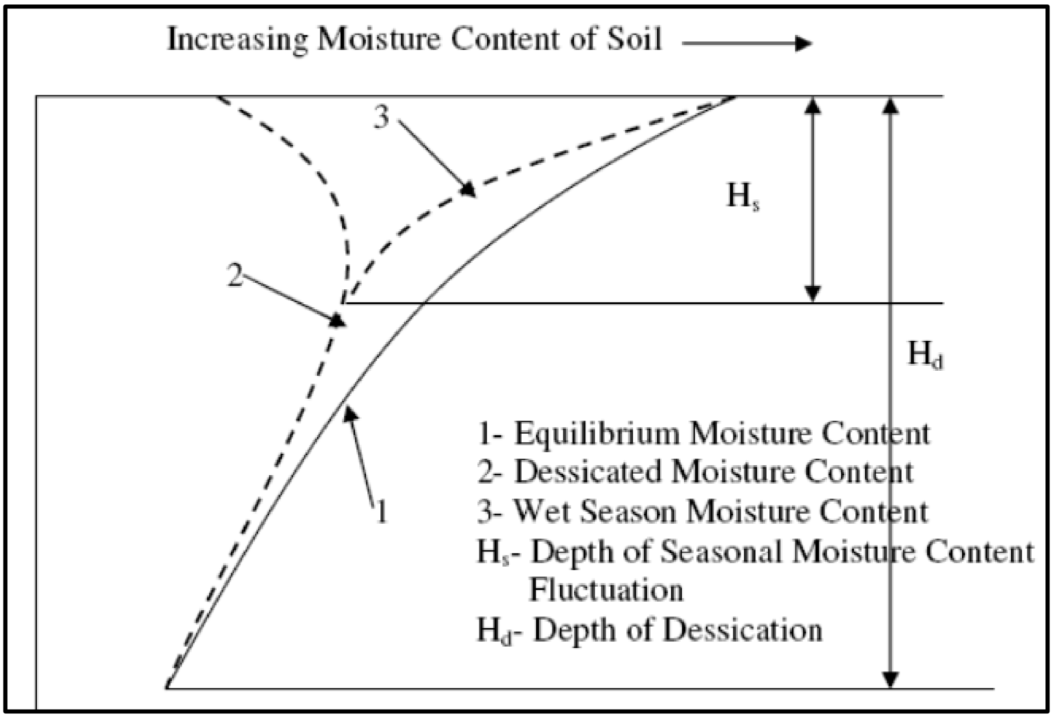


Figure 2-5: Moisture content variation with depth below ground surface [Chen, 1998]

2.9 Formation of Swelling Soils

Swelling soils find wide distribution in areas of volcanic deposition or origin with tropical climate and also in arid and/or semi desert climates. In tropical volcanic settings, alumina rich volcanic ash gets deposited in general over a wide area. Some get concentrated in depressions or low areas which are almost always inundated or saturated with water. This regular inundation tends to leach the alumina and concentrate these at the bottom 1.0 meter to 2.0 meters generally but could be deeper depending on the leaching effects. This explains the sporadic occurrence of expansive soils as generally, the expansive soils are not deposited area wide and thus portions of the project footprint mayor may not be underlain by these soils. [40]

2.9.1 Origin of Swelling Soils

In tropical volcanic environments, volcanic soils rich in alumina is deposited as Aeolian deposits. These Aeolian deposits settle in the land and are thicker in depressed areas. The alumina gets leached and concentrated due to ponding and saturation in the depressed areas. This alumina is the primary source of the expansive tendency and most often are shallow in occurrence due to the limited leveling effects.

2.9.2 Damage to Structures

Type of Damages: Damages sustained by structures include: distortion and cracking of pavements and on-grade floor slabs; cracks in grade beams, walls, and drilled shafts; jammed or misaligned doors and windows; and failure of steel or concrete plinths (or blocks) supporting grade beams. Lateral forces may lead to buckling of basement and retaining walls, particularly in over consolidated and non-fissured soils. The magnitude of damages to structures can be extensive, impair the usefulness of the structure, and detract aesthetically from the environment. Maintenance and repair requirements can be extensive, and the expenses can grossly exceed the original cost of the foundation.

Occurrence of Damages: Damages can occur within a few months following construction, may develop slowly over a period of about 5 years, or may not appear for many years until some activity occurs to disturb the soil moisture. The probability of damages increases for structures on swelling foundation soils if the climate and other field environment, effects of construction, and effects of occupancy tend to promote moisture changes in the soil. [40]

2.10 Mechanism for Moisture Ingress and Removal

Cyclical Water Ingress and Removal causes moisture imbalance that triggers the “Shrink-Swell Cycles”. The cyclical nature of the “shrink-swell cycle” is caused by the periodic entry and evacuation of water in the soil. If only moisture equilibrium can be maintained within the structure then the damage due to cyclic movements of water into and out of the soil can be prevented or minimized. This points to one remediation measure that could be effective in remediating existing structures that have experienced damage due to swelling and shrinking of the soils.

The following properties help us to understand the swell and shrink tendency of high plastic soil.

- Fine Grained Soils possess characteristic Crystal Lattices that are very small and could not normally be seen even under a Microscope.
- These Crystals possess electrical charges. The finer the crystals the greater is the surface area and the attractive electrical charges.
- The electrical attractive forces and the high affinity for water are very great as to cause separation of the clay platelets to adsorb the water and cations. This continued adsorption and absorption causes the swelling of the soil which could be reversible during periods of evapotranspiration and Matric suction. This phenomenon causes the shrink swell cycle.
- Salt Cations in the soil water are attracted to the surface of the Lattice crystals to balance the Charges. These salt cations such as magnesium, alumina, sodium, potassium are dissolved in the soil water and adsorbed on the clay surfaces as exchangeable cations. The hydration of these Cations can cause the attraction and accumulation of water between the clay particles.[40]

2.11 Application of heave predictions

Reasonable estimates of the anticipated vertical and horizontal heave and the differential heave are necessary for the following applications.

- Determination of adequate designs of structures that will accommodate the differential soil movement without undue distress. These predictions are also needed to estimate upward drag from swelling soils on portions of deep foundations such as drilled shafts within the active zone of moisture change and heave. Estimates of upward drag help determine an optimum design of the deep foundation.
- Determination of techniques to stabilize the foundation and to reduce the anticipated heave

2.11.1 Potential total Vertical heave

The foundation soil may expand both vertically and laterally. The vertical movement is usually of primary interest, for it is the differential vertical movement that causes most damages to overlying structures. Methodology for prediction of the potential total vertical heave requires an assumption of the amount of volume change that occurs in the vertical direction. The vertical heave ΔH from a consolidometer test can be found by: [40]

$$\frac{\Delta H}{H} = \frac{C_s}{1+C_s} \text{ Log } \frac{\delta_s}{\delta'_v}$$

Where: H = thickness of expansive soil layer, m

Cs = Swell Index, slope of the curve between initial and final effective stress

Δs = Swell pressure, kpa

δ'_v = final vertical effective stress, kpa

The final effective stress is given by: $\delta'_v = \delta'_v - u_w$; where δ_v is the total vertical overburden pressure and u_w is the equilibrium pore water pressure.

2.12 Previously Developed Equations of Study Area

Several investigators attempted to develop correlations for prediction of swelling pressure in terms of their index properties. Some of the previous experimental works are:

- Komornik and David, (1969) found out this empirical equation [20]: -

  Log Ps = 0.132 + 0.0208*LL + 0.6688* γd- 0.0269* w …………….2.1

- Vijayvergiya and Ghazzaly (1973) found out those empirical equations [20]:-

  Log Ps = 1/12 (0.4*LL – **ω** +23.6 …………………2.2

  Log Ps = 1/19.5(6.24*γd + 0.65*LL-100 …………………2.3

Some of researches on the relationship between index properties and swelling pressure of expansive soils of Ethiopia have been developed by:

- Ashenafi (2013) studied about Index Properties and Swelling Pressure of Expansive soils found in Dukem using the regression analysis based on experimental results and found out this empirical equation [33]:-

  Ps = 1.639* γd +32.676* PL-3110.94 ………………………………….2.4

- Daniel (2003) studied about Examining the Swelling Pressure of Addis Ababa Expansive Soils using multiple regression analysis and he recommended the following empirical equations [20]:-

  Log Ps = -5.00 - 0.0002064*LL + 0.003477*PI + 0.005827* γd…………2.5

  Log Ps = -9.384 + 0.02748*W + 0.006307*PI + 0.008359* γd …………2.6

CHAPTER THREE
MATERIAL SAMPLING AND TESTING METHODOLOGY

3.1 Introduction

In order to achieve the objectives of this research thesis, literature reviews of many investigators used. Necessary information about the geology, climatic condition, and topography of the site collected and analyzed. The research methodology of this study will contain the laboratory analysis that focus on index properties and swelling pressure of the expansive soil and the estimation and prediction of their relationships using the laboratory test results of the given soil properties.

3.2 Description of the study area

Burayu town is one of the Oromia special zone surrounding Finfinne which was established in August 2008 as one of zones of Oromia National Regional State. This Zone is located in the central part of Oromia National Regional State. This research conducted in Burayu town, which is one of the nine municipal town administration of Oromia Special Zone Surrounding Finfinne.

Burayu town is located in Oromia National Regional State in the western fringe of Finfinne, along the Finfinne-Ambo road; 15km away from the center of Finfinne measured from Birbirsa Goro. Astronomically the town extends roughly from 9^{o} 02' to 9^{o} 02'30" North latitudes and 38^{o}03'30" to 38^{o}41'30" East longitudes. According to census, the population of Burayu town was 4,138 in 1984, 10,027 in 1994, 63,873 in 2007 and 100,200 in 2010 (estimated). Burayu town administration has estimated that the population of the town has grown to more than 150,000 in 2014 showing that the town is growing very fast. Location of the research area on the map of Ethiopia shown as in figure 3.1 below [35].

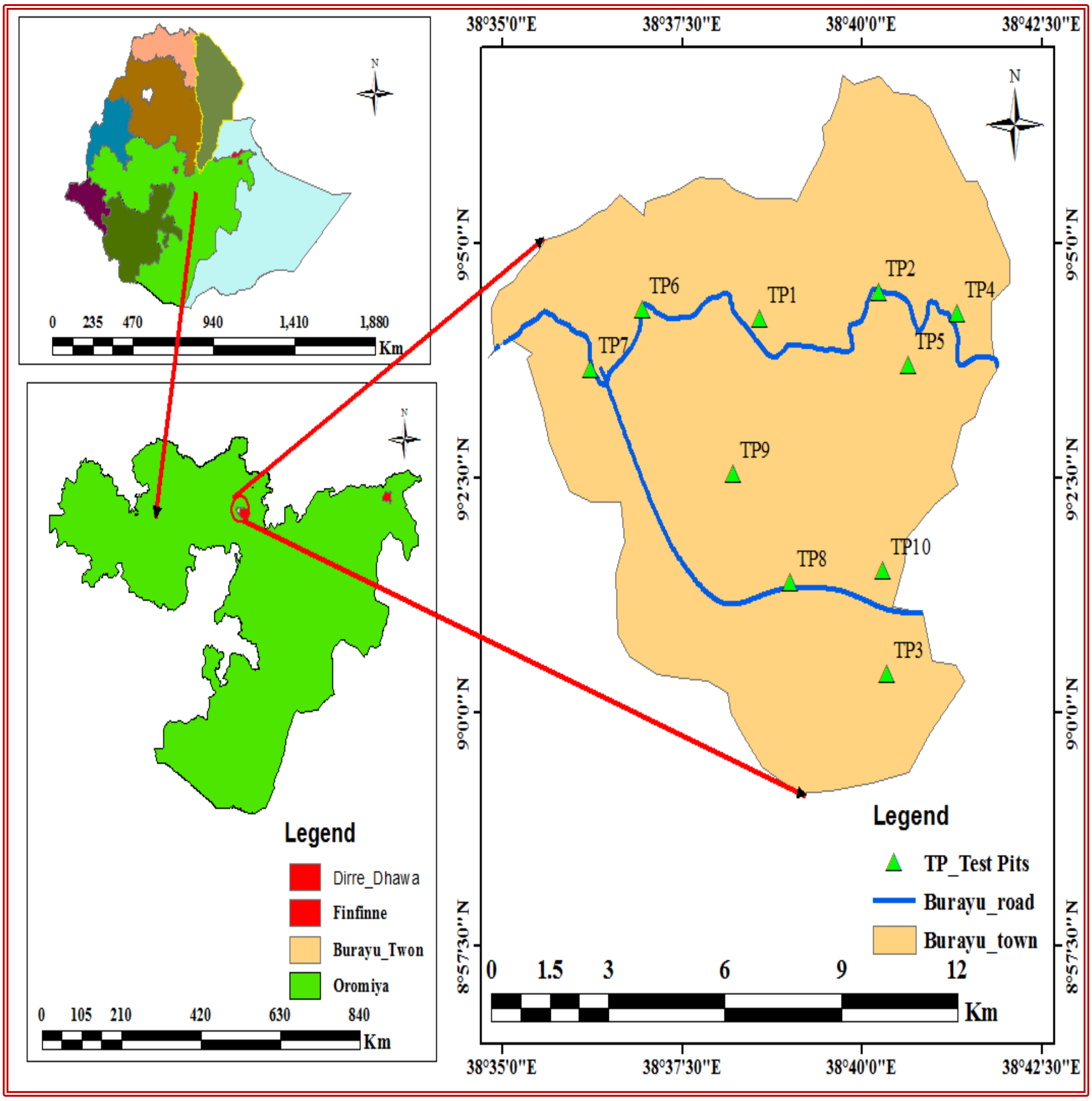


Figure 3-1: Location of Study area on the map of Ethiopia (Source: Based on Maps of Oromia National Regional State, 2012) [35].

Table 3-1: Test Pit Location of Study Area

Test Pits	Location of Test Pits	Northing	Easting
TP1	Gafarsa Burayu (Burayu Stadium)	9.0700582	38.6430701
TP2	Burayu Katta (Burayu Qera)	9.0746226	38.6705131
TP3	Malka Gafarsa (Anfo Meda)	9.0067820	38.6724442
TP4	Lakku Katta (Sansusi)	9.0709269	38.6888562
TP5	Lakku Katta (Wisdom Seeder School)	9.0618292	38.6773577
TP6	Gafarsa Guje (Corrisa)	9.0715696	38.6157807
TP7	Gafarsa Guje (Kella)	9.0610531	38.6038624
TP8	Gafarsa Nonno (Gabriel)	9.0230317	38.6500000
TP9	Gafarsa Burayu (Xache)	9.0423191	38.6367890
TP10	Gafarsa Nonno (A/meda)	9.0251030	38.6714959

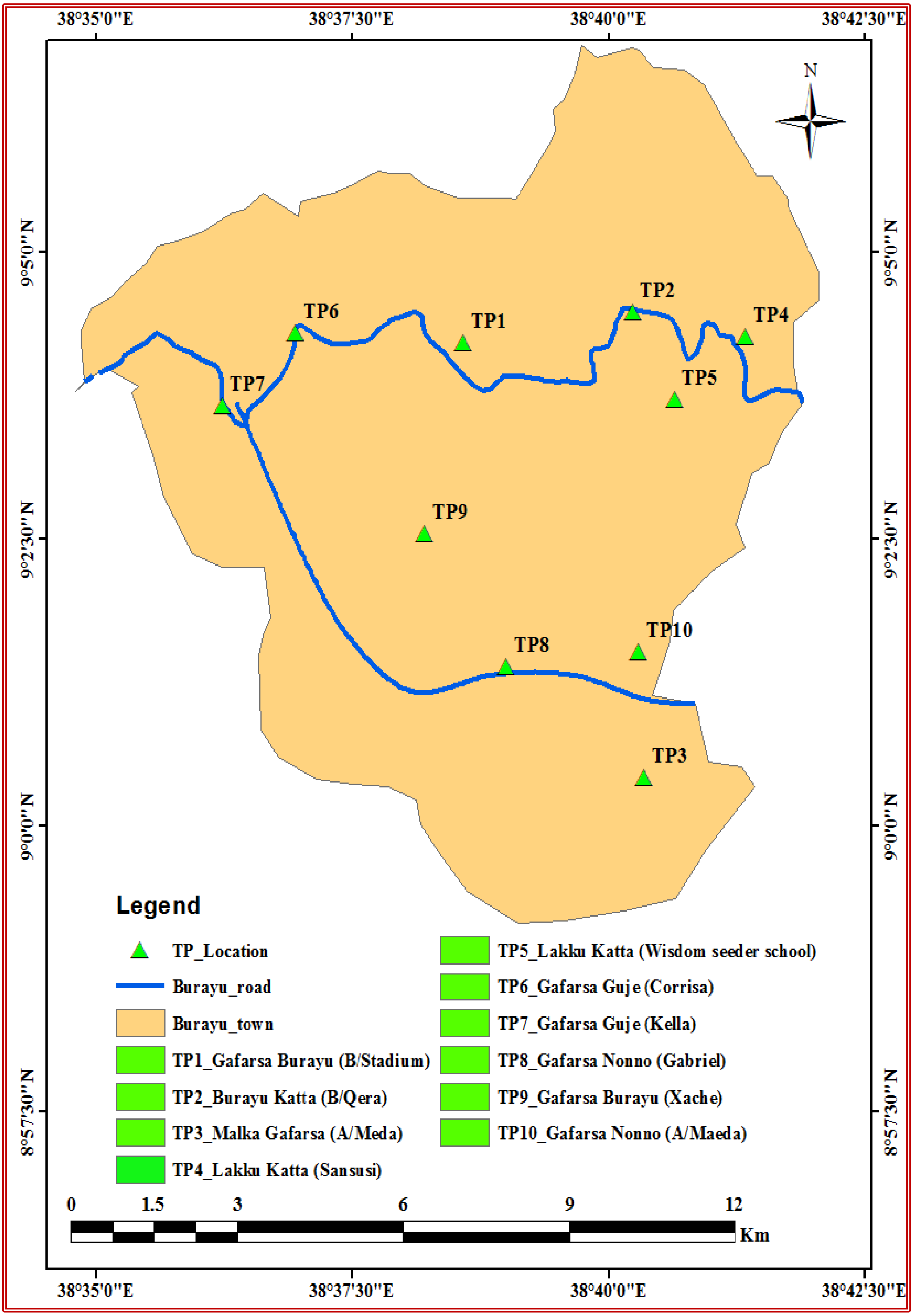


Figure 3-2: Sampling Locations of the Study Area on the Map of Burayu Town

3.3 Study design

A study design/frame is the process that guides researchers on how to collect, analyze, and interpret observations. Therefore, the objective of the research will be achieved in accordance with th methodology outlined below

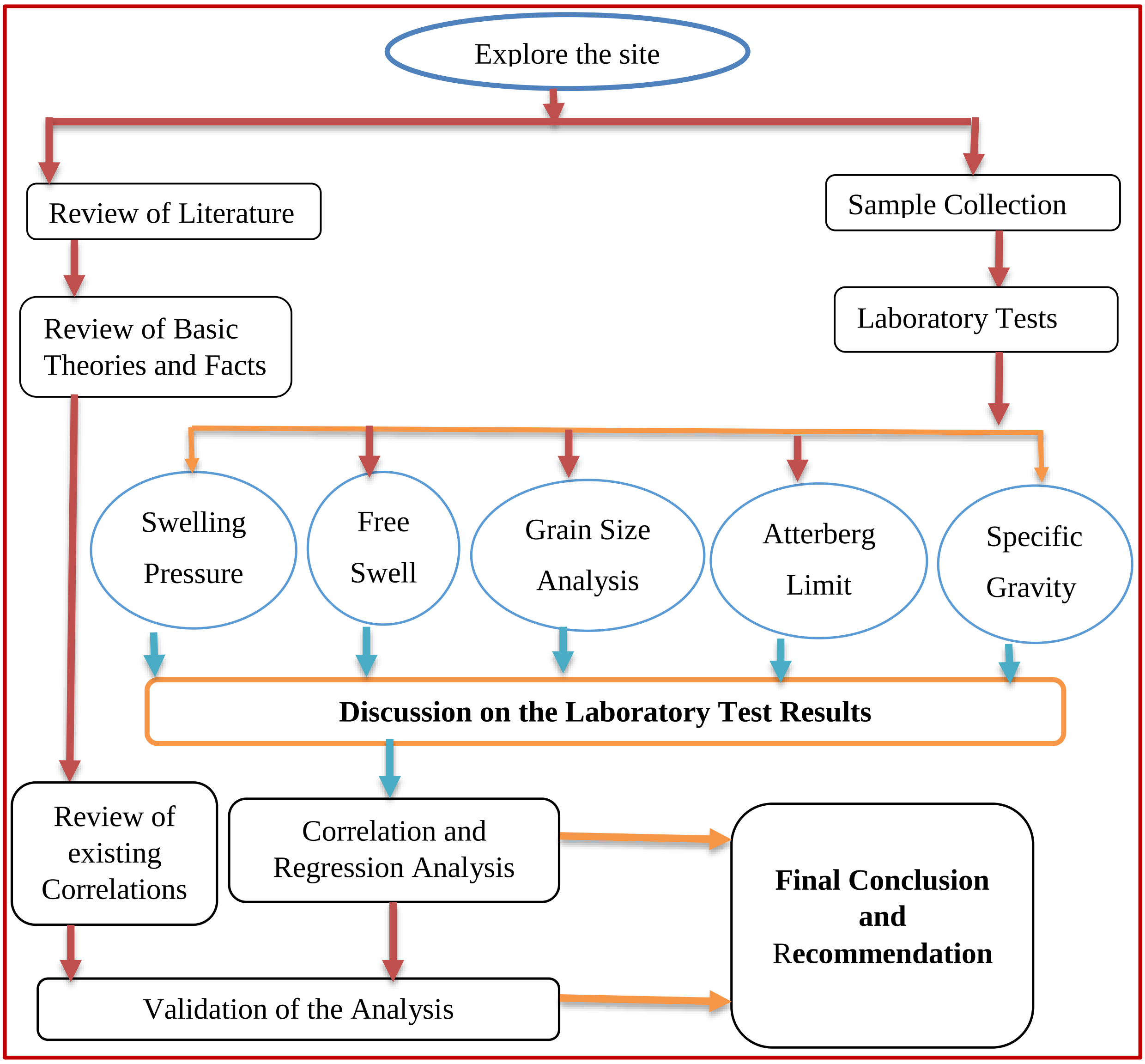


Figure 3-3: Flow chart for the overall frameworks

3.4 Study Population

At an early stage in the planning of any investigation, decisions must made concerning the study population. That is, concerning the population of individual units investigated. According to this Research thesis, the study population that will concern the study of Engineering properties of the sub-surface soils that is collected from 10(ten) test pits around study area. So that, the geology, climate condition and the topography of the surrounding study area considered as the study population, which will be required as a source for data sampling and collection process.

The population is too large to consider during data collection process from all test pits. Instead, the samples selected individually from each test pits; that the sample is representative of the population. That means, each samples taken from each test pits (population) for data collection and analysis.

3.5 Sampling techniques and procedures

3.5.1 Sampling Techniques

Random sampling technique was used to explore the site within and outskirt of Burayu town. Sampling is mainly concerned to ensure that a sample is representative of the study population, which should be large enough to provide sufficient material to achieve the desired detection limit. Sampling involves the selection of a number of study units from a defined study population.

Ten test pits excavated using local labor and all samples were collected from each test Pits at different depths from different parts of Burayu Town. Three soil samples taken from one test pit that is totally thirty disturbed and undisturbed samples collected for further laboratory investigations.

3.5.2 Sampling Procedures

Reconnaissance study of the area done by visiting the entire part and the surrounding part of the town. The location of test pits will selected, so that it can well represent the soil types (visually) found in the Burayu town. During roughly selection of location of test pits, that includes red clay, gray and the black cotton soils were more preferable for the study of expansive characteristics of soils.

3.5.3 Selection of Sampling Sites

When selecting possible sampling sites, the major factor considered was that the site to be definitely located in the expansive soil region. To ensure the sites covered with expansive soil, the sites identified by visual investigation and field identification. After identification of the area thirteen (10) different test pits was selected from different locations. Thirty-(30) disturbed and undisturbed samples taken from depths (1m, 2m and 3m). Sampling locations of the town shown as in the above figure 3.2.

Depending on the above criterion the sites that show expansive in nature excavated and collected for the laboratory test analysis.

3.5.4 Collection of Soil Samples

After locations of the test pits was selected and the excavation work was conducted, It was decided to collect approximately thirty(30) samples from ten(10) test pits for testing. Then the soil samples collected from the field for further analysis and the laboratory tests carried out. Collection of Soil Samples was takes pace up to 3m depth then disturbed and undisturbed samples taken by plastic bags. The undisturbed samples extracted in which both ends of steel tube sealed with wax (melted candle) and tighten by polyethylene bags. Both the disturbed and undisturbed samples transported to the Jimma University Geotechnical laboratory o classify and categorize the soil type and the regression and correlation analysis will be determined.

3.6 Experimental study or Laboratory Tests

In order to classify the soils and assess the correlations between swelling pressure and index properties of soils, a series of tests conducted. To obtain the intended purpose of this research thesis the following laboratory tests must carried out.

- Particle size distribution (ASTM D422-98)
- Specific gravity of soil solid (Gs) (ASTM D854-98)
- Natural moisture content (ASTM D2216-98)
- Dry density (γd) (ASTM D2937-98)
- Atterberg limits (ASTM D4318-98)
- Linear Shrinkage Limit (ASTM D427-98)
- Swelling Pressure test (ASTM D4546-96
- Free swell test

3.7 Data collection process and Analysis

3.7.1 Data collection process

The data collection represents a plan for gathering data information from the study area. A set of the procedure followed to get the desired data or information from the fieldwork according to the ASTM Standard Manual in order to process and analysis the facts in a logical and scientific manner.

The investigation involved collection of relevant geologic maps and associated reports and supplementary study materials from different sources. Regional geologic setting of the area mainly referred from the countrywide geologic map prepared by the Geological Survey of Ethiopia

3.7.2 Collection Data for analysis

Detail statistical analyses of soil index properties and swelling pressure of expansive soils of the study area carried out using various data sets to determine suitable correlations for estimating swelling pressure. For analysis, different data points used for development of new model. The analysis carried out by using Computer Software Program (SPSS-20) and Microsoft Spreadsheet (MS- Excel) to predict the correlation between swelling pressure and index properties of expansive soils.

Using laboratory test results new correlations developed and the best formula selected from developed equations and the graph of predicted value with the measured values of swelling pressure plotted.

3.8 Statistical Data Analysis for Correlation and Regression

Many problems in engineering and the sciences involve a study or analysis of the relationship between two or more variables. In statistical terms, a correlation is a mathematical measure of the strength of association between two quantitative variables. A closely related cousin of correlation analysis is regression analysis. The collection of statistical tools that are used to model and explore relationships between variables are related in a non-deterministic manner is called regression analysis. Because problems of this type occur so frequently in many branches of engineering and science, regression analysis is one of the most widely used statistical tools.[36]

3.8.1 Data distribution Analysis of the Model

3.8.1.1 Choice of Sample Size

Technically, the size of the sample depends upon the precision the researcher desires in estimating the population parameter at a particular confidence level. There is no single rule that can use to determine sample size. A larger sample is much more likely to be representative of the population. Furthermore, with a large sample the data are likely to be more accurate and precise. It was pointed out in that the larger the sample, the smaller the standard error. In general, the standard error of a sample mean is inversely proportional to the square root of sample size (n). [38]

According to [38] the equation to yield a representative sample for proportions of large sample developed as follows:

$$N = \frac{Z^2 P * q}{\varepsilon^2}$$

Where: N is the sample size,

Z^2 = the abscissa of the normal curve that cuts off an area α at the tails (1 – α) equals the desired confidence level is 95%),

ε = the desired level of precision

p = the estimated proportion of an attribute that is present in the population, and

q = 1-p.

When conducting research investigation on quantitative data, the sample size calculated by the following formula:

$$N = \frac{t_{\alpha}{}^{2} * s^2}{\varepsilon^2}$$

Where; N = the desired sample size,

S = the standard deviation of observations,

ε = the permissible in the estimate of mean and tα is the value of at 5% level of significance

3.8.1.2 Normality Test

To supplement the graphical assessment of normality, you can formally test for normality. For example, the Kolmogorov-Smirnov and ShapiroWilk test reported in the SPSS Explore procedure used to test the hypothesis that the distribution is normal. (SPSS recommends these tests only when your sample size is less than 50). The hypotheses used in testing data normality are as follows [37]:

H_0: the distribution of the data is normal.

H_a: the distribution of the data is not normal.

If a test does not reject normality, this suggests that a parametric procedure that assumes normality, (e.g., a t-test) safely used. However, we emphasize again that it is always a good idea to examine data graphically in addition to the formal tests for normality.

To further examine the data (and perhaps understand the reasons for the discrepancy), you can visualize the distribution of the data using graphical displays such as a histogram, boxplot, stem-and-leaf diagram, and normal Q-Q plot.

A brief explanation of how to interpret each of these plots in the context of normality:

- **Histogram:** When a histogram's shape approximates a bell curve, it suggests that the data may have come from a normal population.
- **Q-Q Plot:** A quantile-quantile (q-q) plot is a graph used to display the degree to which quantizes of a reference (known) distribution differ from the sample quantizes of the data. When the data fit the reference distribution, then the points will lie in a tight random scatter around the reference line.

3.9 Considerations for Statistical Analysis

There are various statistical techniques for analyzing data. To choose an appropriate technique of statistical analysis in the challenging task to a research worker. The major types of tests employed for analyzing data to interpret the test results are:

- Parametric statistics or tests, and
- Non-parametric statistics or tests.

A researcher has to select either of these approaches for analyzing his own research data depending on the criteria for choosing an appropriate statistical approach. [39]

3.9.1 Parametric Tests

The parametric tests are the tests of the most powerful type and used if their basic assumptions will based upon the nature of the population values and the ways of sample selection.

- The observations are independent. The selection of one case is in no way dependent upon the selection of any other case,
- The population values are normally distributed or, if not, the nature of their distribution known.
- The population values have equal variances or the ratio of their variances known.
- The variables measured are expressed in interval or ratio scales. Nominal or ordinal do not qualify.

3.9.1.1 Standard Error of the Mean or SE_{Mn}

The means of randomly selected samples, which are normally distributed, have their own standard deviation known as the standard deviation or standard error of the mean. The standard error of mean of a sample computed from the following formula:

SE_{Mn} or $\sigma M = \frac{S}{\sqrt{N}}$, Where, SE_{Mn} = Standard error of mean

S = Standard deviation of sample scores

N = Size of the sample

However, a particular mean calculated from a randomly selected sample related to the population mean in the following way.

68 % of sample means will lie within a range of ± 1 SEMn of the population mean.

95 % of sample means will lie within ± 1.96 SEMn of the population mean.

99 % of sample means will lie within ± 2.58 SEMn of the population mean.

3.9.1.2 Level of Significance

The rejection or acceptance of a null hypothesis depends upon level of significance as a criterion. Rejecting the null hypothesis at the 5 percent level indicates that a difference in means as large as that found between the experimental and control group means would not likely have resulted from sampling error in more than 5 out of 100 experiment. This suggests 95 percent likelihood or probability that the difference was due to the experimental variable.

The Sigma values that must exceed according to the values in the table for Rejection of Hypothesis.

Table 3-2: Sigma value that must be exceeded for Rejection of Hypothesis

Test	Level of 0.05	Significance 0.01
One tailed test	1.64	2.33
Two tailed	1.96	2.58
Probability	0.95	0.99

3.9.1.3 The Significance of R

To test the significance of a coefficient of correlation we may establish the null hypothesis that r = 0 and that any value of r, other than 0, is the possible result of sampling error. We assume that the sample r is one of a number of random samples. To use the z value and the probability table the r converted into z value by the formula: $Z = r\sqrt{N-1}$

If z value exceeds the table value, the hypothesis rejected and if not then the hypothesis is accepted.

3.9.1.4 The t- Test

The t- Test is a simple experiment that designed to establish cause effect relationships. It is used to determine whether the difference between means of two groups or conditions is due to the independent variable, or if the difference is simply due to chance. Thus, this procedure establishes the probability of the outcome of an experiment, and in doing so enables the researcher to reject or retain the null hypothesis. When small samples, fewer than 30 observations in number, are involved, the t-test used to determine the statistical significance. To compute t-value for the significance of the difference between two means, when N is fewer than 30, the formula is:

$$t = \frac{(M_1 - M_2)}{\sqrt{\frac{(N_1 - 1)S_1^2 + (N_2 - 1)S_2^2}{N_1 + N_2 - 2}}\sqrt{\frac{1}{N_1} + \frac{1}{N_2}}}$$

3.9.1.5 Analysis of Variance (F) ANOVA Test

The analysis of variance is a convenient way to determine whether the means of more than two random samples are too different to attribute to sampling error. The question raised by the analysis of variance is whether the sample means differ from their own sample means (within group variance).

If the variation of sample means from the grand mean is greater enough than the variance of the individual values from their sample means, the samples are different enough to reject a null hypothesis or sampling error explanation. If the among groups variance is not substantially greater than the within group variance, the samples are not significantly different and probably behave as random samples from the same population.

$$F = \frac{\text{Variance among groups}}{\text{Variance within groups}}$$

The significance of the 'f 'ratio found in 'f 'tables which indicate the values necessary to reject the null hypothesis at the 0.05 or the 0.01 levels.

3.9.2 Non-Parametric Tests

Non-parametric, or distribution free tests are used when the nature of the population distribution is not known or when the data are expressed as nominal or ordinal measures. The variables in non-parametric tests usually presented in rank order or discrete values.

3.9.2.1 Chi-Square Test (χ^2)

The Chi-square test applies only to discrete data (discrete variables are those expressed in frequency counts). The test would provide a method of testing the difference between actual preferences and choices based upon a probability assumption.

The Chi-square formula: $\chi^2 = \sum\left[\frac{(f_o - f_e)^2}{f_e}\right]$

Where, χ^2 = Chi-square

f_o = frequency of observed sampling error

f_e = frequency of Expected sampling error

3.9.2.2 The Sign Test

The sign test sometimes used to evaluate the effect of a type of treatment in a before-after experiment. The sign test uses the principles of the standard error of a dichotomous variable; deriving a Z-score by the formula:

$$Z = \frac{\mathbf{O-NP}}{\sqrt{\mathbf{NP(1-\rho)}}}$$ Where, O = +ve changes

N = + and –ve changes

P = 0.5 (equal probability of a gain or loss)

If Z value exceeds the table value, the null hypothesis rejected and if not exceeded then the null hypothesis is accepted.

3.10 Correlation and Regression Analysis

Regression analysis is an important technique in engineering and science to model and study relationships between two or more variables. The method of regression analysis used to develop the line or curve, which provides the best fit through a set of data points. The best-fit model will be in the form of linear, parabolic or logarithmic trend.

Best fitting a regression model requires several assumptions. [36] [37]

- The method of least squares used in order to choose the best fitting line for a set of data.
- The confidence level of an estimate will gives some idea about the accuracy of an estimate. A variable with a confidence level (CL) ≥ 95% is the best to choose.

3.10.1 Simple Linear Regression

The case of simple linear regression considers a single regressor variable or predictor variable X and a dependent or response variable Y. Suppose that the true relationship between Y and X is a straight line and that the observation Y at each level of X is a random variable.

Therefore, the fitted or estimated regression line is $\boldsymbol{Y = \beta_0 + \beta_1 X}$, where the intercept β_0 and the slope β_1 are unknown regression coefficients. Note that each pair of observations satisfies the relationship: $\boldsymbol{Y_i = \beta_0 + \beta_1 x_i + e_i}$, Where $\boldsymbol{e_i = Y_i - Y}$ is called the residual. The residual describes the error in the fit of the model to the i^{th} observation Yi. The residuals used to provide information about the adequacy of the fitted model.

3.10.2 Multiple Linear Regression Model

Many applications of regression analysis involve situations that have more than one regressor or predictor variable. A regression model that contains more than one regressor variable called a multiple regression model. A multiple regression model described by the following relationship: $\mathbf{Y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_k x_k + \epsilon}$; Where, Y= Dependent variable or response, x_i (i = 1, 2 … k) = independent variables or predictors, and β_j (j = 0, 1…k) = Regression coefficients

3.10.2.1 R-squared (R^2) and Adjusted R-square (Adj. R^2)

The coefficient of multiple determination R^2 used as a global statistic to assess the fit of the model. Computationally:

$R^2 = \frac{SS_R}{SS_T} = 1 - \frac{SS_E}{SS_T}$; Where, SS_R = Regression or model sum of squares

SS_T = Total sum of square

SS_E = Error or residual Sum of squares

Many regression users prefer to use an adjusted R^2 statistic, which is:

$R_{adj}^2 = 1 - \frac{SS_E/(n-p)}{SS_T/(n-1)}$; Where, $SS_E/(n-p)$ = Error or residual Sum of squares

$SS_T/(n-1)$ = Constant

3.10.2.2 Multicollinearity

Multiple regression expects to find the dependencies between the response variable Y and the regressor x_i. In situations in which these dependencies are strong, we say that Multicollinearity exists. Multicollinearity can have serious effects on the estimates of the regression coefficients and on the general applicability of the estimated model.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Laboratory Test Analysis and their Results

Laboratory tests carried out in accordance with the ASTM standard testing methods. The actual test results presented in the Appendices.

4.1.1 Atterberg limit Test Result (ASTM D4318-98)

The Atterberg limits of a fine-grained soil represent the moisture content at which the physical state of the soil changes. The tests for the Atterberg limits are referred to as index tests because they serve as an indication of several physical properties of the soil, including strength, permeability, compressibility, and shrink/swell potential.

Table 4-1: Determination of Atterberg limits (LL, PL and PI) of soil for TP1 @1m

Determination of Liquid Limit & Plastic Limit Of Soil						
Determination	Liquid Limit @ 1m				Plastic Limit @1m	
Number of blows		17	24	34		
Container	No	C-1	E-5	C-3	A-4	C-6
Wt. of container + wet soil	(gm)	59.282	57.516	56.517	27.729	29.716
Wt. of container + dry soil	(gm)	42.062	41.329	41.101	23.878	25.387
Wt. of container	(gm)	23.732	23.612	23.592	13.412	13.431
Wt. of water	(gm)	17.220	16.187	15.416	3.851	4.329
Wt. of dry soil	(gm)	18.330	17.717	17.509	10.466	11.956
Moisture content	(%)	93.944	91.364	88.046	36.795	36.208
Average	(%)	91.118			36.502	
Determination of (PI)	(LL - PL)					
	LL	91.20				
	PL	36.50				
	PI	54.70				

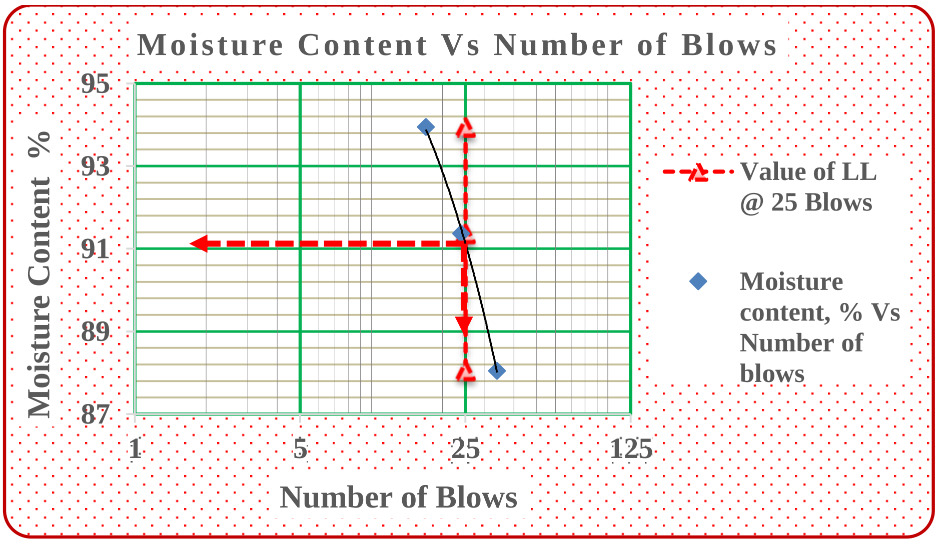


Figure 4-1: Graph of Moisture Content vs. Number of Blows for Determination of LL

Liquidity Index of the Soil: Atterberg limits, when compared with the natural water content of the soil, give a valuable indication of the natural state of the soil in the ground. The parameter used for this purpose is the liquidity index (LI), which expresses the water content of the soil in relation to the PL and LL which is defined by the following relationship:

$$LI = \frac{w - PL}{LL - PL}$$

Table 4-2: Atterberg Limit test and Liquidity Index Results of the study area

Test Pits	Depth (m)	LL	PL	PI	LI	Test Pits	Depth (m)	LL	PL	PI	LI
TP1	1	91.20	36.50	54.70	0.11	TP6	1	110.80	42.07	68.73	0.05
	2	88.70	34.58	54.12	0.12		2	108.60	39.60	69.00	0.01
	3	80.40	30.48	49.92	0.03		3	103.00	36.12	66.88	0.02
TP2	1	107.40	40.11	67.29	0.07	TP7	1	65.80	34.30	31.50	-0.08
	2	104.25	39.61	64.64	0.07		2	63.81	33.51	30.29	-0.17
	3	95.40	35.07	60.33	0.08		3	60.00	33.11	26.89	-0.24
TP3	1	81.28	29.23	52.05	0.19	TP8	1	113.40	45.38	68.02	0.03
	2	74.02	26.08	47.94	0.18		2	105.80	43.32	62.48	-0.01
	3	73.40	29.62	43.78	0.03		3	91.82	36.82	55.00	0.04
TP4	1	80.52	31.78	48.74	0.22	TP9	1	86.40	37.59	48.81	0.09
	2	79.02	29.04	49.98	0.18		2	79.56	31.34	48.22	0.14
	3	70.20	30.89	39.31	0.10		3	74.40	34.67	39.73	-0.02
TP5	1	77.20	34.05	43.15	0.13	TP10	1	116.40	45.16	71.24	0.08
	2	69.90	31.24	38.66	0.19		2	102.00	41.46	60.54	0.09
	3	67.10	34.40	32.70	-0.06		3	95.83	40.85	54.98	0.04

4.1.2 Linear shrinkage limit test result

Linear shrinkage test, by British standard BS 1377 1990 part 2, defines the determination of total linear shrinkage from linear measurement on a standard bar of length 140 mm with a semicircular section of diameter 25 mm. The grove filled by a soil of the fraction passing 0.425 mm test sieve, originally having the moisture content of the liquid limit.

$$\text{Linear shrinkage (\%)} = \frac{\text{Initial Length} - \text{Oven Length}}{\text{Initial Length}} * 100\%$$

The linear shrinkage value is the way of quantifying the amount of shrinkage likely to be experienced by clayey material. The results of linear shrinkage tests tabulated in table below.

Table 4-3: Determination of Linear Shrinkage limit test for Test pit 1

	Test pits	TEST PIT 1					
At 25 blows	Depth	1m		2m		3m	
	Container number	C1	E4	D2	F4	B-1	A-1
	Initial length of specimen (L_1),mm	140	140	140	140	140	140
	Length of dried specimen (L_2),mm	125.4	124.2	126.1	127.5	127.6	128.7
	Linear shrinkage;(L1-L2/L1)*100,%	10.429	11.286	9.929	8.929	8.857	8.071
	Avg. Linear shrinkage, (%)	10.86		9.43		8.46	

Table 4-4: Linear shrinkage limit test results of the study area

TEST PITS	Depth (m)	Linear shrinkage, (%)	TEST PITS	Depth (m)	Linear shrinkage, (%)
TP1	1	10.86	TP6	1	11.68
	2	9.43		2	11.29
	3	8.46		3	10.36
TP2	1	10.71	TP7	1	8.29
	2	9.86		2	7.86
	3	10.25		3	7.71
TP3	1	8.43	TP8	1	12.04
	2	8.54		2	11.39
	3	8.75		3	10.43
TP4	1	8.46	TP9	1	9.68
	2	7.82		2	9.25
	3	7.32		3	7.79
TP5	1	8.71	TP10	1	12.50
	2	9.36		2	11.07
	3	7.93		3	11.00

4.1.3 Specific Gravity Tests of soils (ASTM D854-98)

The specific gravity (Gs) of soil defined as the ratio of mass in air of a given volume of soil particles to the weight in air of an equal volume of distilled water at standard temperature. The specific gravity of soil used in calculating the phase relationships of soils water, and solids in a given volume of the soil. In addition, the specific gravity of soils is an important quantity, which frequently used in the calculation of percentage finer and diameter of the soil grains in hydrometer analysis.

Computations

$$Gs = \frac{K * W_S}{(W_s + W_{pw}(@Tx) - W_{pws})};$$

$$\text{Where: } w_{pw}(\text{atTx}) = \frac{\text{Density of water at Tx}}{\text{Density of water at Ti}} * \left(W_{pw}(\text{at Ti}) - W_p\right) + W_p$$

Table 4-5: Specific Gravity Determination for Test Pit 1

TEST PIT 1						
Depth	1m		2m		3m	
Pycnometer No.	O1	O2	O3	O4	O5	O6
Weight of dry, clean pycnometer, w_p (g)	28.511	29.442	28.515	29.46	30.069	29.964
Weight of pycnometer + water, w_{pw} (g)	124.495	123.572	124.851	126.338	125.342	121.856
Observed temperature of water, T_i (oc)	23	23	23	23	23	23
Weight of pycnometer + soil + water, W_{pws} (g)	130.961	130.029	131.257	132.738	131.671	128.178
Temperature, T_x(°c)	22	22	22	22	22	22
Weight of pycnometer + water at T_x , $W_{pw}(atT_x)$ (g)	124.52	123.59	124.87	126.36	125.36	121.88
Weight of dry soil , w_s (gm)	10	10	10	10	10	10
Conversion factor , K	1.0000	1.0001	1.0001	1.0001	1.0001	1.0001
Gs of soil at 20°c.	2.805	2.808	2.764	2.759	2.707	2.702
Average Gs of soil.	**2.81**		**2.76**		**2.70**	

Table 4-6: Specific Gravity Test Results of expansive soils found in study area

Test Pits	Depth (m)	Specific Gravity, Gs	Test Pits	Depth (m)	Specific Gravity, Gs
TP1	1	2.81	TP6	1	2.79
	2	2.76		2	2.74
	3	2.70		3	2.72
TP2	1	2.86	TP7	1	2.67
	2	2.81		2	2.65
	3	2.77		3	2.63
TP3	1	2.74	TP8	1	2.85
	2	2.70		2	2.77
	3	2.68		3	2.71
TP4	1	2.67	TP9	1	2.73
	2	2.65		2	2.69
	3	2.63		3	2.69
TP5	1	2.69	TP10	1	2.82
	2	2.67		2	2.78
	3	2.66		3	2.75

4.1.4 Natural Moisture Content Test Result (ASTM D2216-98)

The moisture content test is one of the simplest and less expensive laboratory tests to perform. The values of the natural moisture content test result of the study area carried out during swelling pressure test from undisturbed samples and summarized in Table 4-10.

4.1.5 Dry Density tests of soils (ASTM D 2937-00)

In the laboratory, soil unit weight and mass density they easily measured on undisturbed samples of natural soils. The relationship between the total and dry mass density and unit weight in terms of natural moisture content, NMC given by: $\gamma_d = \gamma t / (1 + NMC)$. The values of the dry density test result of the study area carried out during swelling pressure test from undisturbed samples and summarized in Table 4-10.

4.1.6 Swelling Pressure Test (ASTM D4546-96)

For this test undisturbed soil samples are taken from different test pits at a depth ranging from 1m to 3m. The swelling pressure is determined in the laboratory using an odometer consolidation cell.

In this test, the sample under a 7kPa-applied load is wetted and allowed to fully swelling. After swelling, the sample is further loaded by applying incremental loads starting with 50kPa till the initial specimen height is obtained. The pressure required to revert the specimen to its initial void ratio (height) is determined from graph plotted Void ratio as ordinate and applied pressure as abscissa as indicated in in figure below.

Table 4-7: Deformation reading during Swell-consolidation test for Tp1 @1m

Time (min)	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.0	0.00	2.706	0.654	0.856	1.246	1.466
0.1	…….	0.298	0.667	1.064	1.308	1.479
0.25	…..	0.318	0.671	1.078	1.320	1.488
1	…..	0.349	0.693	1.092	1.332	1.497
1	…..	0.394	0.716	1.106	1.344	1.506
2	…..	0.454	0.749	1.120	1.356	1.515
4	…..	0.501	0.772	1.134	1.368	1.524
8	…..	0.532	0.795	1.148	1.380	1.533
15	…..	0.562	0.808	1.162	1.392	1.542
30	…..	0.584	0.819	1.176	1.404	1.551
60	…..	0.602	0.828	1.190	1.416	1.560
120	…..	0.618	0.837	1.204	1.428	1.569
240	…..	0.630	0.848	1.218	1.440	1.578
480	…..	0.642	0.852	1.232	1.452	1.587
1440	2.706	0.654	0.856	1.246	1.466	1.596

Table 4-8: Determination of dry unit weight and Height of solids

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring, (g)	134.05
Specimen dry mass + can, (g)	119.994
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.683
Water Content, %	27.030
Dry density, (g/cm^2)	**1.325**
Height of solid (cm)	0.943
Initial void ratio, eo	**1.121**
Height of Solids, Hs in mm	9.43
Specific gravity of solids, Gs	2.81

Table 4-9: Determination of void ratio for each load increments

Applied Pressure P (KPa)	Final Deformation Reading (mm)	Cumulative Change in Specimen height, ΔH (mm)	Final Height of Specimen Hf = Hi - ∑ΔH (mm)	Final Void Ratio: ef = (Hf-Hs) / Hs
7	0.00	0	20	1.121
7	2.706	-2.706	22.706	1.408
50	0.554	-2.152	22.152	1.349
100	0.856	-1.296	21.296	1.259
200	1.246	-0.050	20.050	1.127
400	1.466	1.416	18.584	0.971
800	1.596	3.012	16.988	0.802

Swelling Potential	
Initial dial reading (adjusted to Zero Reading), mm	0.0
Final Dial Reading (mm)	2.706
Specimen Height (mm)	20
Free swell index, (%)	13.53
Swelling Pressure (Sp) (KPa)	265

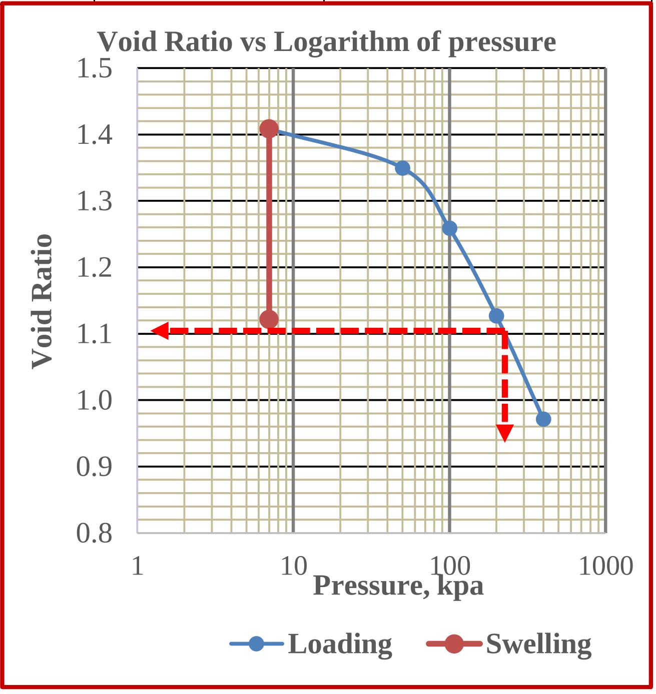


Figure 4-2: Graph of Logarithm of pressure Vs Void Ratio

Table 4-10: Natural Moisture Contents, Bulk Density, Dry Density, Swelling potential and swelling pressure tests Result of the study area

Test Pits	Depth m	NNMC, (%)	(γb), g/cm^3	(γd) g/cm^3	Swelling Potential %	Swelling Pressure KPa
TP1	1	27.03	1.80	1.26	13.53	265
	2	26.80	1.85	1.31	13.21	215
	3	42.72	1.81	1.37	11.24	120
TP2	1	29.00	0.75	0.52	14.58	285
	2	27.56	1.40	0.97	12.54	195
	3	40.01	1.61	1.15	10.07	200
TP3	1	31.72	1.88	1.35	8.41	245
	2	35.97	1.97	1.46	7.87	190
	3	40.75	1.98	1.51	7.49	115
TP4	1	32.65	1.99	1.39	9.87	240
	2	37.82	2.00	1.45	8.31	150
	3	44.70	2.20	1.63	7.57	90
TP5	1	39.68	1.96	1.41	8.82	210
	2	44.49	2.33	1.68	7.94	125

	3	49.52	2.29	1.72	7.48	105
TP6	1	25.22	0.92	0.63	15.86	325
	2	30.22	1.30	0.93	14.29	290
	3	34.21	1.41	1.03	10.44	210
TP7	1	40.73	2.33	1.77	8.25	125
	2	45.47	2.34	1.82	8.04	105
	3	50.69	2.39	1.89	7.73	65
TP8	1	24.69	0.69	0.47	14.94	280
	2	22.90	1.04	0.73	12.46	260
	3	39.28	1.46	1.05	10.08	155
TP9	1	42.01	1.97	1.39	9.46	205
	2	38.24	2.01	1.45	8.77	170
	3	33.73	2.11	1.58	7.93	105
TP10	1	25.75	0.54	0.36	15.69	300
	2	21.98	1.16	0.79	13.48	285
	3	32.89	1.61	1.13	11.88	210

4.1.7 Grain Size Analysis of soils (ASTM D422-98)

This method covers the quantitative determination of the distribution of particle size of the soil in the study area using ASTM D422 standard test method. The distribution of particle sizes larger than 75 µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using hydrometer 152H.

Since surface force between particles depends upon particle size, for soils of different test pits, grain analysis is carried out to determine the ranges of sizes in which the soil samples fall and their relative proportions.

In this study, hydrometer and sieve analysis is performed on all the samples and percent finer against size of soil particle in millimeter on a semi-log scale is plotted. From this curve the proportion and type of soil grains is determined and Particle size analysis run by this test method is grouped in to Gravel, sand, silt and clay is summarized in table below.

A) SIEVE ANALYSIS

Table 4-11: Sample Preparation: Oven-Dried Sample

Method of sieving: Wet sieving		
Mass dry soil (before wash)	1000	gm
mass pass 0.075 mm	933	gm
percentage of pass 0.075 mm	93.25	%

Table 4-12: Grain size Distribution Analysis using Sieve Size Analysis

Sieve Size (mm)	Mas of Retained, gm	% Retained	% Cum. Retained	% of Passing
9.5	0	0	0	100
4.75	2.8	0.28	0.28	99.72
2	6.4	0.64	0.92	99.08
0.85	12.5	1.25	2.17	97.83
0.425	8.5	0.85	3.02	96.98
0.300	11.2	1.12	4.14	95.86
0.150	10.7	1.07	5.21	94.79
0.075	15.4	1.54	6.75	93.25
Pass	933	93.25	100	0

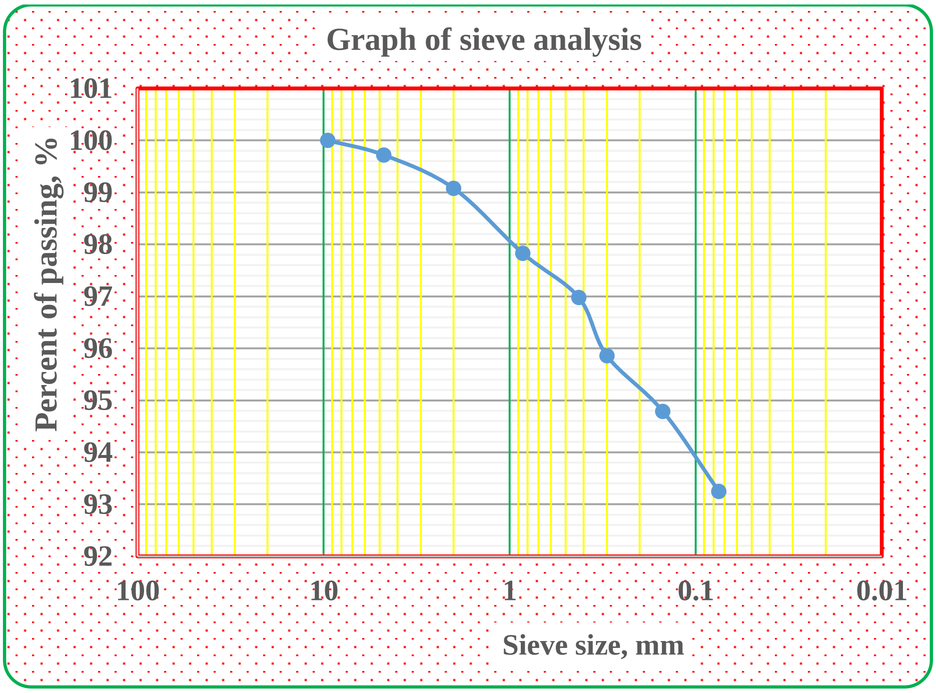


Figure 4-3: Graph of Grain size Distribution by using sieve size analysis

B) Hydrometer Analysis

Hydrometer analysis data

- ✓ Total oven Dried mass = 50 gm
- ✓ Specific Gravity = 2.81

Table 4-13: Grain size Distribution determination using Hydrometer analysis

			Correction For Hydrometer Reading					Corr. factor (A)
Time (min.)	Actual Hydro. Reading	Temp.	T° corr.	meniscus correction	zero corr.	Composite Correction	Corrected Hydrometer Reading	
1	51	21	0.2	1	-5	-3.8	47.2	0.968
2	49	21	0.2	1	-5	-3.8	45.2	0.968
5	47	21	0.2	1	-5	-3.8	43.2	0.968
15	44.5	21	0.2	1	-5	-3.8	40.7	0.968
30	43	21	0.2	1	-5	-3.8	39.2	0.968
60	42	21	0.2	1	-5	-3.8	38.2	0.968
120	41	21	0.2	1	-5	-3.8	37.2	0.968
240	40.5	21	0.2	1	-5	-3.8	36.7	0.968
480	40.2	21	0.2	1	-5	-3.8	36.4	0.968
1440	40	20	0	1	-5	-4	36	0.968

Eff. Depth of Hydrometer (L)	Values of K	Diameter of soil Particle (mm)	% finer, P	Adjusted % of finer
8.0	0.01287	0.036	91.38	85.21
8.3	0.01287	0.026	87.51	81.60
8.6	0.01287	0.017	83.64	77.99
9.0	0.01287	0.010	78.80	73.48
9.3	0.01287	0.007	75.89	70.77
9.5	0.01287	0.005	73.96	68.96
9.6	0.01287	0.004	72.02	67.16
9.7	0.01287	0.003	71.05	66.26
9.7	0.01287	0.002	70.47	65.71
9.8	0.01303	0.001	69.70	64.99

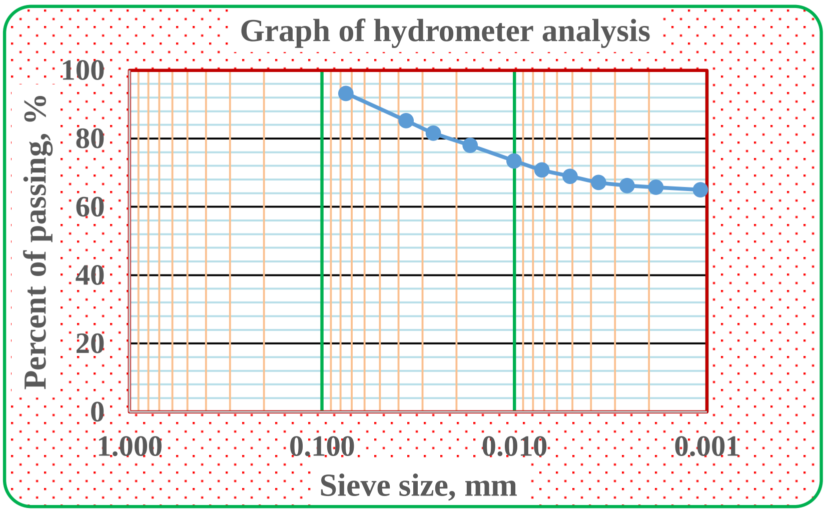


Figure 4-4: Graph of grain size Distribution analysis by using hydrometer analysis

C) Combined Sieve Analysis and Hydrometer Analysis

Table 4-14: Combined Sieve Analysis and Hydrometer Analysis

Sieve size	% pass
9.5	100
4.75	99.72
2	99.08
0.85	97.83
0.425	96.98
0.300	95.86
0.150	94.79
0.075	93.25
0.036	85.21
0.026	81.60
0.017	77.99
0.010	73.48
0.007	70.77
0.005	68.96
0.004	67.16
0.003	66.26
0.002	65.71
0.001	64.99

% of soil particle size	AASHTO	USCS
% of gravel	0.92	0.28
% of Sand	5.83	6.47
% of Silt	27.54	24.29
% of Clay	65.71	68.96

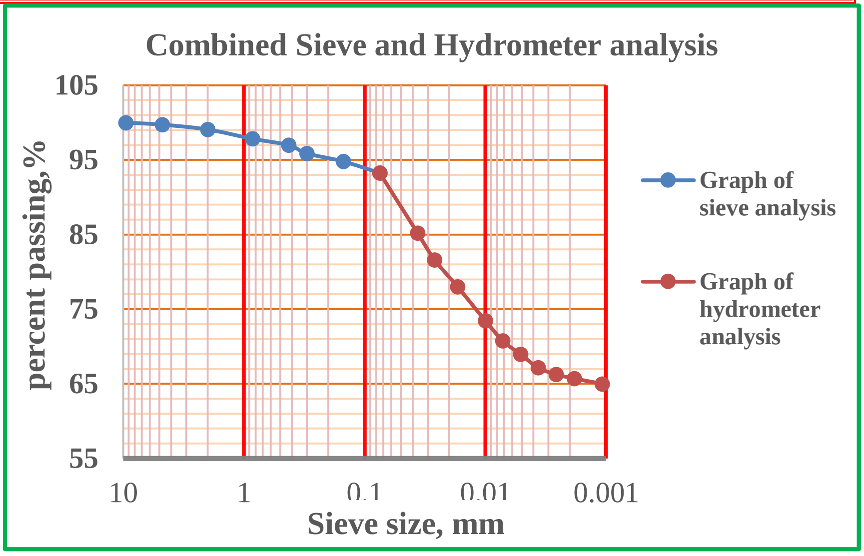


Figure 4-5: Graph of Particle size Distribution for Combined sieve and Hydrometer Analysis

Table 4-15: Percent of Grain Size Distribution Result for the soils of the study area

Test pits	Depth	% of passing 0.075mm	Percent of Grain size Distribution According to AASHTO				Percent of Grain size Distribution According to USCS			
			% Gravel	% Sand	% silt	% clay	% Gravel	% Sand	% silt	% clay
TP1	1	93.25	0.92	5.83	27.54	65.71	0.28	6.47	24.29	68.96
	2	90.45	0.46	9.09	22.51	67.94	0.04	9.09	22.51	67.94
	3	87.90	0.82	11.28	21.15	66.75	0.04	12.06	24.29	63.61
TP2	1	92.42	0.50	7.08	22.09	70.33	0.12	7.46	22.09	70.33
	2	88.73	0.61	10.66	26.20	62.53	0.08	11.19	26.20	62.53
	3	86.39	0.24	13.37	19.52	66.87	0.04	13.57	23.41	62.98
TP3	1	93.43	0.90	5.67	23.33	70.10	0.30	6.27	27.00	66.43
	2	90.61	1.08	8.31	21.72	68.89	0.27	9.12	24.95	65.66
	3	87.90	0.82	11.28	21.15	66.75	0.04	12.06	24.29	63.61
TP4	1	91.18	0.67	8.15	17.11	74.07	0.09	8.73	24.83	66.35
	2	87.84	0.50	11.66	20.38	67.46	0.07	12.09	23.54	64.30
	3	85.89	0.64	13.47	20.01	65.88	0.04	14.07	23.11	62.78
TP5	1	91.49	0.42	8.09	22.15	69.34	0.00	8.51	25.42	66.07
	2	91.08	0.67	8.25	21.41	69.67	0.24	8.68	24.68	66.40
	3	81.95	0.80	17.25	19.47	62.48	0.20	17.85	22.41	59.54
TP6	1	91.04	0.21	8.75	23.43	67.61	0.00	8.96	26.62	64.42

	2	86.10	1.53	12.37	18.12	67.98	0.56	13.34	21.17	64.93
	3	82.32	2.08	15.60	17.06	65.26	0.66	17.02	19.50	62.82
TP7	1	80.34	2.29	17.37	17.61	62.73	1.04	18.62	19.69	60.65
	2	77.90	1.64	20.46	18.38	59.52	0.16	21.94	21.19	56.71
	3	70.89	2.61	26.50	15.80	55.09	0.95	28.16	18.79	52.10
TP8	1	92.34	0.48	7.18	24.61	67.73	0.00	7.66	28.16	64.18
	2	90.09	0.24	9.67	22.56	67.53	0.04	9.87	25.73	64.36
	3	86.73	0.61	12.66	21.26	65.47	0.08	13.19	24.35	62.38
TP9	1	84.50	1.80	13.70	16.82	67.68	0.60	14.90	23.14	61.36
	2	82.55	0.60	16.85	19.66	62.89	0.00	17.45	22.61	59.94
	3	78.80	1.00	20.20	19.08	59.72	0.20	21.00	21.89	56.91
TP10	1	94.03	0.34	5.63	24.63	69.40	0.00	5.97	27.90	66.13
	2	92.51	0.86	6.63	23.31	69.20	0.22	7.27	26.55	65.96
	3	88.25	0.92	10.83	22.18	66.07	0.28	11.47	25.29	62.96

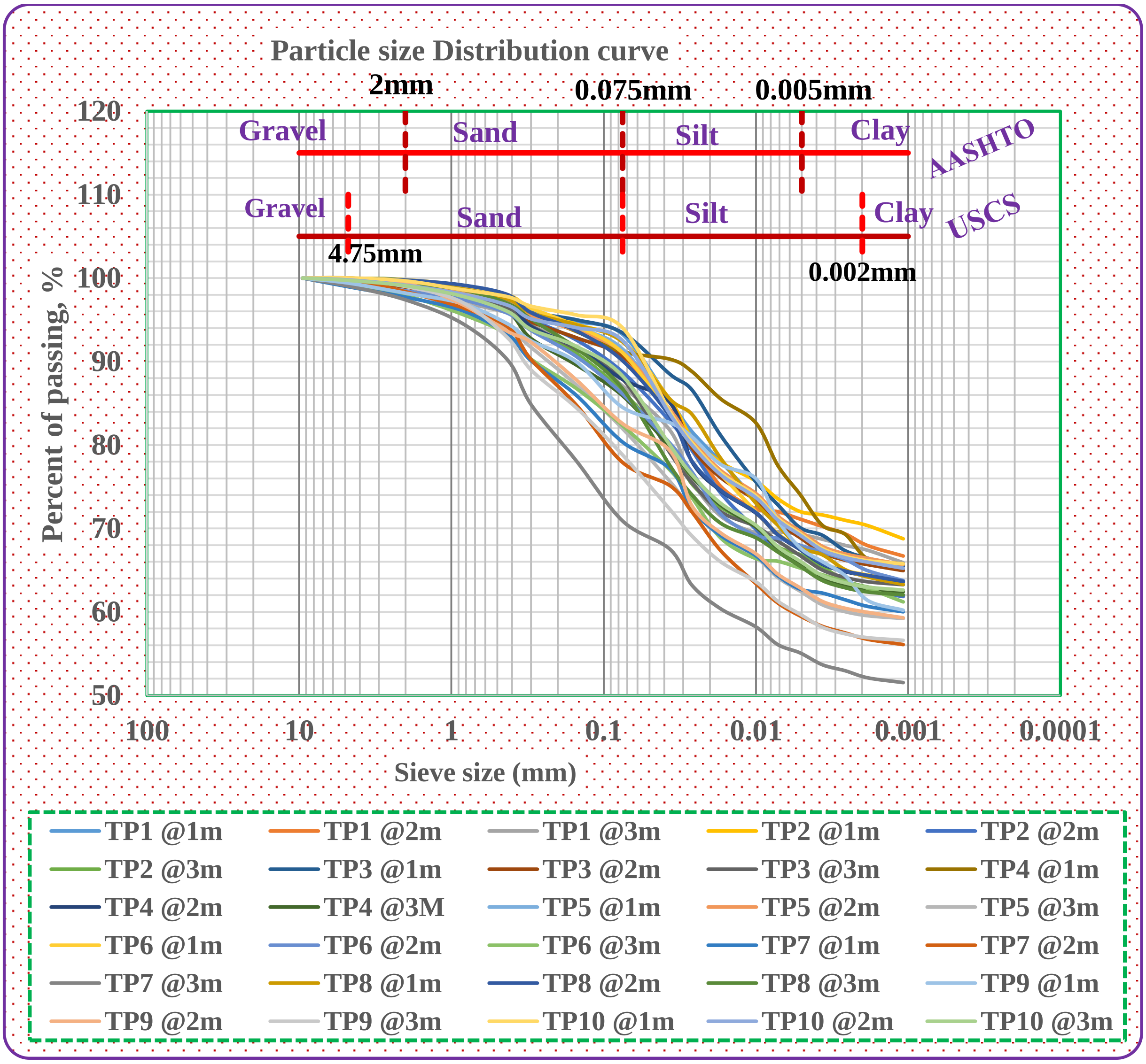


Figure 4-6: Graph of Particle size Distribution curve for all test pits of the study area

4.1.8 Free Swell test

This test suggested by Holtz and Gibbs (1956) that carried out on all specimens from the study area. The test is performed by slowly pouring $10cm^3$ of dry soil passing a 0.425mm sieve into a $100cm^3$ graduated jar cylinder with water, and observing the swelled volume of the soil after it comes to rest (Holtz and Kovacs, 1981). Soils with free swell less than 50% are not likely to show expansive property, while soils with free swell in excess of 50 percent could present swell problems. Values of 100% or more are associated with high clay, which could swell considerably, especially under light loading structures:

Free swell $=\frac{(V_d - V_k)}{V_k} * \mathbf{100}$**;** Where, Vd = volume in Distilled water after 24hr swell (vd)

Vk = volume in Distilled water after 24hr swell (vd)

Table 4-16: Free swell test Results of the study area.

Test pits	Depth (m)	soil pass 0.425mm sieve (gm)	volume of Distilled water (vd)	volume in kerosene (vk)	Free swell Index (%)
TP1	1	10	20.5	10	105
	2	10	20	10	100
	3	10	18.5	10	85
TP2	1	10	23	10	130
	2	10	21.5	10	115
	3	10	19.5	10	95
TP3	1	10	19	10	90
	2	10	17.5	10	75
	3	10	16	10	60
TP4	1	10	19	10	90
	2	10	18.5	10	85
	3	10	17	10	70
TP5	1	10	19	10	90
	2	10	17.5	10	75
	3	10	16.5	10	65
TP6	1	10	22	10	120
	2	10	21.5	10	115
	3	10	19.5	10	95
TP7	1	10	17	10	100
	2	10	16.5	10	65
	3	10	15.5	10	55
TP8	1	10	23.5	10	135
	2	10	20.5	10	105
	3	10	20	10	100
TP9	1	10	20	10	100
	2	10	18	10	80
	3	10	17.5	10	75
TP10	1	10	24	10	140
	2	10	22.5	10	125
	3	10	21.5	10	115

4.1.9 Activity of clay

Activity of clay defined as the ratio of the plastic index to the percent of clay fraction finer than 0.002mm. It is one means of classifying expansive soils based on their index property. Skempton (1953) observed that the plasticity index of a soil increases linearly with the percentage of clay-size fraction (% finer than 2μm by weight). He proposed three classes of clays according to the activity ratio as follows: Soil with activity less than 0.75 is inactive indicating low potential for volume change, that with activity between 0.75 and 1.25 is normal, and above 1.25 is very active demonstrating very high potential for volume change. The activity of a clay soil denoted by Ac and defined as follows:

$$\text{Activity of Clay, Ac} = \frac{\mathbf{PI}}{\mathbf{CF}}$$

Where CF is the clay fraction of the soil with a particle size less than 0.002mm.

Table 4-17: Activity of clay Result in the study area

Test pits	Depth (m)	PI	Percent of Clay		Ac = (PI / %Clay)		Remark
			AASHTO	USCS	AASHTO	USCS	
TP1	1	54.70	65.71	68.96	0.83	0.79	Normal
	2	54.12	67.94	67.94	0.80	0.80	Normal
	3	49.92	66.75	63.61	0.75	0.78	Normal
TP2	1	67.29	70.33	70.33	0.96	0.96	Normal
	2	64.64	62.53	62.53	1.03	1.03	Normal
	3	60.33	66.87	62.98	0.90	0.96	Normal
TP3	1	52.05	70.10	66.43	0.74	0.78	Normal
	2	47.94	68.89	65.66	0.70	0.73	Normal
	3	43.78	66.75	63.61	0.66	0.69	Inactive
TP4	1	48.74	74.07	66.35	0.66	0.73	Inactive
	2	49.98	67.46	64.30	0.74	0.78	Normal
	3	39.31	65.88	62.78	0.60	0.63	Inactive
TP5	1	43.15	69.34	66.07	0.62	0.65	Inactive
	2	38.66	69.67	66.40	0.55	0.58	Inactive
	3	32.70	62.48	59.54	0.52	0.55	Inactive
TP6	1	68.73	67.61	64.42	1.02	1.07	Normal
	2	69.00	67.98	64.93	1.02	1.06	Normal
	3	66.88	65.26	62.82	1.02	1.06	Normal
TP7	1	31.50	62.73	60.65	0.50	0.52	Inactive
	2	30.29	59.52	56.71	0.51	0.53	Inactive
	3	26.89	55.09	52.10	0.49	0.52	Inactive
TP8	1	68.02	67.73	64.18	1.00	1.06	Normal
	2	62.48	67.53	64.36	0.93	0.97	Normal
	3	55.00	65.47	62.38	0.84	0.88	Normal
TP9	1	48.81	67.68	61.36	0.72	0.80	Normal
	2	48.22	62.89	59.94	0.77	0.80	Normal
	3	39.73	59.72	56.91	0.67	0.70	Inactive
TP10	1	71.24	69.40	66.13	1.03	1.08	Normal
	2	60.54	69.20	65.96	0.87	0.92	Normal
	3	54.98	66.07	62.96	0.83	0.87	Normal

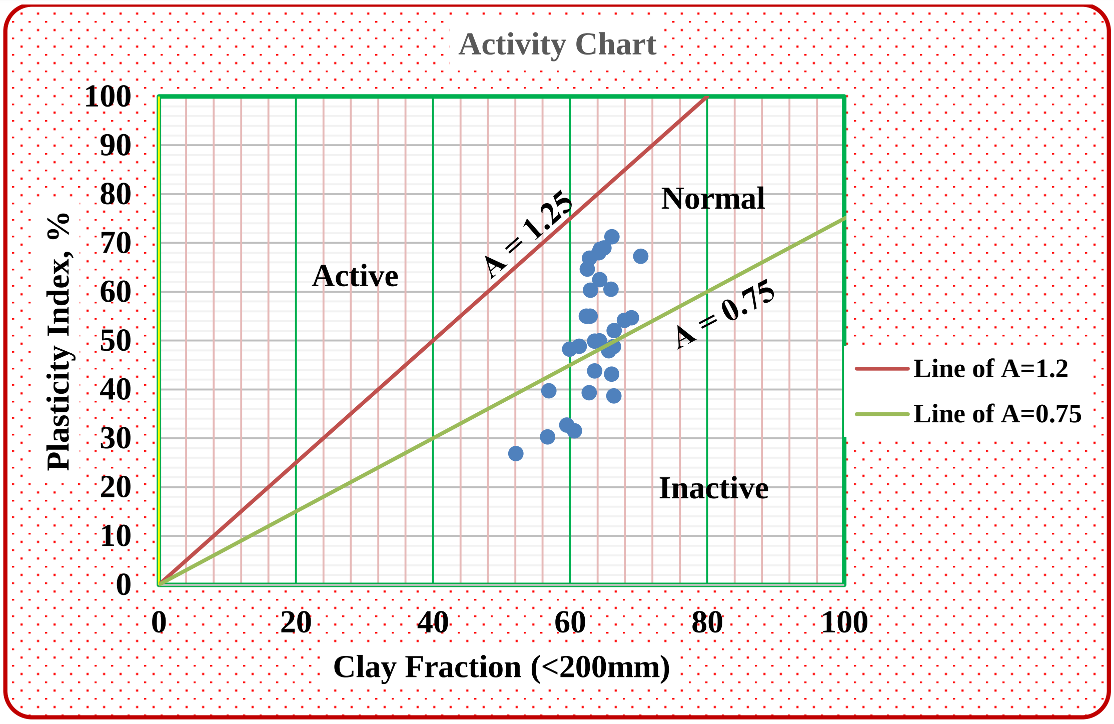


Figure 4-7: Activity chart of the Study Area

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. The 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 soils.

I. AASHTO Classification System

According to this system, the soil of the study area falls in the region of A-7-6 and A-7-5 as shown in Figure below. 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 considerable volume change between wet and dry states.

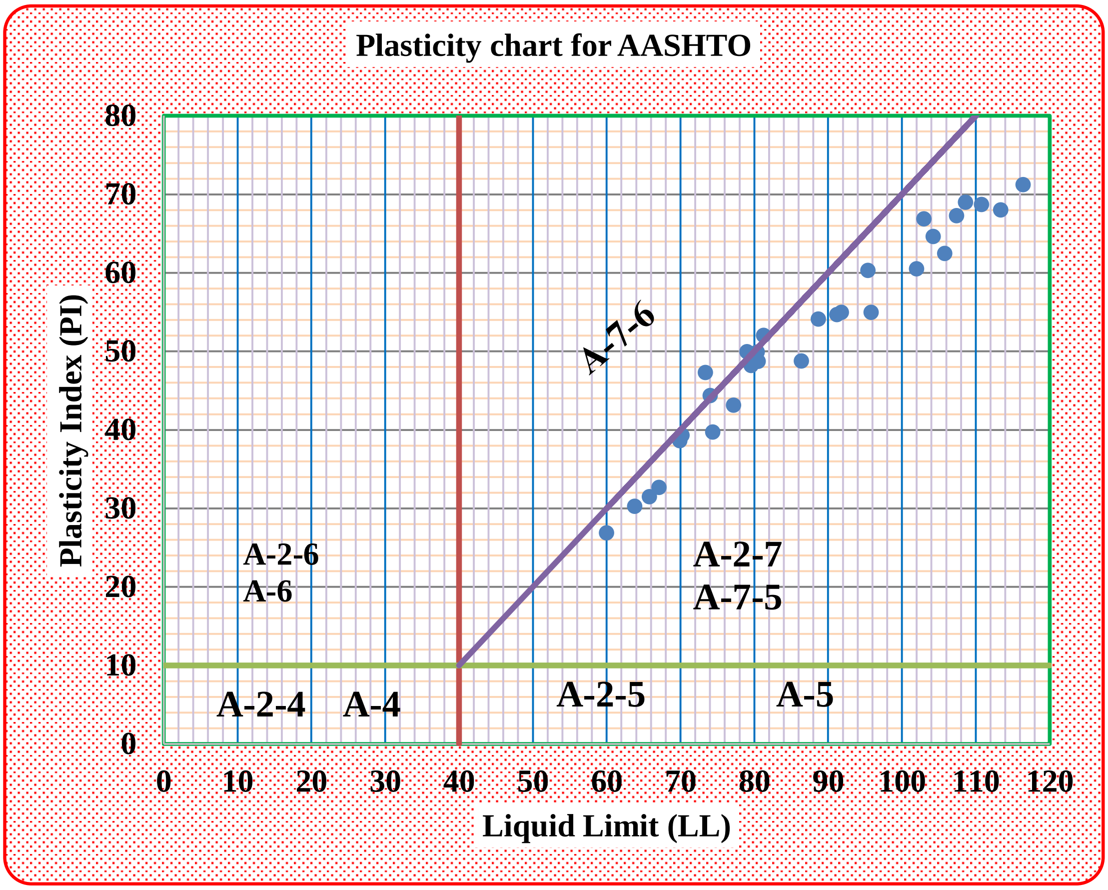


Figure 4-8: Plasticity chart for soil Classifications According to AASHTO System

Table 4-18: AASHTO soil Classification system result of the study area

Test Pits	Depth (m)	Liquid Limit (LL), %	Plastic Limit (PL), %	Plastic Index (PI), %	Equation of line: PI=LL-30	Percentage of passing No. 200 sieve, %	AASHTO Classification
TP1	1	91.20	36.50	54.70	61.20	93.25	A-7-5
	2	88.70	34.58	54.12	58.70	90.45	A-7-5
	3	80.40	30.48	49.92	50.40	87.90	A-7-5
TP2	1	107.40	40.11	67.29	77.40	92.42	A-7-5
	2	104.25	39.61	64.64	74.25	88.73	A-7-5
	3	95.40	35.07	60.33	65.40	86.39	A-7-5
TP3	1	81.28	29.23	52.05	51.28	93.43	A-7-6
	2	73.40	26.08	47.32	43.40	90.61	A-7-6
	3	74.02	29.62	44.40	44.02	87.90	A-7-6
TP4	1	80.52	31.78	48.74	50.52	91.18	A-7-5
	2	79.02	29.04	49.98	49.02	87.84	A-7-6
	3	70.20	30.89	39.31	40.20	85.89	A-7-5
TP5	1	77.20	34.05	43.15	47.20	91.49	A-7-5
	2	69.90	31.24	38.66	39.90	91.08	A-7-5
	3	67.10	34.40	32.70	37.10	81.95	A-7-5
TP6	1	110.80	42.07	68.73	80.80	91.04	A-7-5
	2	108.60	39.60	69.00	78.60	86.10	A-7-5
	3	103.00	36.12	66.88	73.00	82.32	A-7-5
TP7	1	65.80	34.30	31.50	35.80	80.34	A-7-5
	2	63.81	33.51	30.29	33.81	77.90	A-7-5

	3	60.00	33.11	26.89	30.00	70.89	A-7-5
TP8	1	113.40	45.38	68.02	83.40	92.34	A-7-5
	2	105.80	43.32	62.48	75.80	90.09	A-7-5
	3	91.82	36.82	55.00	61.82	86.73	A-7-5
TP9	1	86.40	37.59	48.81	56.40	84.50	A-7-5
	2	79.56	31.34	48.22	49.56	82.55	A-7-5
	3	74.40	34.67	39.73	44.40	78.80	A-7-5
TP10	1	116.40	45.16	71.24	86.40	94.03	A-7-5
	2	102.00	41.46	60.54	72.00	92.51	A-7-5
	3	95.83	40.85	54.98	65.83	88.25	A-7-5

I. Unified Soil Classification system (USCS)

According to USCS classification scheme the soil of the study area falls in CH or OH region but specific gravities were greater than two it categorized under CH (Fat clay), which shows that the soil is potentially expansive as shown in Figure below.

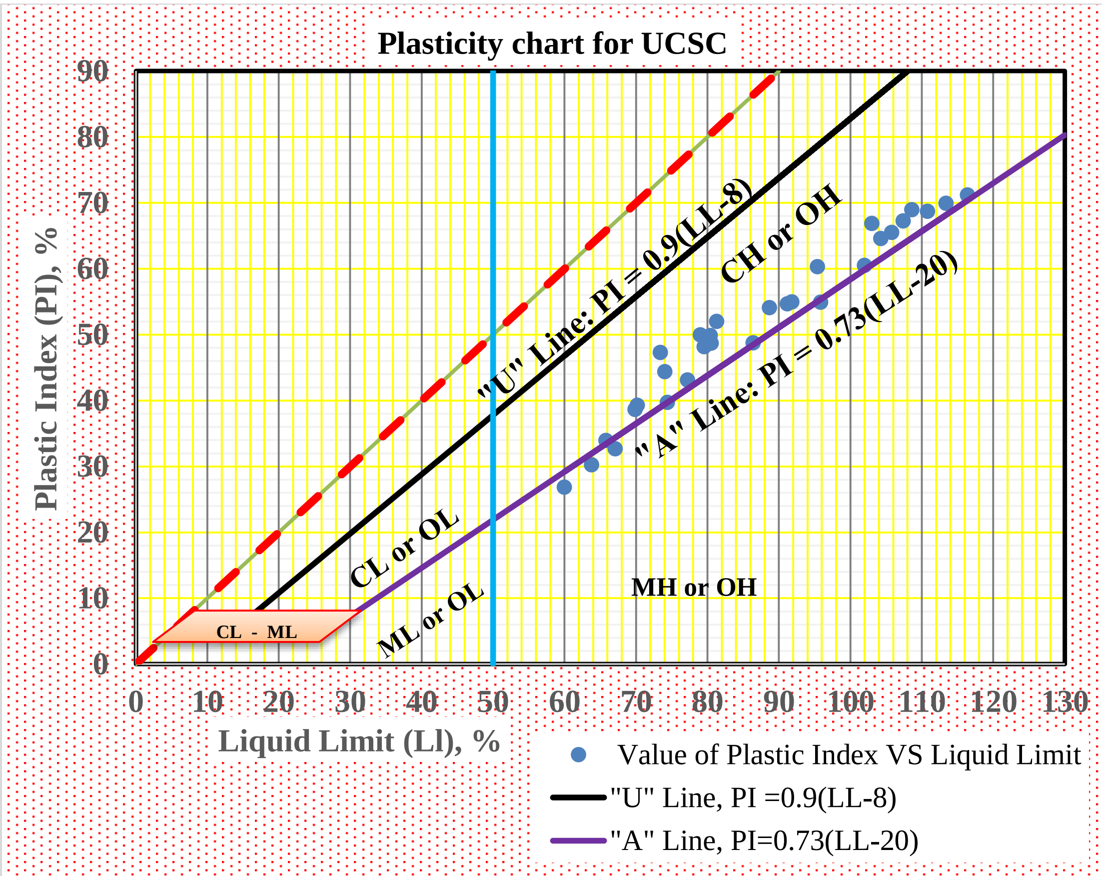


Figure 4-9: Graph of Plasticity chart of the Study Area According to USCS System

Table 4-19: Unified soil Classification system result of the study area

Test Pits	Depth (m)	Liquid Limit (LL) %	Plastic Limit (PL) %	Plastic Index (PI) %	Equation of A-line: PI = 0.73(LL-20)	Equation of U-line: PI = 0.9(LL-8)	Percentage of passing No. 200 sieve (%)	USCS
TP1	1	91.20	36.50	54.70	51.98	74.88	93.25	CH
	2	88.70	34.58	54.12	50.15	72.63	90.45	CH
	3	80.40	30.48	49.92	44.09	65.16	87.90	CH
TP2	1	107.40	40.11	67.29	63.80	89.46	92.42	CH
	2	104.25	39.61	64.64	61.50	86.63	88.73	CH
	3	95.40	35.07	60.33	55.04	78.66	86.39	CH
TP3	1	81.28	29.23	52.05	44.73	65.95	93.43	CH
	2	73.40	26.08	47.32	38.98	58.86	90.61	CH
	3	74.02	29.62	44.40	39.43	59.42	87.90	CH
TP4	1	80.52	31.78	48.74	44.18	65.27	91.18	CH
	2	79.02	29.04	49.98	43.08	63.92	87.84	CH
	3	70.20	30.89	39.31	36.65	55.98	85.89	CH
TP5	1	77.20	34.05	43.15	41.76	62.28	91.49	CH
	2	69.90	31.24	38.66	36.43	55.71	91.08	CH
	3	67.10	34.40	32.70	34.38	53.19	81.95	MH
TP6	1	110.80	42.07	68.73	66.28	92.52	91.04	CH
	2	108.60	39.60	69.00	64.68	90.54	86.10	CH
	3	103.00	36.12	66.88	60.59	85.50	82.32	CH
TP7	1	65.80	31.85	33.95	33.43	52.02	80.34	CH
	2	63.81	33.51	30.29	31.98	50.23	77.90	MH
	3	60.00	33.11	26.89	29.20	46.80	70.89	MH
TP8	1	113.40	43.46	69.94	68.18	94.86	92.34	CH
	2	105.80	40.25	65.55	62.63	88.02	90.09	CH
	3	91.82	36.82	55.00	52.43	75.44	86.73	CH
TP9	1	86.40	37.59	48.81	48.47	70.56	84.50	CH
	2	79.56	31.34	48.22	43.48	64.40	82.55	CH
	3	74.40	34.67	39.73	39.71	59.76	78.80	CH
TP10	1	116.40	45.16	71.24	70.37	97.56	94.03	CH
	2	102.00	41.46	60.54	59.86	84.60	92.51	CH
	3	95.83	40.85	54.98	55.36	79.05	88.25	CH

4.3 Discussion on Laboratory Test Results

From the test results of the Atterberg limits, the Plasticity and Activity chart was developed which is used to define the category of fine-grained materials. The measured liquid limit and plastic limit was found to be in the range of 60.0 – 116.40% and 26.08 – 45.16% respectively. The plasticity index and Liquid Index were found to be in the range of 26.89 - 71.24% and -0.32 - 0.65% respectively.

The linear shrinkage limit test values of the study area ranges from 7.32% – 12.5%. This shows that the value of test results greater than 8 % indicates that the soil have critical degree of expansion.

The Specific Gravity of the study area falls in the range of (2.63 - 2.86). This indicates that the soil type in the study area covers silt soils of high plasticity up to the clay soils of high plasticity behaviors. The moisture contents of the study area range from 26.69 up to 50.75 in percent. This indicates that the soil type of the study area is soft clay. The Dry density of the study area falls in the range of (0.36 -1.89) g/cm^3 and the Bulk density ranges from (0.54-2.39)g/cm^3.

The swelling pressure and the amount of swell (Swelling potential) of the soil were measured by means of one-dimensional compression tests using the odometer apparatus as per ASTM D4546-08. The results of the odometer tests showed that the soils can exhibit swelling pressure in the range of 65kPa to 325kPa and swelling potential in the range of 7.48 to 15.86 percent. That means the expansive clay in area under study can exert an upward swelling pressure in this range, which is much greater than pressure exerted by lightweight structures on the subsoil.

From the grain size analysis test result, it has been found that the percentage of Gravel is in between 0.21-2.61%, the Percentage (%) of sand content is in between 5.63-26.50%, the percentage of silt content is in between 15.8-27.54% and the percentage of clay content is in between 55.09-74.07% according to AASHTO. And the percentage of Gravel is in between 0.00-1.04%, the Percentage (%) of sand content is in between 5.97-28.16%, the percentage of silt content is in between 18.79-28.16% and the percentage of clay content is in between 52.10-70.33% according to USCS. This indicates that the percent of clay according to both classification is greater than 50% which shows the soils of the study area have clay materials with moderate to high plasticity clay.

The free swell test is a simple test that is widely accepted as a way of getting an estimate of soil swelling potential. In this study, the variation in free swell percent ranges from 55%

to 140% indicating marginal to high swelling potential. This implies that the soils in the area can swell considerably when wet.

The activity of clay soils of the study area falls in the range of normal to inactive clay behavior. A clay soil that consists predominantly of the clay mineral like montmorillonite behaves very differently from a clay soil composed predominantly of kaolinite

After classification was done by using AASHTO Classification System, the soils in the study area are classified in to soil groups A-7-6 and A-7-5. These soil groups' materials have high liquid limits and are highly plastic as well as these types of soil groups will subject to considerable volume change up on moisture change.

Using Unified Soil Classification System (USCS) the soils of the study area are classified by using the Casagrande Plasticity Chart. Based on this chart, most of the soils were grouped as CH (inorganic clay with high plasticity) and only three of the thirteen soil test samples are on MH group (inorganic silt of high compressibility).

4.4. Results of Correlation and Regression Analysis

4.4.1 Determination of Sample size

Since the research investigation carried out on quantitative data, the sample size calculated by the following formula [38]:

$$N = \frac{t_{\alpha^2} * \sigma^2}{\varepsilon^2} = \frac{1.96^2 * 0.1405^2}{0.05^2} = 30$$

Where, $t_{0.05\alpha}$ =1.96 for 95% confidence interval

E= 0.05 for 95% confidence interval

From statistical output, the Avg. Standard deviation of all sample data can be used to determine the sample size.

$$\text{Avg. } \sigma^2 = \frac{(16.469+12.766+1.473+8.049+0.419+0.18+0.25+72.765)}{8} = 14.05\%$$

Therefore, σ^2 = 0.1405

4.4.1.1 Discussion on Sample Size

It will often suggested that one should include at least 30 subjects in a sample since this number permits the use of large sample statistics. Statistically speaking, a sample n= 30 is considered large, since with this n, the t-distribution and the normal curve are practically the same for hypothesis testing purposes. In experimental research, one should select a sample that will permit at least 30 in each group.

Based on the statistical data output the predicted standard deviation was 14% and the margin of error is dependent on the level of confidence. The 95% percent of level of confidence gives 5% of error from the population mean.

4.4.2 Statistical Data distribution result

Table 4-20: Results of Descriptive Statistics of Data Distribution

Statistics									
		LL	PI	LS	NMC	Dd	Ac	LI	Swelling Pressure (Sp), kPa
N	Valid	30	30	30	30	30	30	30	30
	Missing	0	0	0	0	0	0	0	0
Mean		87.254	51.902	9.574	35.281	1.220	.810	.051	194.67
Std. Error of Mean		3.007	2.331	.269	1.469	.0765	.033	.046	13.285
Median		83.840	51.012	9.393	35.0901	1.219	.794	.046	202.50
Mode		60.000	26.890	8.46	21.98	.36	.52	-.32	105
Std. Deviation		16.469	12.766	1.473	8.049	.419	.180	.250	72.765
Variance		271.233	162.977	2.171	64.793	.176	.032	.063	5294.713
Skewness		.182	-.183	.282	.081	-.320	-.038	.425	-.004
Std. Error of Skewness		.427	.427	.427	.427	.427	.427	.427	.427
Kurtosis		-1.196	-.898	-1.115	-.982	-.545	-1.066	-.458	-1.134
Std. Error of Kurtosis		.833	.833	.833	.833	.833	.833	.833	.833
Range		56.40	44.35	5.18	28.71	1.61	.56	.98	260
Minimum		60.00	26.89	7.32	21.98	.36	.52	-.32	65
Maximum		116.40	71.24	12.50	50.69	1.97	1.08	.65	325
Sum		2617.61	1557.05	287.2	1058.43	36.59	24.29	1.53	5840
Percentiles	25	74.020	43.1475	8.429	27.560	.970	.688	-.165	123.33
	50	83.840	51.012	9.393	35.0901	1.219	.794	.0464	202.50
	75	103.000	64.635	10.86	40.7489	1.513	.958	.2452	260.00

4.4.2.1 Discussion on Statistical data output

From the above table, the result of Skewness over its standard error as well as kurtosis over its standard error is between ± 2. The histogram and Q-Q plot of each variable is shown figure below which shows each dependent and independent variables are normally distributed. [36]

4.4.3 Normality Test Result

Table 4-21: Test of Normality for each variables

Tests of Normality						
Variables	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
LL	.142	30	.129	.951	30	.185
PI	.107	30	.200*	.957	30	.259
LS	.145	30	.107	.948	30	.145
NMC	.098	30	.200*	.966	30	.433
γd	.076	30	.200*	.977	30	.736
Ac	.111	30	.200*	.940	30	.088
LI	.139	30	.143	.961	30	.326
Swelling Pressure (Sp), kPa	.131	30	.200*	.955	30	.235

4.4.3.1 Discussion on Normality Test output

From the above table and figure, the normality test result fulfill the basic assumption of normality test. The value of Skewness and kurtosis over its standard error is between the ranges of -1.96 to +1.96, this implies that the data is normally distributed. The kolmogrov-smirnov[a] and shapiro-wilk test shows, the significance levels (α) greater than 0.05, this shows the sample data are not significantly different than a normal population or we accept the null hypothesis.

Ho: The sample data are not significantly different than a normal population.

Ha: The sample data are significantly different than a normal population

So that the shapiro-wilk and kolmogrov-smirnova test results fulfill assumption for normally distributed data.

In general, the test results fulfil the basic requirement of normal probability distribution data. So that we use parametric statistical test for evaluation of the hypothesis test. The independent t-test is used for parametric statistical test. The reason for selecting independent t-test is based on the data is continuous, fulfill normality test and it compares the means of two independent variables.

4.4.4 Correlation Analysis Result

4.4.4.1 Pearson correlation coefficient, R

The Pearson correlation coefficient (r) is used specifically to describe relationships when the variables to be correlated are continuous (measured on at least an interval scale). The possible values of the correlation coefficient range from -1 to +1 and the closer the number is to an absolute value of 1, the greater the degree of relatedness. The Pearson correlation coefficient can be tested for statistical significance (using the conventional probability criterion of .05).

Table 4-22: Result of Pearson correlation coefficient in Correlation matrix.

Correlations									
		LL	PI	LS	NMC	Dd	Ac	LI	Swelling Pressure (Sp)
LL	Pearson Correlation	1	.977	.920	-.823	-.947	.968	-.898	.859
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
PI	Pearson Correlation	.977	1	.865	-.822	-.930	.981	-.880	.857
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
LS	Pearson Correlation	.920	.865	1	-.740	-.868	.845	-.822	.826
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
NMC	Pearson Correlation	-.823	-.822	-.740	1	.846	-.765	.959	-.861
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
γ_d	Pearson Correlation	-.947	-.930	-.868	.846	1	-.883	.889	-.911
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	30	30	30	30	30	30	30	30
Ac	Pearson Correlation	.968	.981	.845	-.765	-.883	1	-.842	.791
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000
	N	30	30	30	30	30	30	30	30
LI	Pearson Correlation	-.898	-.880	-.822	.959	.889	-.842	1	-.871
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
	N	30	30	30	30	30	30	30	30
Swelling Pressure (Sp)	Pearson Correlation	.859	.857	.826	-.861	-.911	.791	-.871	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	
	N	30	30	30	30	30	30	30	30
**. Correlation is significant at the 0.01 level (2-tailed).									

4.4.4.1 Discussion on Correlation output

There are two ways to interpret the degree of relationship:

- If the Sig., or probability (p), associated with the R value 0.05 or less, then we reject Ho, and conclude that there is a statistically significant relationship between pair of variables.
- If $p > 0.05$, then we retain Ho, and conclude that the variables are unrelated.

Thus, from the table correlation matrix the p-value or Sig. (2-tailed) value is less 0.05, we can say that the correlation is not the result of chance or random sampling error. That is why we would reject Ho and conclude that the correlation is a real one, and thus, one that can be generalized from the sample to the overall population in which we are interested.

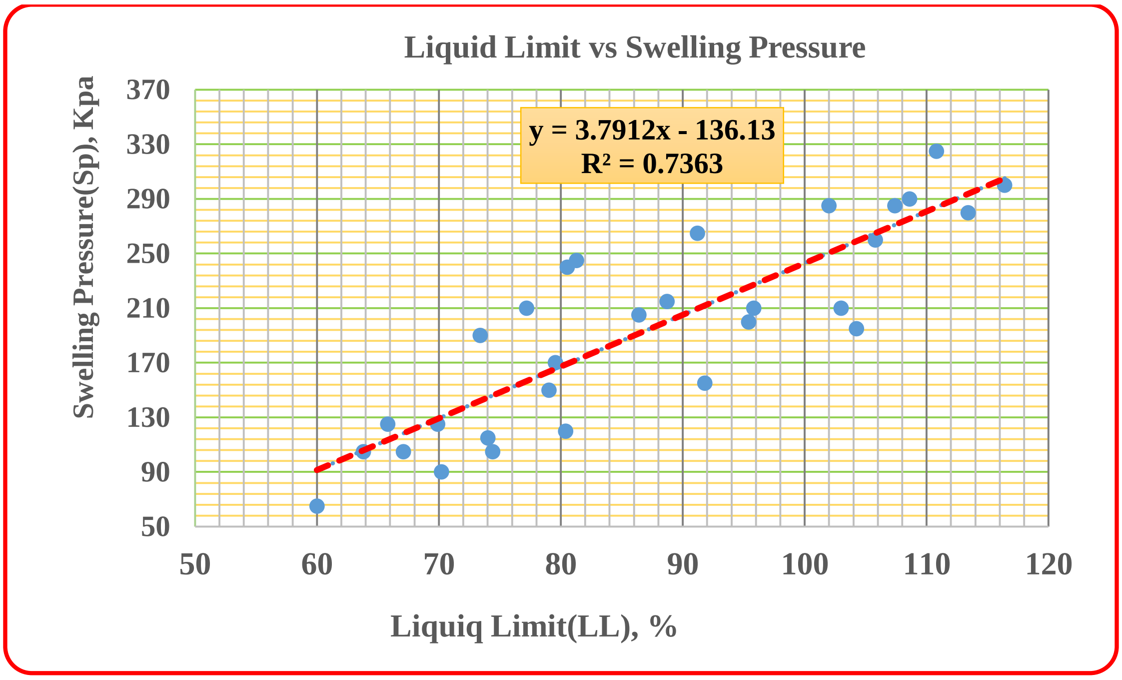
4.5 Formulation of New Empirical Equations

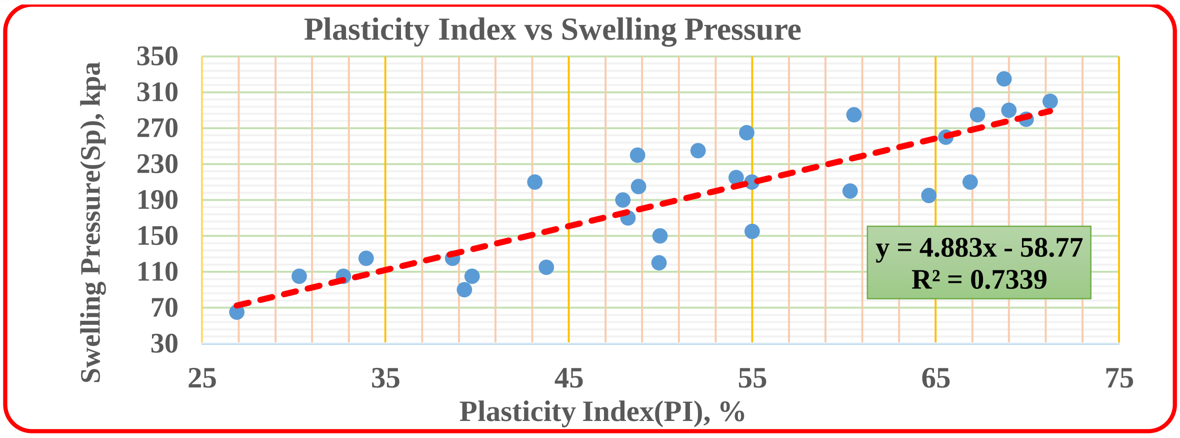
4.5.1 Using Simple Linear Regression Analysis

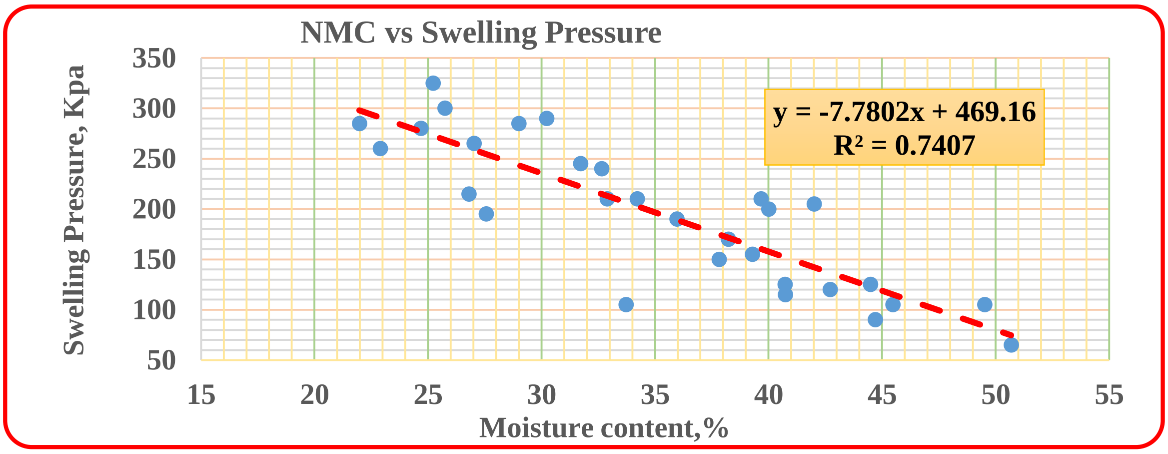
The relationship of two or more variables expressed in mathematical form by determining an equation connecting the two variables. Generally in this work, the value of swelling pressure (Ps) was considered as the dependent variable whereas liquid limit (LL), plasticity index (PI), Linear shrinkage limit (LS), Dry Density (γd), liquidity index (LI), Activity of Clay (Ac) and Natural moisture content (NMC) are the independent (Predictor) variables.[36]

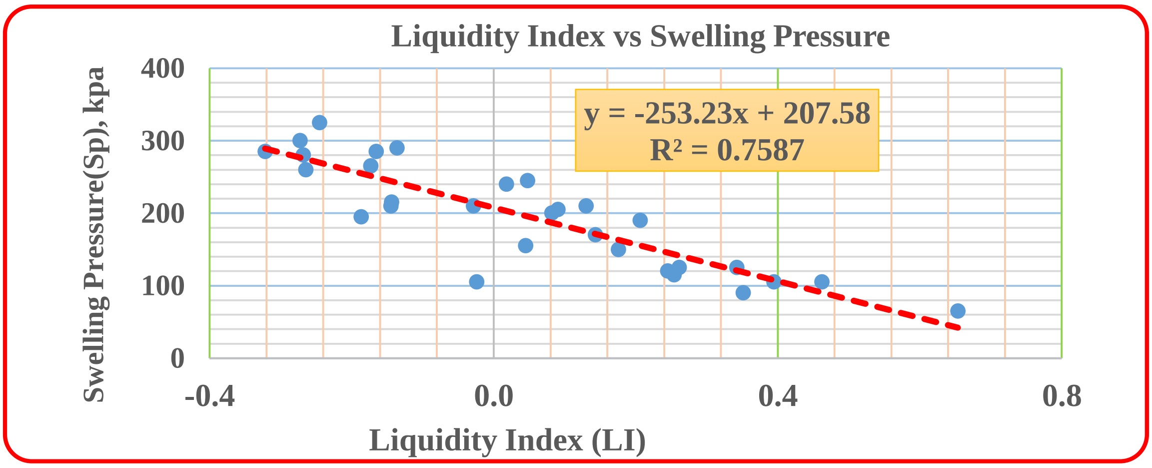
4.5.1.1 Scatter Plot and Best Curve Fit Results for Simple Linear Regression

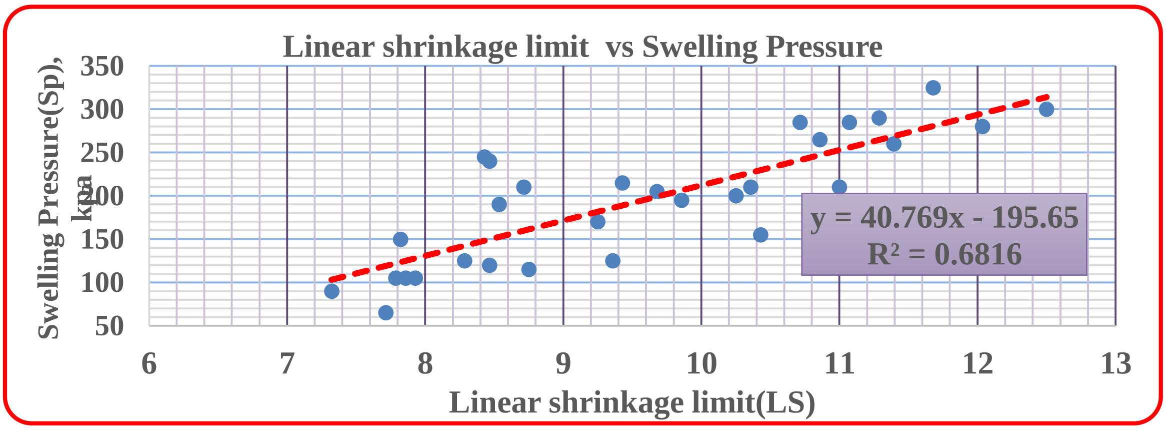
The MS excel spread sheet is found to be the most powerful and manageable tool for scatter plot analysis and determination of correlation between two variables. However, when determination of the relationships between more than two variables are required (the dependent variable requires two or more independent variables) regression analysis is used and the SPSS software is found to be the most powerful and descriptive tool.

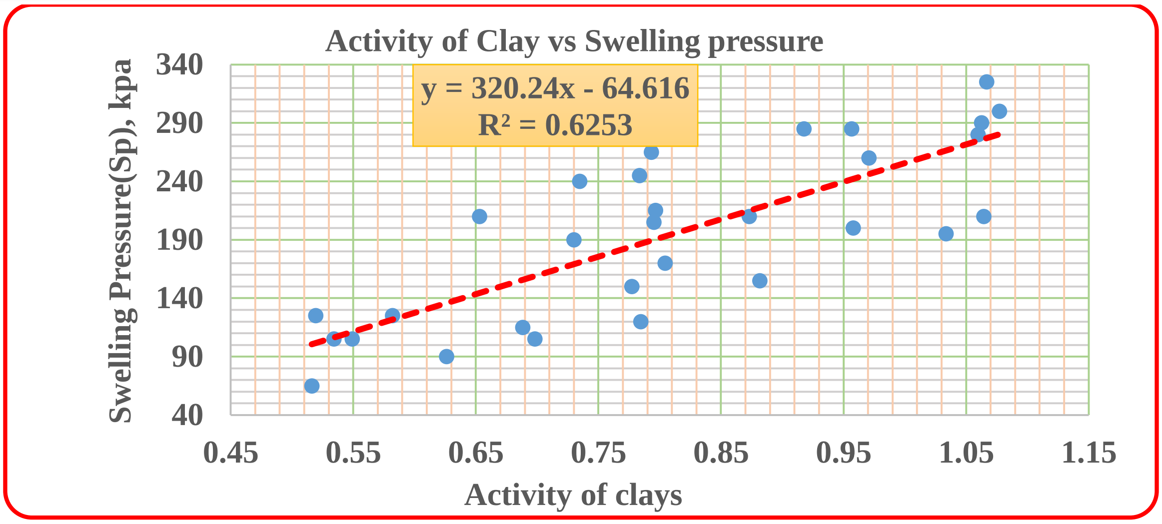



Plasticity Index vs Swelling Pressure
Swelling Pressure(Sp), kpa
350
310
270
230
190
150
110
70
30
25
35
45
55
65
75
Plasticity Index(PI), %
y = 4.883x - 58.77
R² = 0.7339


NMC vs Swelling Pressure
Swelling Pressure, Kpa
350
300
250
200
150
100
50
15
20
25
30
35
40
45
50
55
Moisture content,%
y = -7.7802x + 469.16
R² = 0.7407


Liquidity Index vs Swelling Pressure
Swelling Pressure(Sp), kpa
400
300
200
100
0
-0.4
0.0
0.4
0.8
Liquidity Index (LI)
y = -253.23x + 207.58
R² = 0.7587


Linear shrinkage limit vs Swelling Pressure
Swelling Pressure(Sp), kpa
350
300
250
200
150
100
50
6
7
8
9
10
11
12
13
Linear shrinkage limit(LS)
y = 40.769x - 195.65
R² = 0.6816



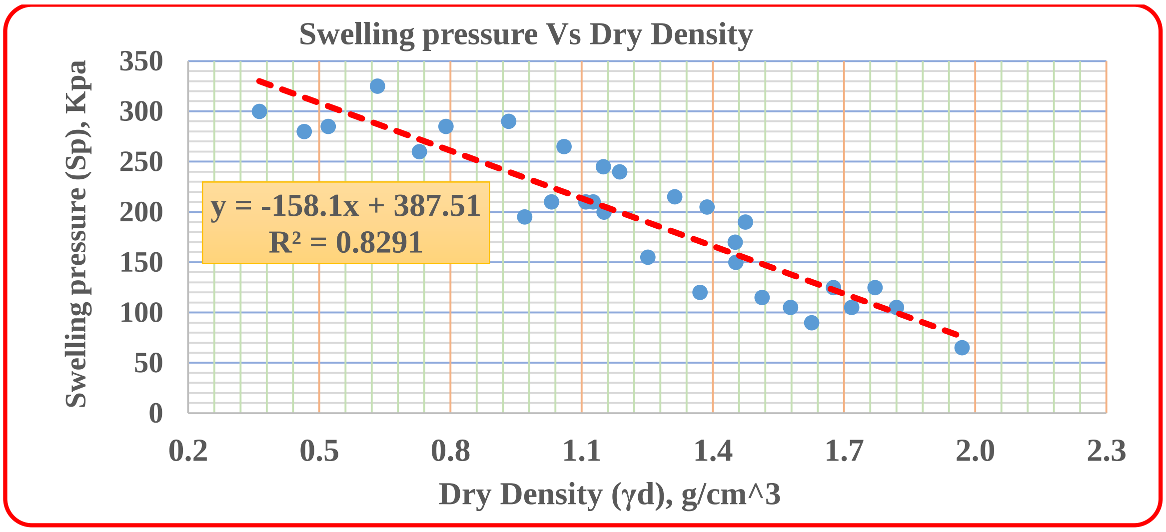


Figure 4-10: Scatter Plots of Dependent Variable vs Independent Variables

4.5.1.2 Formula developed from Simple Linear Regression outputs

1. $Sp = -158.1*\gamma d + 387.51$; $R^2 = 0.8291$
2. $Sp = -7.7802*NMC + 469.16$; $R^2 = 0.7407$
3. $Sp = 4.883*PI – 58.77$; $R^2 = 0.7339$

4.5.1.3 Discussion on Single Linear Regression

After carefully analyzing the data on the scatter plot and different models, Sp is highly influenced by γd, NMC and PI by achieving a coefficient of determination value (R^2) of 0.829, 0.741 and 0.734 respectively. This category also shows that correlation of Sp has very good relation with γd, NMC and PI that gave good correlation result.

4.5.2 Using Multiple Linear Regression Analysis

A number of techniques used to judge the adequacy of a regression model. Some of which are confidence level (CL), R-squared value (R^2), and adjusted R-square (Adj.R^2). The regression coefficients then calculated using SPSS 20 software for each sample parameters to develop best empirical equations and their validation carried out using control test results. Out of many equations, equations with higher R^2 values selected and using these equations the swelling pressure of the study area were predicted. Then a graph is plotted which shows the measured value against the predicted value.

Table 4-0-23: Input Data for SPSS 20 computer program

Test Pits	Depth (m)	Test No.	LL	PI	LS	NMC	Dd	Ac	LI	Swelling Pressure Sp, kPa
TP1	1	1	91.20	54.70	10.86	27.03	1.06	0.79	-0.17	265
	2	2	88.70	54.12	9.43	26.80	1.31	0.80	-0.14	215
	3	3	80.40	49.92	8.46	42.72	1.37	0.78	0.25	120
TP2	1	4	107.40	67.29	10.71	29.00	0.52	0.96	-0.17	285
	2	5	104.25	64.64	9.86	27.56	0.97	1.03	-0.19	195
	3	6	95.40	60.33	10.25	40.01	1.15	0.96	0.08	200
TP3	1	7	81.28	52.05	8.43	31.72	1.15	0.78	0.05	245
	2	8	74.02	47.94	8.54	35.97	1.47	0.73	0.21	190
	3	9	73.40	43.78	8.75	40.75	1.51	0.69	0.25	115
TP4	1	10	80.52	48.74	8.46	32.65	1.19	0.73	0.02	240
	2	11	79.02	49.98	7.82	37.82	1.45	0.78	0.18	150
	3	12	70.20	39.31	7.32	44.70	1.63	0.63	0.35	90
TP5	1	13	77.20	43.15	8.71	39.68	1.11	0.65	0.13	210
	2	14	69.90	38.66	9.36	44.49	1.68	0.58	0.34	125
	3	15	67.10	32.70	7.93	49.52	1.72	0.55	0.46	105
TP6	1	16	110.80	68.73	11.68	25.22	0.63	1.07	-0.25	325
	2	17	108.60	69.00	11.29	30.22	0.93	1.06	-0.14	290
	3	18	103.00	66.88	10.36	34.21	1.03	1.06	-0.03	210
TP7	1	19	65.80	33.95	8.29	40.73	1.77	0.52	0.26	125
	2	20	63.81	30.29	7.86	45.47	1.82	0.53	0.39	105
	3	21	60.00	26.89	7.71	50.69	1.97	0.52	0.65	65
TP8	1	22	113.40	69.94	12.04	24.69	0.47	1.06	-0.27	280
	2	23	105.80	65.55	11.39	22.90	0.73	0.97	-0.26	260
	3	24	91.82	55.00	10.43	39.28	1.25	0.88	0.04	155
TP9	1	25	86.40	48.81	9.68	42.01	1.39	0.80	0.09	205
	2	26	79.56	48.22	9.25	38.24	1.45	0.80	0.14	170
	3	27	74.40	39.73	7.79	33.73	1.58	0.70	-0.02	105
TP10	1	28	116.40	71.24	12.50	25.75	0.36	1.08	-0.27	300
	2	29	102.00	60.54	11.07	21.98	0.79	0.92	-0.32	285
	3	30	95.83	54.98	11.00	32.89	1.13	0.87	-0.14	210

4.5.2.1 New Formula developed from Multiple Linear Regression output

To select the best fit model the following points are taken in to consideration

- The value of R^2 for the regression analysis should have relatively higher value and approaches to one.
- The slopes of the line for the measured versus Predicted swelling pressure graph should have relatively higher value and approaches to one.
- The equation should give approximately the same swelling pressure value compared with the measured one for the control test samples.
- Equations that have parameters which could be easily determined in soil mechanics laboratories.

From Multi Linear regression output the following equations gave a better estimation of calculated Swelling Pressure than many other models developed.

MODEL 1: SP = -111.42*γd - 2.873*NMC + 431.920; R^2 = 0.858
Adj. R^2 = 0.847 and $P < 0.05$

MODEL 2: SP = -91.456*γd + 6.665*LS - 2.849*NMC + 342.925; R^2 = 0.862
Adj. R^2 = 0.846 and $P < 0.05$

MODEL 3: SP = -2.924 NMC - 124.125*γd - 35.751*Ac + 478.171; R^2 = 0.86
Adj. R^2 = 0.843 and $P < 0.05$

MODEL 4: SP = - 0.405*LL - 2.936*NMC -*125.444*γd + 486.564; R^2 = 0.859
Adj. R^2 = 0.842 and $P < 0.05$

MODEL 5: SP = 436.066 - 0.057*PI - 2.884*NMC - 112.863*γd; R^2 = 0.858
Adj. R^2 = 0.841 and $P < 0.05$

MODEL 6: SP = -1.575*LL +13.675*LS - 3.07*NMC - 125.043*γd + 462.017
R^2 = 0.87, Adj. R^2 = 0.85 and $P < 0.05$

MODEL 7: SP = 4.134*PI - 2.406*NMC - 95.564*γd - 247.366*Ac + 381.831
R^2 = 0.869, Adj. R^2 = 0.849 and $P < 0.05$

MODEL 8: SP = - 62.329*AC + 9.078*LS – 2.93*NMC – 106.379*γd + 391.346
R^2 = 0.867, Adjusted R2 = 0.846 and $P < 0.05$

MODEL 9: SP = 4.108*PI + 9.007*LS – 2.415*NMC – 78.138*γd – 272.399*Ac
+ 296.29; R^2 = 0.876, Adj. R^2 = 0.85 and $P < 0.05$.

4.5.2.2 Discussion on Multiple Linear Regression

The results of the Regression output of the above models shows that the relationship developed is relatively reasonable because ($P < 0.05$), this shows there is significance relationship between the correlated variables, and the value of R^2 and Adj.R^2 from the multiple linear regression analysis is improved than the R^2 value of the single linear regression analysis.

Among Models developed from Multiple Linear Regression, ***MODEL 5:*** $SP = 436.066 - 0.057*PI - 2.884*NMC - 112.863*\gamma_d$ describes the relation better than the others. This is because that, the soil under investigation found to be sensitive to plastic index, natural moisture content and dry density. And also, it has good regression analysis with coefficient of determination (R^2) of 0.858 and the slope of the line for the measured versus calculated swelling pressure shows best curve fits. The equation developed has parameters that easily determined in soil mechanics laboratories. Thus, one may use these suggested equations for the estimation of the swelling pressure of the study area.

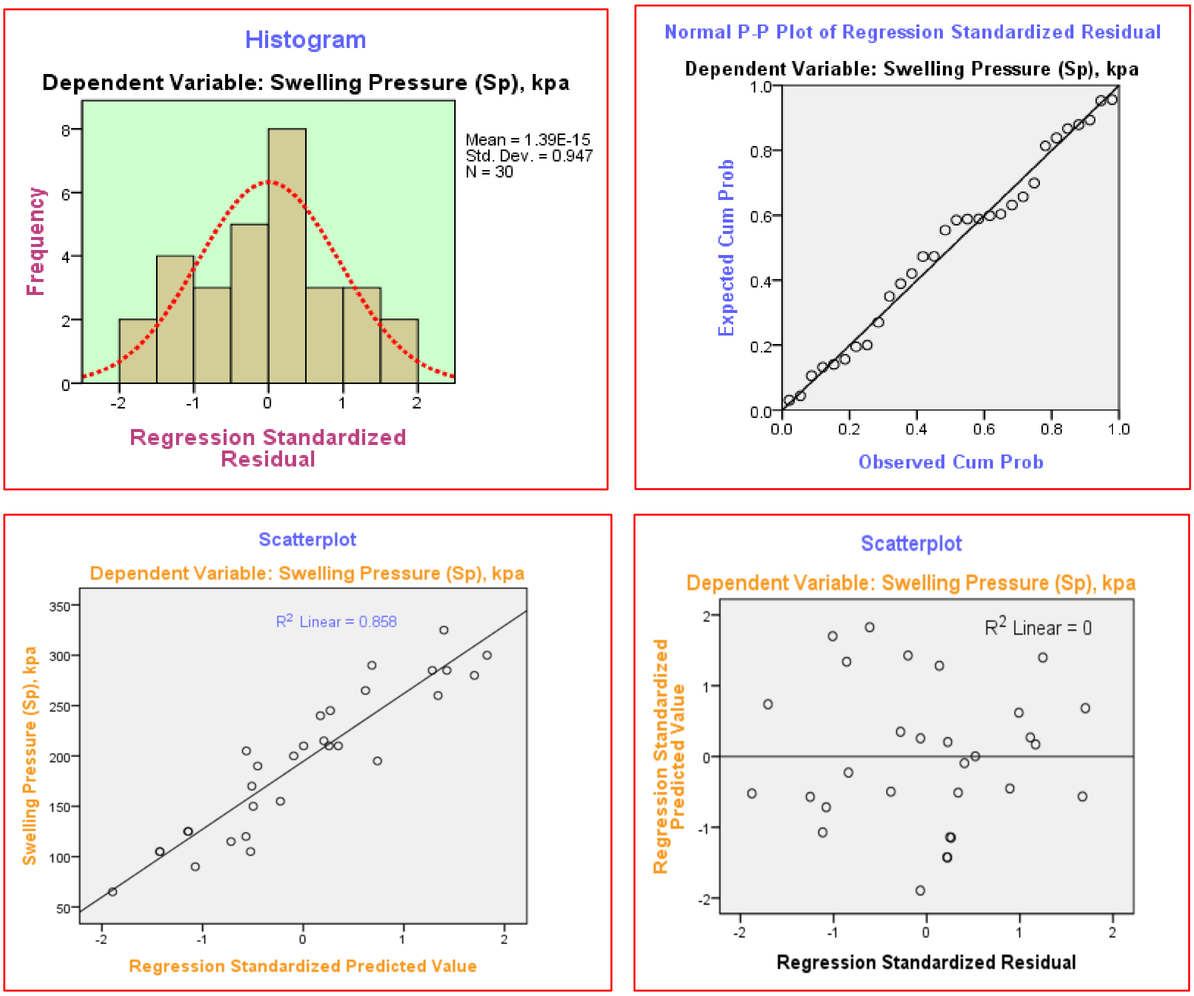


Figure 4-11: Graphical output of developed Regression model

4.6 Checking Adequacy of Developed model using SPSS output

4.6.1 Interpreting Descriptive Statistics

The output described in this section is produced using the options in the Regression as the table below. This table tells us the mean and standard deviation of each variable in a data set, so that the average number of swelling pressure is 194.67. This table isn't necessary for interpreting the regression model, but it is a useful summary of the data.

In addition to the descriptive statistics, selecting this option produces a correlation matrix too. This table shows three things. First, the table shows the value of Pearson's correlation coefficient between every pair of variables (e.g. NMC has a large negative correlation with PI, R =.858). Second, the one-tailed significance of each correlation is displayed (e.g. the correlation above is significant, p <.005). Finally, the number of cases contributing to each correlation (N =30) is shown. The correlation matrix is extremely useful for getting a rough idea of the relationships between predictors and the outcome, and for a preliminary look for multicollinearity.

Table 4-24: Descriptive Statistics of the Developed model

Descriptive Statistics			
	Mean	Std. Deviation	N
Swelling Pressure (Sp), kpa	194.67	72.765	30
NMC	35.2810	8.04943	30
γd	1.2198	.41909	30
PI	51.9016	12.76625	30

Table 4-25: Correlation Matrix of developed model

		Swelling Pressure (Sp), kpa	NMC	γd	PI
Pearson Correlation	Swelling Pressure (Sp), kpa	1.000	-.861	-.911	.857
	NMC	-.861	1.000	.846	-.822
	γd	-.911	.846	1.000	-.930
	PI	.857	-.822	-.930	1.000
Sig. (1-tailed)	Swelling Pressure (Sp), kpa	.	.000	.000	.000
	NMC	.000	.	.000	.000
	γd	.000	.000	.	.000
	PI	.000	.000	.000	.
N	Swelling Pressure (Sp), kpa	30	30	30	30
	NMC	30	30	30	30
	γd	30	30	30	30
	PI	30	30	30	30

4.6.2 Regression Model Summary

This section of output describes the overall model, whether the model is successful in predicting swelling pressure. This option is selected by default in SPSS because it provides us with some very important information about the model on the values of R, R^2 and the adjusted R^2.

Table 4-26: Model summary of developed Regression model

Model Summary[b]										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.926	.858	.841	28.976	.858	52.294	3	26	.000	1.824
a. Predictors: (Constant), PI, NMC, γd										
b. Dependent Variable: Swelling Pressure (Sp), kpa										

From the above model, ***the R^2 value*** is .858 or 85.8 % which means that the predictors accounts 85.8 % of variation in swelling pressure.

The adjusted R^2 gives us some idea of how well the model generalizes and ideally the same or very close to the value of R^2 (Example, the difference is 0.858 - 0.841 = 0.017 (1.7%). This means that if the model derived from the population rather than a sample which account approximately 1.7 % variance in the outcome.

The change statistics tell us whether the change in R^2 is significant. The significance of R^2 can actually be tested using an F-ratio. As such, the change in the amount of variance that can be explained gives F-ratio which is significant ($p <.005$).

Finally, ***Durbin–Watson statistic*** is found in the last column of the table in SPSS Output. This statistic informs us about whether the assumption of independent errors is tenable. The closer to 2 that the value is, the better, and for these data the value is 1.824, which is so close to 2 that the assumption has almost certainly been met.

4.6.3 ANOVA

This section output shows whether the model is significantly better at predicting the outcome than using the mean as a best guess. Specifically, the F-ratio represents the ratio of the improvement in prediction that results from fitting the model, relative to the inaccuracy that still exists in the model.

Table 4-27: ANOVA of the developed model

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	131717.113	3	43905.704	52.294	.000[b]
	Residual	21829.554	26	839.598		
	Total	153546.667	29			
a. Dependent Variable: Swelling Pressure (Sp), kpa						
b. Predictors: (Constant), PI, NMC, Dd						

If the improvement due to fitting the regression model is much greater than the inaccuracy within the model then the value of F will be greater than 1 and SPSS calculates the exact probability of obtaining the value of F by chance. For the model the value of F is 52.294, which is highly significant (p <.005). From the ANOVA test results the model significantly improved our ability to predict the outcome variable.

4.6.4 Regression Model parameters

So far several summary statistics tells us whether or not the model has improved our ability to predict the outcome variable. The next part of the output is concerned with the parameters of the model.

In multiple regression model there are several unknown quantities (the b-values), which tells the relationship between Swelling pressure and each predictors. Therefore the t-test associated with b-value is significant, if the value in the column labelled Sig.is < .05 that indicates the predictor have a significant contribution to the model. The smaller the value of Sig. (and the larger the value of t), the greater the contribution of that predictor. For this model, the NMC (t (26) = -2.262, p <.005), the amount of γd (t (26) = -2.979, p <.005) and PI (t (26) = -1.049, p <.005) are all significant predictors of Swelling pressure.

Table 4-28: Coefficients of Regression model parameters for developed model

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)	437.066	107.373		4.071	.000	216.358	657.774
	NMC	-2.884	1.275	-.319	-2.262	.032	-5.505	-.263
	γd	-112.863	37.882	-.650	-2.979	.006	-190.731	-34.995
	PI	-.057	1.165	-.010	-1.049	.041	-2.452	2.338

Correlations			Collinearity Statistics	
Zero-order	Partial	Part	Tolerance	VIF
-.861	-.406	-.167	.275	3.637
-.911	-.504	-.220	.115	8.706
.857	-.010	-.004	.131	7.642
a. Dependent Variable: Swelling Pressure (Sp), kpa				

4.6.5 Multicollinearity Diagnostics

Multicollinearity exists when there is a strong correlation between two or more predictors in a regression model. SPSS produces various collinearity diagnostics, one of which is the variance inflation factor (VIF). The VIF indicates whether a predictor has a strong linear relationship with the other predictor(s). Specifically, it provides the VIF and tolerance statistics (with tolerance being 1/VIF). There are a few guidelines applied here:

- If the largest VIF is greater than 10 then there is cause for concern
- If the average VIF is substantially greater than 1 then the regression may be biased
- Tolerance below 0.1 indicates a serious problem.
- Tolerance below 0.2 indicates a potential problem.

For this model, the VIF values are all well below 10 and the tolerance statistics all well above 0.2; therefore there is no collinearity within a data.

4.6 Comparisons of Previously Developed Equations with Values of Study Area

- Komornik and David, (1969); $\text{Log } Ps = 0.132 + 0.0208*LL + 0.6688*\gamma d - 0.0269*w$
- Vijayvergiya and Ghazzaly (1973; $\text{Log } Ps = 1/12\,(0.4*LL - \boldsymbol{\omega} + 23.6)$

  $\text{Log } Ps = 1/19.5(6.24*\gamma d + 0.65*LL-100$
- Ashenafi (2013); $Ps = 1.639*\gamma d + 32.676*PL-3110.94$
- Daniel (2003); $\text{Log } Ps = -5.00 - 0.0002064*LL + 0.003477*PI + 0.005827*\gamma d$

  $\text{Log } Ps = -9.384 + 0.02748*W + 0.006307*PI + 0.008359*\gamma d$

Table 4-29: Comparisons of Previously Developed Equations with measured Values of Study Area

Test No.	Calculate Sp, kPa	Komornik and David		Vijayvergiya and Ghazzaly				Ashenafi		Daniel			
		Predicted Sp, kPa	Variation of Sp, %	Predicted Sp, kPa	Variation of Sp, %	Predicted Sp, kPa	Variation of Sp, %	Predicted Sp, kPa	Variation of Sp, %	Predicted Sp, kPa	Variation of Sp, %	Predicted Sp, kPa	Variation of Sp, %
		Eq. #1		Eq. #2		Eq. #3		Eq. #4		Eq. #5		Eq. #6	
1	215	108.60	49.49	135.94	36.77	173.68	19.22	149.84	30.31	201.48	6.29	306.07	42.36
2	120	122.11	1.76	146.78	31.73	236.09	9.81	563.47	162.08	310.17	44.27	370.87	72.50
3	195	174.00	10.77	322.35	49.93	321.91	49.73	150.44	30.03	293.14	36.34	309.74	44.07
4	200	200.21	0.11	316.23	47.08	447.02	107.92	82.25	61.74	121.54	43.47	120.22	44.08
5	190	88.44	53.45	107.98	49.78	109.92	48.87	90.34	57.98	247.44	15.09	226.46	5.33
6	115	107.55	6.48	94.41	56.09	207.49	3.49	87.34	59.38	104.05	51.60	104.00	51.63
7	150	119.79	20.14	251.19	16.83	127.37	40.76	372.81	73.40	339.52	57.92	274.85	27.84
8	90	97.46	8.29	92.61	56.93	163.31	24.04	380.00	76.74	157.32	26.83	162.52	24.41
9	125	149.04	19.23	199.53	7.20	321.91	49.73	378.95	76.26	268.43	24.85	309.25	43.84
10	105	75.06	28.51	66.13	69.24	102.11	52.51	580.78	170.13	216.37	0.64	217.44	1.13
11	290	83.06	71.36	66.83	68.92	149.87	30.29	107.10	50.19	231.98	7.90	283.02	31.64
12	210	135.06	35.69	215.44	0.20	204.35	4.95	231.58	7.71	205.64	4.35	185.43	13.75
13	105	121.73	15.93	138.57	35.55	222.00	3.26	507.00	135.81	249.67	16.13	205.81	4.27
14	65	76.20	17.23	51.09	76.24	121.98	43.27	387.35	80.16	251.67	17.06	236.99	10.23
Average Variation, %			**24.17**		**43.03**		**34.85**		**76.57**		**25.19**		**29.79**

From the above table, one can observe that most of the equations do not predict the swelling pressure of the soil under investigation. However, equation #1 developed by Komornik and David, and equation #5 developed by Daniel, predicts the swelling pressure which is closer to those samples of the study area that have relatively minimum percent of variations than the others as shown in the figure below. This indicates that correlation developed for a certain soil is not applicable for other soil.

The reason for this variation is may be due to the difference in test procedures and the nature of the soil, environmental, climatic condition and geologic formation of the region where the relation is developed to the study area.

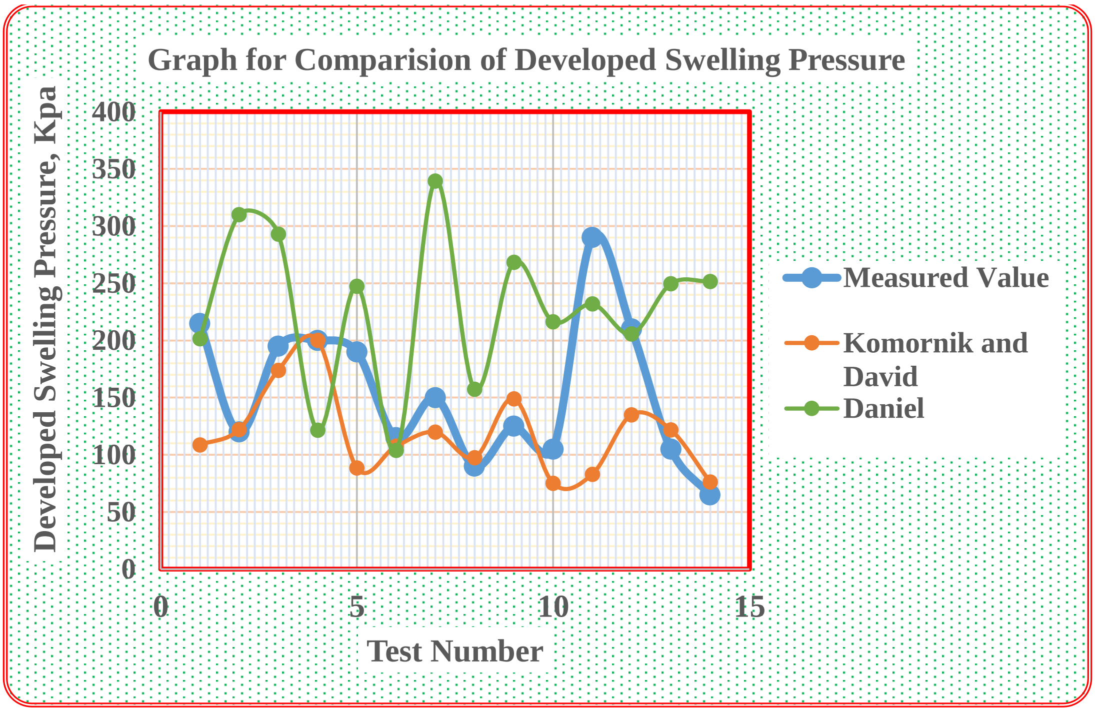


Figure 4-12: Comparison of Measured Values of Swelling Pressure for previously Developed models

4.7 Validation of the Developed Formula

Among the other Models developed the following equation gives best fit model after the interpretation of SPSS out. And also, the selected model gives adequate regression analysis by fulfilling the required statistical considerations.

$$SP = 436.066 - 0.057*PI - 2.884*NMC - 112.863*\gamma d$$

Table 4-30: Predicted Swelling Pressure values using newly developed equations

Sample No.	Calculated Swelling Pressure (Sp), Kpa	Predicted Swelling Pressure (Sp)	Variation $= \frac{\|(A-B)\|}{A} * 100$
	(A)	(B)	
1	265	255.37	3.63
2	215	217.51	1.17
3	120	125.29	4.41
4	285	289.86	1.70
5	195	203.41	4.32
6	200	187.31	6.34
7	245	231.80	5.39
8	190	183.16	3.60
9	115	125.31	8.97
10	240	235.18	2.01
11	150	160.18	6.79
12	90	95.39	5.99
13	210	193.92	7.66
14	125	116.41	6.87
15	105	97.54	7.10
16	325	287.91	11.41
17	290	279.68	3.56
18	210	217.20	3.43
19	125	116.82	6.55
20	105	97.76	6.89
21	65	66.00	1.54
22	280	308.30	10.11
23	260	283.95	9.21
24	155	168.38	8.63
25	205	195.58	4.60
26	170	159.26	6.32
27	105	108.41	3.25
28	300	316.78	5.59
29	285	280.10	1.72
30	210	210.97	0.46
Average Variation			**5.31**

4.7.1 Cross Validation for control test

In this section it was tried to validate the developed equations by using nine control tests. The data that is used as a control test is conducted on different parts of Burayu soil sample.

Table 4-31 : Sample Data for Control test

Location of Test Pits	LL	PI	LS	NMC	γ_d	Ac	LI	Swelling Pressure (Sp)
Gafarsa Burayu (B/Stadium)	97.50	45.99	11.04	44.86	0.93	0.65	-0.14	205
Burayu Katta (B/Qera)	83.00	46.82	10.14	48.67	1.12	0.66	0.27	195
Malka Gafarsa (A/Meda)	69.50	38.25	9.18	51.27	1.29	0.56	0.52	135
Lakku Katta (Sansusi)	105.80	59.73	10.62	28.86	0.52	0.83	-0.29	315
Lakku Katta (Wisdom Seeder School)	88.80	38.83	10.21	31.11	0.94	0.63	-0.49	295
Gafarsa Guje (Corrisa)	71.50	40.90	10.61	36.27	1.18	0.65	0.14	200
Gafarsa Guje (Kella)	84.20	48.02	8.55	30.16	1.16	0.71	-0.13	205
Gafarsa Nono (Gabriel)	76.25	44.96	8.96	37.11	1.46	0.68	0.13	190
Gafarsa Burayu (Xache)	65.50	40.60	8.36	39.30	1.53	0.62	0.35	125

Table 4-32: Prediction of Swelling Pressure and Validation of the newly developed equations by Control test Samples

Location of Test Pits	Calculated Swelling Pressure (Sp)	Predicted Swelling Pressure (Sp)	Variation $\frac{\lvert(A-B)\rvert}{A} * 100$
	(A)	(B)	
Gafarsa Burayu (B/Stadium) @1m	210	199.17	5.16
Burayu Katta (B/Qera) @2m	175	166.65	4.77
Malka Gafarsa (A/Meda) @1m	150	140.04	6.64
Lakku Katta (Sansusi) @1m	295	290.60	1.49
Lakku Katta (Wisdom Seeder School) @1m	235	237.62	1.11
Gafarsa Guje (Corrisa) @2m	200	195.65	2.17
Gafarsa Guje (Kella)@1m	225	214.98	4.45
Gafarsa Nono (Gabriel)@1m	170	161.43	5.04
Gafarsa Burayu (Xache)@2m	145	147.89	1.99
Average Variation			**3.65**

4.7.2 Discussion on the Validation of Developed Formula

The predicted swelling pressure values using newly developed equations shows the variation of the actual value with the predicted value of the model is 5.31%. This indicates there is small variation exits between the actual value and the predicted value and the model developed can be used for estimation of swelling pressures of the study area.

After Checking Validation of the newly developed equations by Control test Samples, the equations give approximately the same swelling pressure value compared with the measured one for the control test samples with accuracy range of 3.65%. This indicates that there is a very good prediction of the values.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Experimental work has been carried out to predict the swelling pressure of expansive soils from easy measured soil properties. Several tests to measure swelling pressure and index properties were performed on disturbed and undisturbed samples to a wide range of the study area.

- The soil initial state parameters such as water content, dry density and void ratio were combined in a way reflecting the influence of each of them on swell percent and swelling pressure.
- The swelling pressure and the amount of swell (Swelling potential) of the soil were measured ASTM D4546-08. The results of the odometer tests showed that the soils can exhibit swelling pressure in the range of 65kPa to 325kPa and swelling potential in the range of 7.48 to 15.86 percent.
- Soil classification was done by using AASHTO Classification System, the soils in the study area are classified in to soil groups A-7-6 and A-7-5 and using Unified Soil Classification System (USCS) the soils of the study area are classified as CH (inorganic clay with high plasticity) and only three of the thirteen soil test samples are on MH group (inorganic silt of high compressibility).
- The equation developed using liquid limit (LL), plasticity index (PI), Linear shrinkage limit (LS), Dry Density (γd), liquidity index (LI), Activity of Clay (Ac) and Natural moisture content (NMC) as an input, can predict swelling pressure of the study area.
- From the Single Linear Regression Analysis, the Dry Density (γd) has good correlation with swelling pressure among other single index parameters.
- In prediction of swelling pressure from Multiple Linear Regression analysis, ***SP = 436.066 - 0.057*PI - 2.884*NMC - 112.863*γd*** describes the relation better than the others with *Coefficient Of Determination* (R^2) of 0.858. This is indicaes Good relationship exists between the swelling pressure and the predictors.
- Comparison of the measured and predicted swelling pressure values of all the studied data indicates that there is a good agreement between the caculated and Predicted swelling pressure values.

5.2 Recommendations

- The accuracy of newly developed equations may be further modified or improved by increasing other additional soil samples and by decreasing expected errors during sampling and testing time.
- Further detailed laboratory analysis must be carried out on a number of additional disturbed and undisturbed soil samples from different locations of the town to prepare a reliable correlation and regression analysis.
- There is 3.65% precision variation by using control test in between actual laboratory and predicted Sp values. So that, it is recommended to use the developed equations for preliminary design and small projects to predict the swelling pressure of the study area.
- Finally, Burayu is one of the fast growing towns and commercial centers in the Oromia Special Zone in which further detailed Engineering soil investigation is essential.

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APPENDIX A: Representative Atterberg Limit test Results

Table A1: Determination of LL, PL and PI of Soil for TP1 @2m

TEST METHOD: ASTM D4318-98						
Determination	**Liquid Limit @ 2m**				**Plastic Limit @2m**	
Number of blows		18	25	30		
Container	No	B-4	B-1	A-5	A-7	A-1
Wt. of container + wet soil	(g)	51.530	52.796	53.570	25.996	24.845
Wt. of container + dry soil	(g)	38.249	39.214	39.628	22.787	21.937
Wt. of container	(g)	23.520	23.890	23.660	13.436	13.591
Wt. of water	(g)	13.281	13.582	13.942	3.209	2.908
Wt. of dry soil	(g)	14.729	15.324	15.968	9.351	8.346
Moisture content	(%)	90.169	88.632	87.312	34.317	34.843
Average MC	(%)	**88.704**			**34.580**	
Determination of (PI)	**(LL - PL)**					
	LL	88.70				
	PL	34.58				
	PI	54.12				

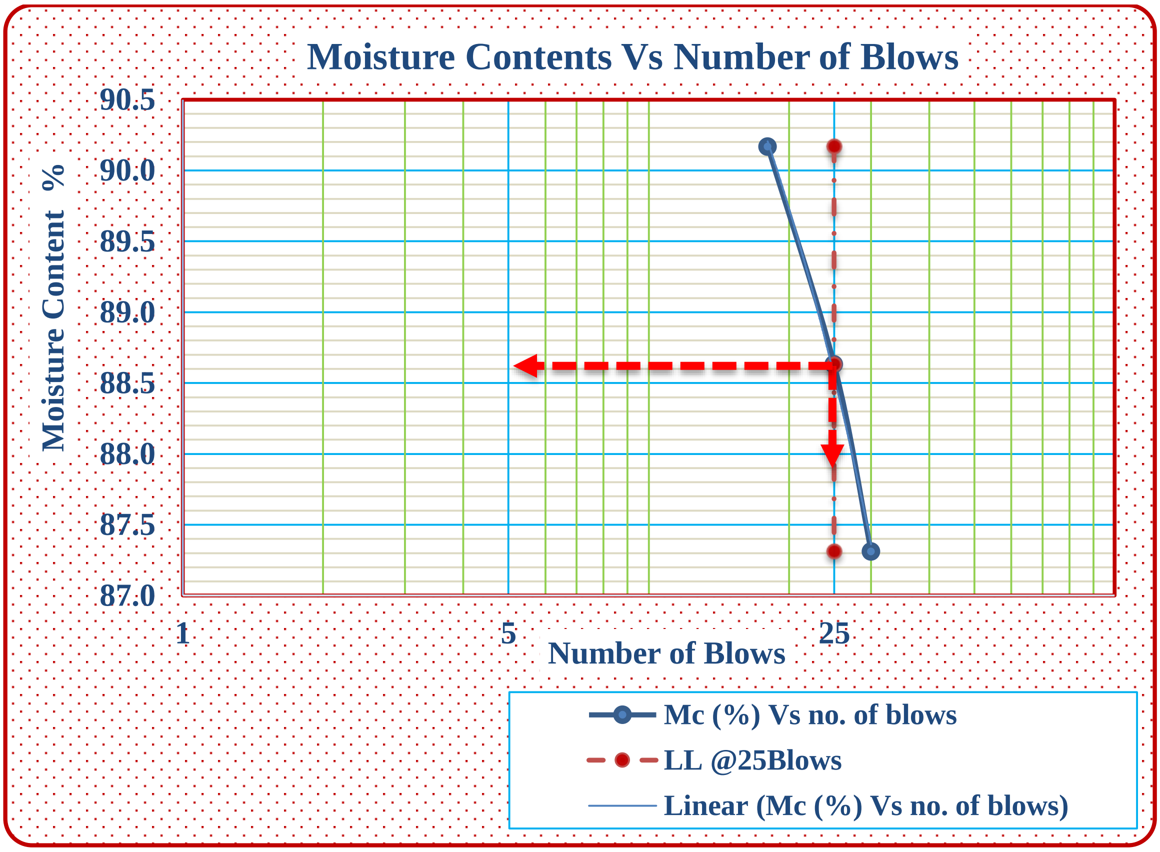


Figure A1: Moisture Content versus Number of Blows for TP1 @2m

Table A2: **Determination of LL, PL and PI of Soil for TP2 @3m**

TEST METHOD: ASTM D4318-98						
Determination	TEST PIT 2: Liquid Limit @ 2m				Plastic Limit @2m	
Number of blows		16	29	34		
Container No.	No	NB	II	J6	B3	3
Wt. of container + wet soil	(gm)	35.978	36.528	32.629	18.113	30.529
Wt. of container + dry soil	(gm)	26.675	27.282	25.187	14.798	26.948
Wt. of container	(gm)	17.154	17.483	17.176	5.471	16.596
Wt. of water	(gm)	9.303	9.246	7.442	3.315	3.581
Wt. of dry soil	(gm)	9.521	9.799	8.011	9.327	10.352
Moisture content	(%)	97.708	94.357	92.897	35.542	34.592
Average	(%)	94.987			35.067	
Determination of (PI)	(LL - PL)					
	LL	95.40				
	PL	35.07				
	PI	60.33				

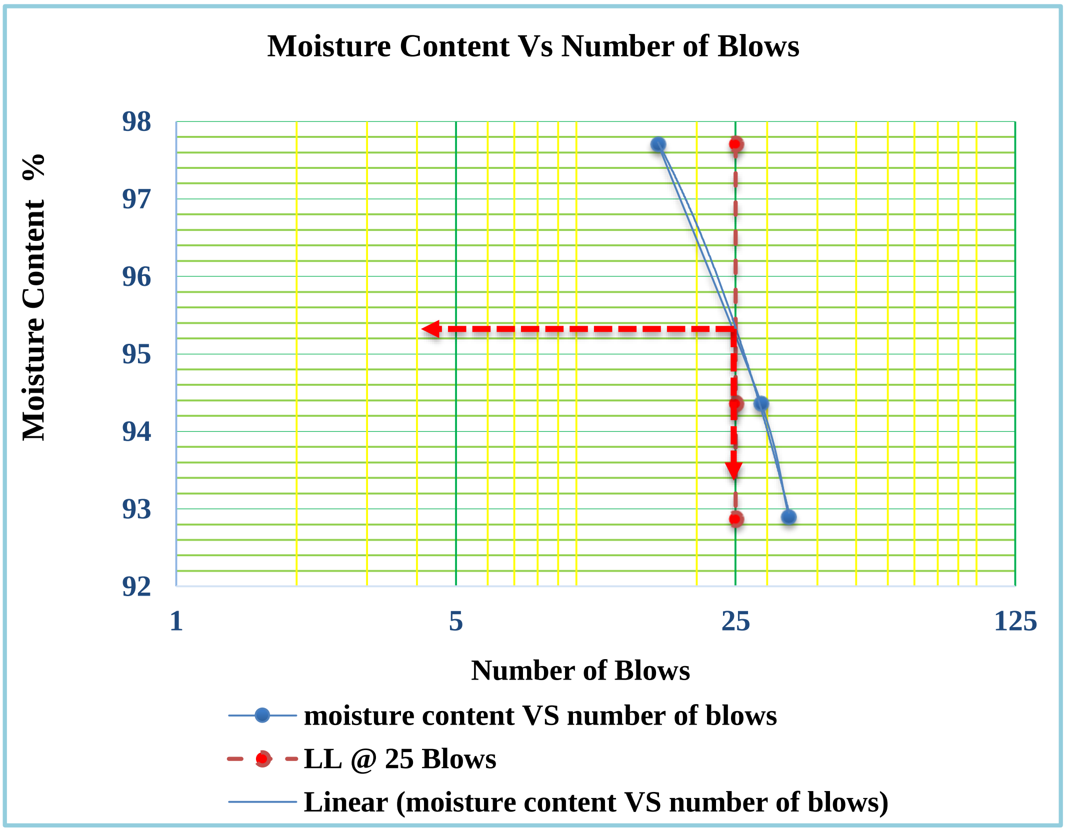


Figure A2: Moisture Content versus Number of Blows for TP2 @3m

Table A3: **Determination of LL, PL and PI of Soil for TP3 @1m**

TEST METHOD: ASTM D4318-98						
Determination	**Liquid Limit TP3 @ 1m**				**Plastic Limit TP3 @1m**	
Number of blows		18	25	30		
Container No.	No	B-4	B-1	A-5	A-7	A-1
Wt. of container + wet soil	(gm)	51.530	52.796	53.570	25.996	24.845
Wt. of container + dry soil	(gm)	38.925	39.829	40.204	23.187	22.271
Wt. of container	(gm)	23.520	23.890	23.660	13.436	13.591
Wt. of water	(gm)	12.605	12.967	13.366	2.809	2.574
Wt. of dry soil	(gm)	15.405	15.939	16.544	9.751	8.680
Moisture content	(%)	81.824	81.354	80.791	28.807	29.654
Average	**(%)**	**81.323**			**29.231**	
Determination of (PI)	**(LL - PL)**					
	LL	81.28				
	PL	29.23				
	PI	52.05				

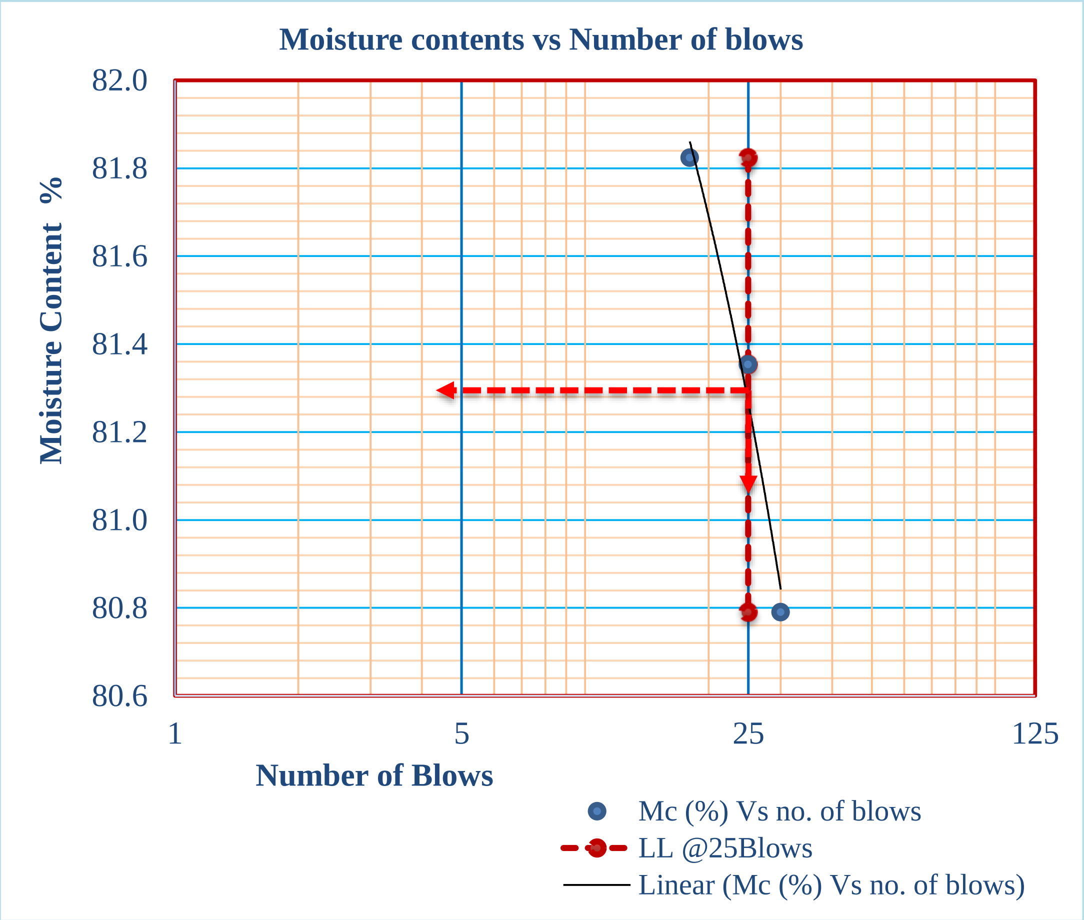


Figure A3: Moisture Content versus Number of Blows for TP3 @1m

Table A4: **Determination of LL, PL and PI of Soil for TP4 @3m**

TEST METHOD: ASTM D4318-98						
Determination	**TEST PIT 4: Liquid Limit @ 3m**				**Plastic Limit @3m**	
Number of blows		18	28	34		
Container	No	II	G7	B3	A1	C4
Wt. of container + wet soil	(gm)	40.973	43.876	38.456	32.273	33.834
Wt. of container + dry soil	(gm)	31.918	34.672	29.963	29.442	30.153
Wt. of container	(gm)	19.287	21.394	17.481	20.184	18.354
Wt. of water	(gm)	9.055	9.204	8.493	2.831	3.681
Wt. of dry soil	(gm)	12.631	13.278	12.482	9.258	11.799
Moisture content	(%)	71.689	69.318	68.042	30.579	31.198
Average	(%)	**69.683**			**30.888**	
Determination of (PI)	**(LL - PL)**					
	LL	70.2				
	PL	30.89				
	PI	39.31				

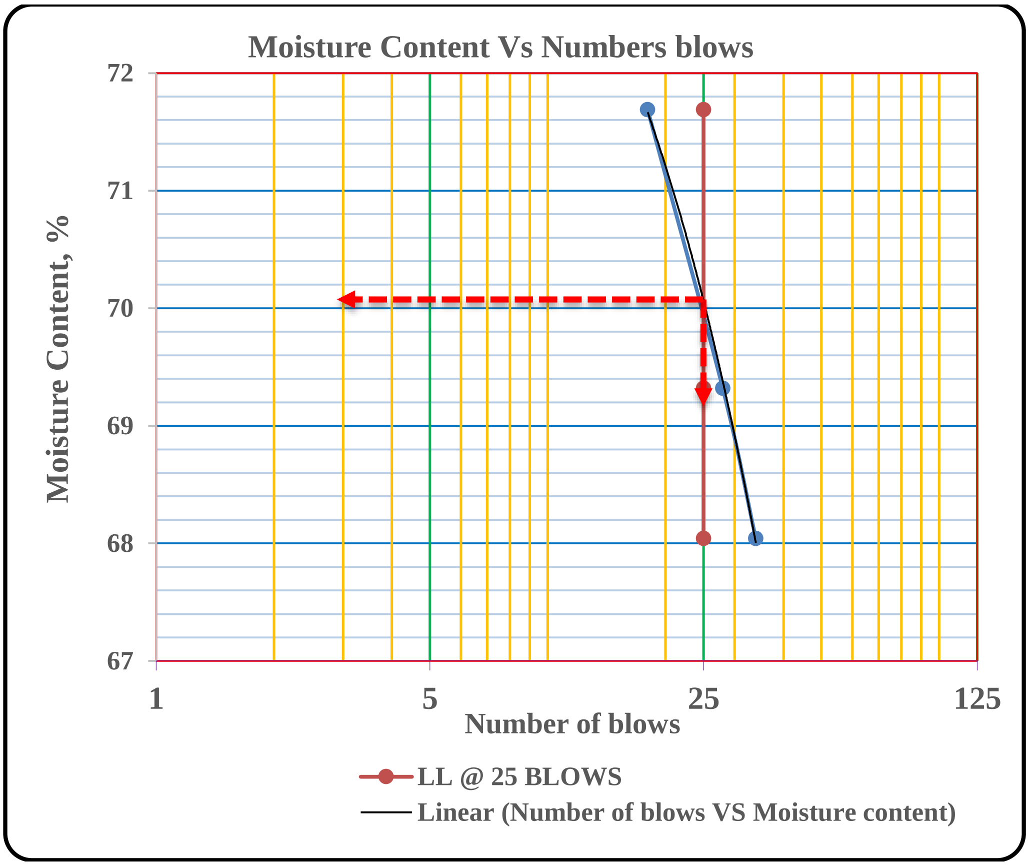


Figure A4: Moisture Content versus Number of Blows for TP4 @3m

Table A5: **Determination of LL, PL and PI of Soil for TP5 @1m**

TEST METHOD : ASTM D4318-98						
Determination		**Liquid Limit TP5 @1m**			**Plastic Limit @1m**	
Number of blows		18	25	30		
Container No.		B-4	B-1	A-5	A-7	A-1
Wt. of container + wet soil	(gm)	40.538	43.056	41.579	28.498	27.846
Wt. of container + dry soil	(gm)	30.819	32.902	31.902	24.529	23.999
Wt. of container	(gm)	18.528	19.756	19.128	12.435	13.097
Wt. of water	(gm)	9.719	10.154	9.677	3.969	3.847
Wt. of dry soil	(gm)	12.291	13.146	12.774	12.094	10.902
Moisture content	(%)	79.074	77.240	75.755	32.818	35.287
Average	**(%)**	**77.357**			**34.053**	
Determination of (PI)	**(LL - PL)**					
	LL	77.2				
	PL	34.05				
	PI	43.15				

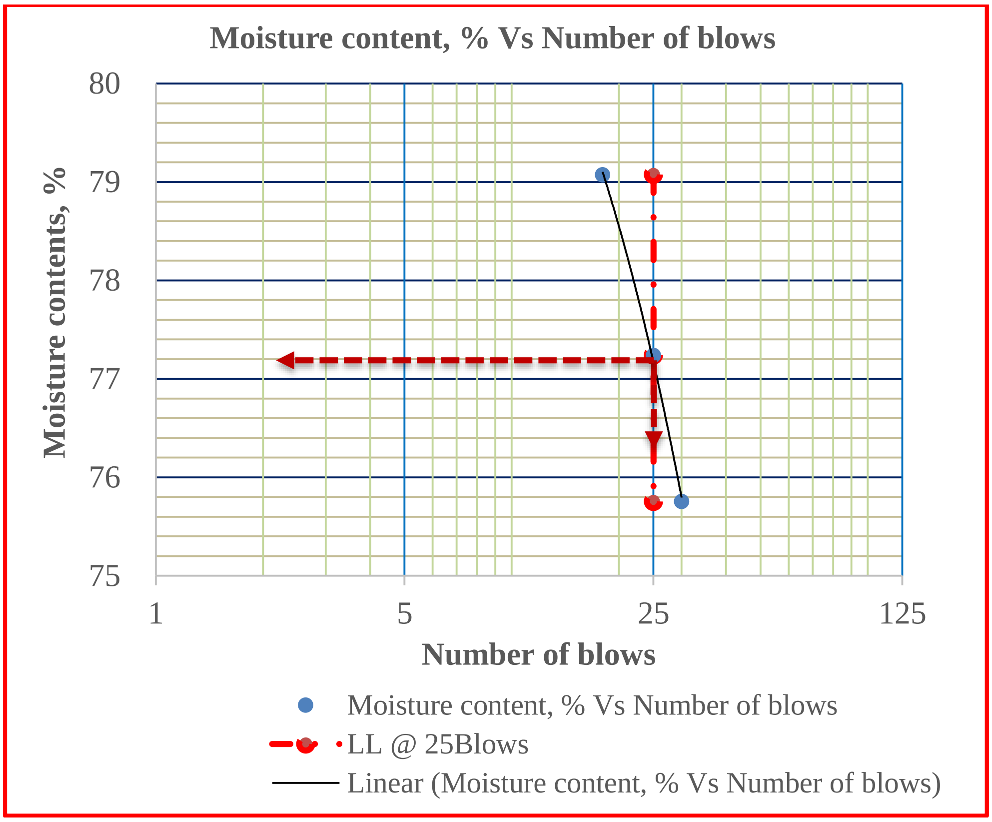


Figure A5: Moisture Content versus Number of Blows for TP5 @1m

Table A6: **Determination of LL, PL and PI of Soil for TP6 @3m**

TEST METHOD : ASTM D4318-98						
Determination	TEST PIT 6: Liquid Limit @ 3m				Plastic Limit @3m	
Number of blows		18	28	34		
Container	No	II	G7	B3	A1	C4
Wt. of container + wet soil	(g)	34.903	33.815	33.915	35.873	36.034
Wt. of container + dry soil	(g)	26.191	25.495	25.663	31.194	31.193
Wt. of container	(g)	18.000	17.393	17.394	18.243	17.787
Wt. of water	(g)	8.712	8.320	8.252	4.679	4.841
Wt. of dry soil	(g)	8.191	8.102	8.269	12.951	13.406
Moisture content	(%)	106.361	102.691	99.794	36.128	36.111
Average	(%)	**102.949**			**36.120**	
Determination of (PI)	**(LL - PL)**					
	LL	103				
	PL	36.12				
	PI	66.88				

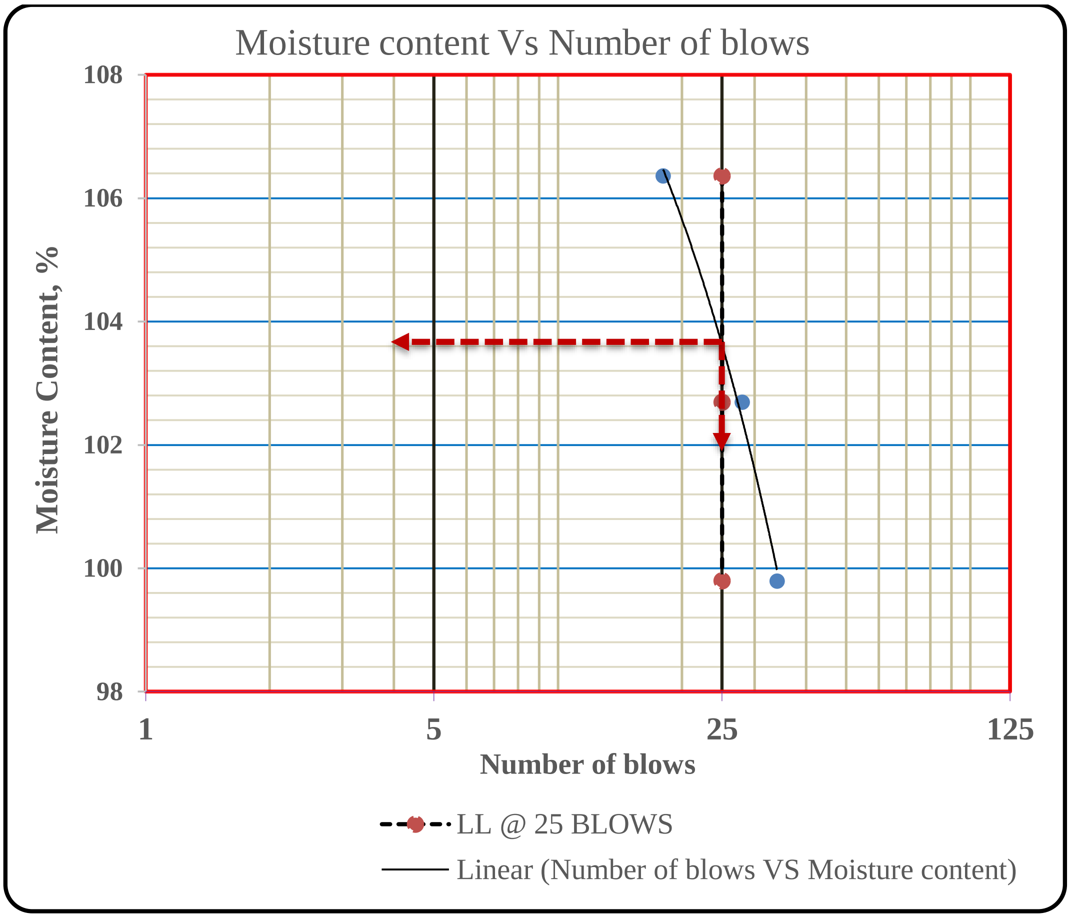


Figure A6: Moisture Content versus Number of Blows for TP6 @3m

Table A7: **Determination of LL, PL and PI of Soil for TP7 @1m**

TEST METHOD : ASTM D4318-98						
Determination		**Liquid Limit @ 1m**			**Plastic Limit @1m**	
Number of blows		16	24	30		
Container	No	B-4	B-1	A-5	A-7	A-1
Wt. of container + wet soil	(gm)	44.530	43.125	43.570	25.894	24.840
Wt. of container + dry soil	(gm)	36.089	35.492	35.805	22.896	22.111
Wt. of container	(gm)	23.520	23.897	23.660	13.431	13.592
Wt. of water	(gm)	8.441	7.633	7.765	2.998	2.729
Wt. of dry soil	(gm)	12.569	11.595	12.145	9.465	8.519
Moisture content	(%)	67.157	65.830	63.936	31.675	32.034
Average	(%)	65.641			31.854	
Determination of (PI)	**(LL - PL)**					
	LL	65.8				
	PL	31.85				
	PI	33.95				

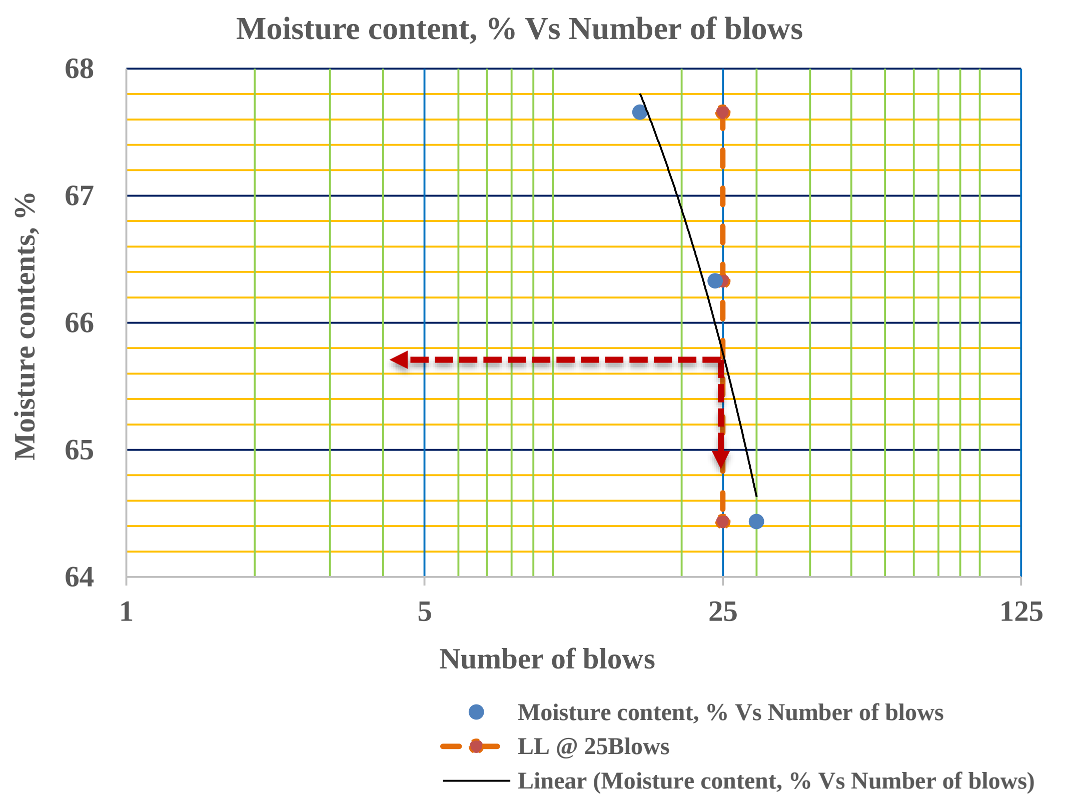


Figure A7: Moisture Content versus Number of Blows for TP7 @1m

Table A8: **Determination of LL, PL and PI of Soil for TP8 @2m**

TEST METHOD : ASTM D4318-98						
Determination	**TEST PIT 8: Liquid Limit @ 2m**				**Plastic Limit @2m**	
Number of blows		16	29	34		
Container	No	NB	II	J6	B3	3
Wt. of container + wet soil	(gm)	36.978	37.528	34.629	18.013	30.429
Wt. of container + dry soil	(gm)	26.675	27.282	25.787	14.498	26.398
Wt. of container	(gm)	17.154	17.483	17.176	5.571	16.596
Wt. of water	(gm)	10.303	10.246	8.842	3.515	4.031
Wt. of dry soil	(gm)	9.521	9.799	8.611	8.927	9.802
Moisture content	(%)	108.211	104.562	102.683	39.375	41.124
Average	(%)	105.152			40.250	
Determination of (PI)	**(LL - PL)**					
	LL	105.80				
	PL	40.25				
	PI	65.55				

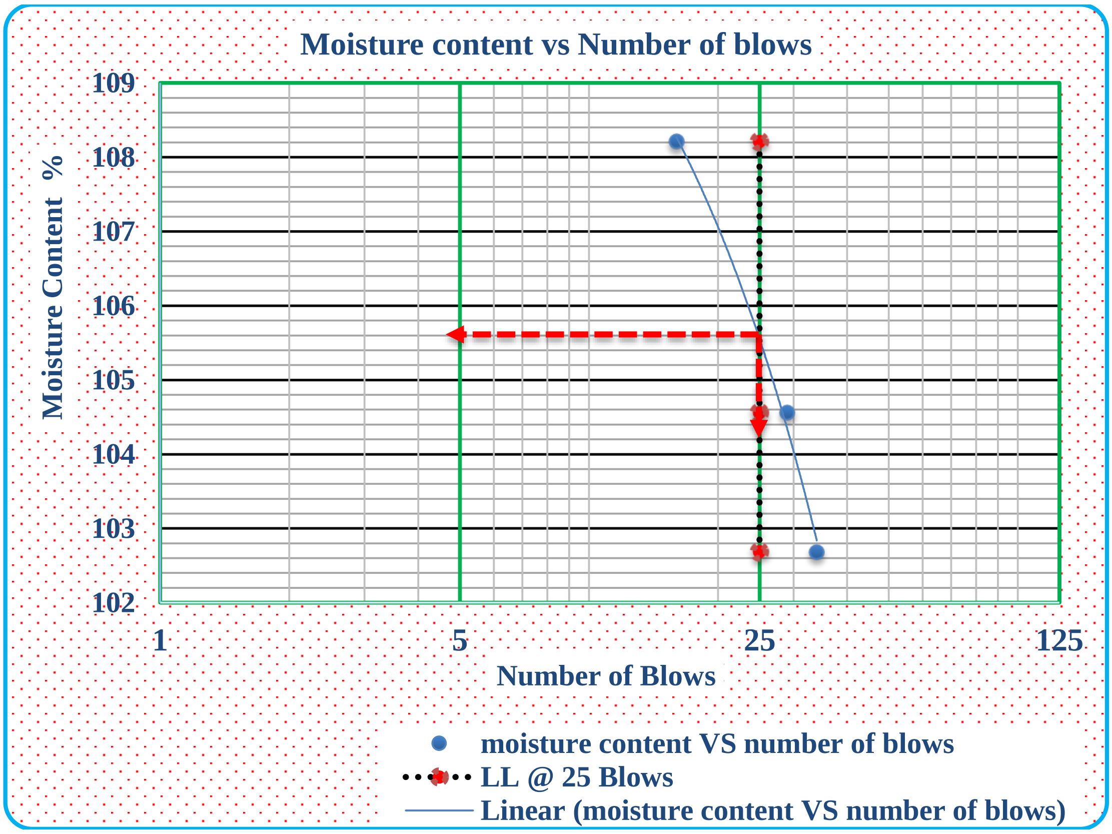


Figure A8: Moisture Content versus Number of Blows for TP8 @2m

Table A9: **Determination of LL, PL and PI of Soil for TP9 @2m**

TEST METHOD : ASTM D4318-98						
Determination		**Liquid Limit @ 2m**			**Plastic Limit @2m**	
Number of blows		18	25	30		
Container	No	B-4	B-1	A-5	A-7	A-1
Wt. of container + wet soil	(gm)	51.530	52.796	53.570	25.996	24.845
Wt. of container + dry soil	(gm)	37.049	38.614	38.858	22.987	21.987
Wt. of container	(gm)	19.520	20.890	19.660	13.136	13.091
Wt. of water	(gm)	14.481	14.182	14.712	3.009	2.858
Wt. of dry soil	(gm)	17.529	17.724	19.198	9.851	8.896
Moisture content	(%)	82.612	80.016	76.633	30.545	32.127
Average	**(%)**	**79.753**			**31.336**	
Determination of (PI)	**(LL - PL)**					
	LL	79.56				
	PL	31.34				
	PI	48.22				

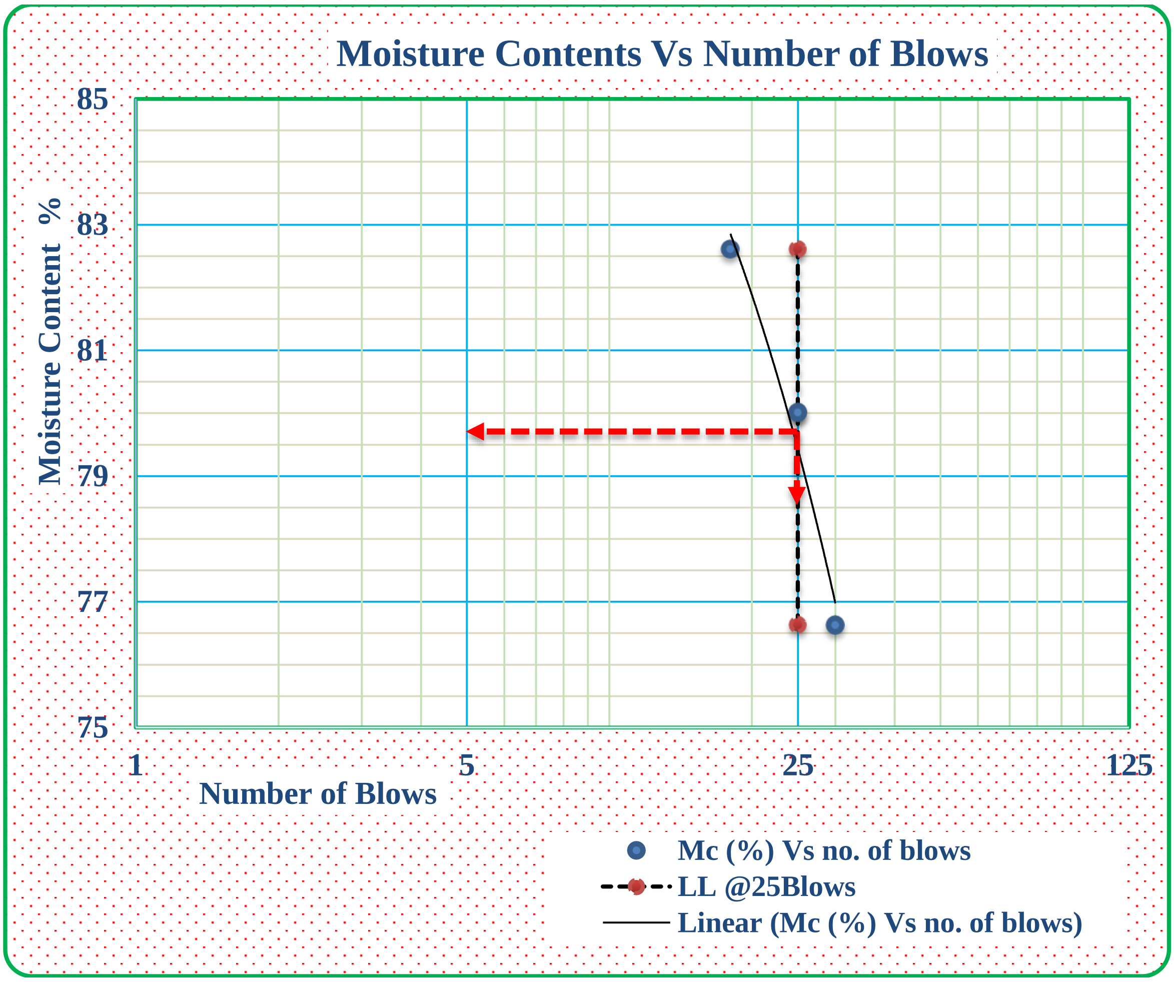


Figure A9: Moisture Content versus Number of Blows for TP9 @2m

Table A10: **Determination of LL, PL and PI of Soil for TP10 @1m**

TEST METHOD : ASTM D4318-98						
Determination	TEST PIT 2: Liquid Limit @ 1m				**Plastic Limit @1m**	
Number of blows		17	28	34		
Container	No	DH	P2	HC11	A2	O2
Wt. of container + wet soil	(g)	33.145	33.939	33.153	27.896	17.886
Wt. of container + dry soil	(g)	24.379	25.118	24.915	23.622	13.916
Wt. of container	(g)	16.989	17.492	17.667	14.149	5.133
Wt. of water	(g)	8.766	8.821	8.238	4.274	3.970
Wt. of dry soil	(g)	7.390	7.626	7.248	9.473	8.783
Moisture content	(%)	118.620	115.670	113.659	45.118	45.201
Average	**(%)**		**115.983**		**45.159**	
Determination of (PI)	**(LL - PL)**					
	LL	116.40				
	PL	45.16				
	PI	71.24				

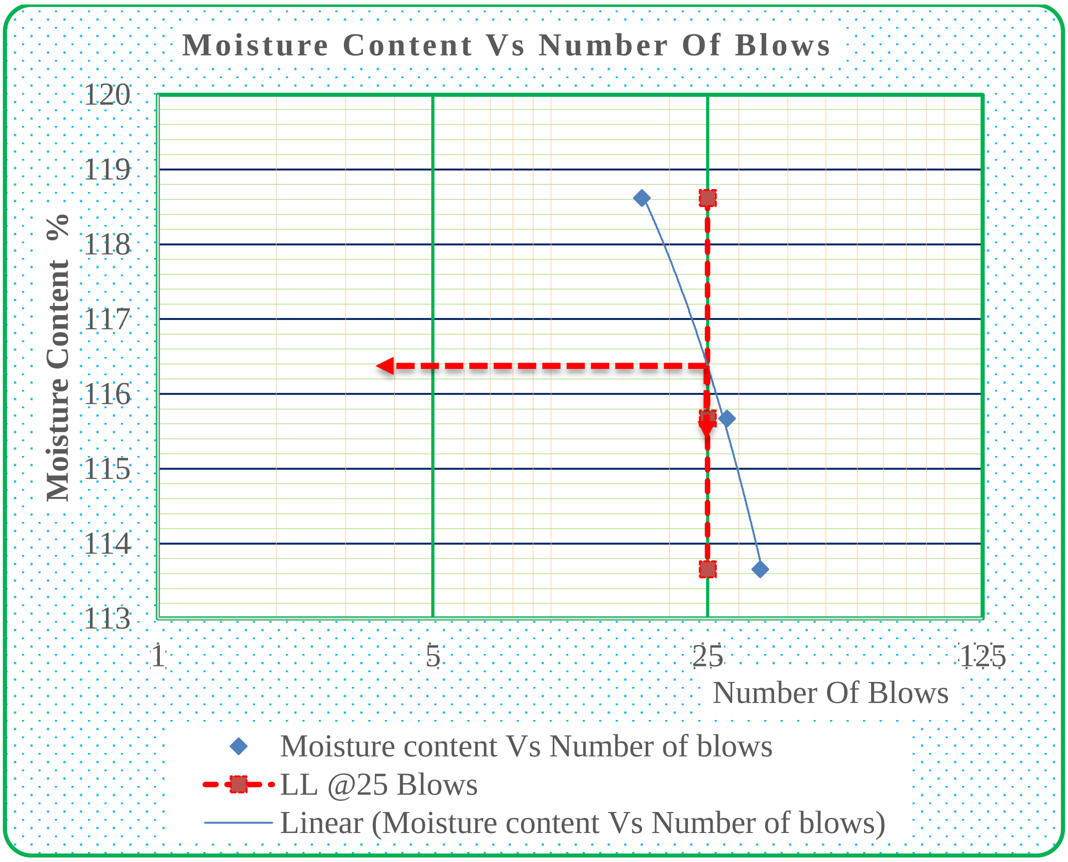


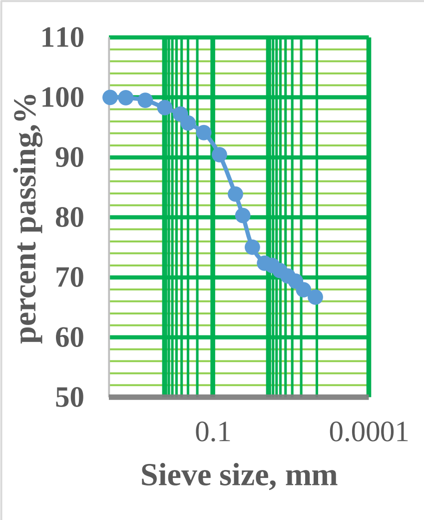
Figure A10: Moisture Content versus Number of Blows for TP10 @1m

APPENDIX B: Representative Grain size distribution Analysis Result

Table B1: Determination of particle size distribution for TP1 @ 2m

TEST METHOD: D 422 – 63 (Reapproved 2002)					**C)) Combined sieve and Hydrometer Analysis**			
Sample preparation : Oven-dried sample				particle size	% pass		AASHTO	USCS
Method of sieving:				9.5	100	% of gravel	0.46	0.04
Wet sieving	☑			4.75	99.96	% of Sand	9.09	9.51
Dry sieving	☐			2	99.54	% of Silt	22.51	22.51
Mass dry soil (before wash)		1000	gm	0.85	98.26	% of Clay	67.94	67.94
mass pass 0.075 mm		904.50	gm	0.4250	97.21			
%age of pass 0.075 mm		90.45	%	0.300	95.74			
	A) Sieve Analysis			0.150	94.11			
Total mass =	1000	gm		0.075	90.45			

Sieve Size mm	Wt. R	% R	% Cum. Retained	% P	particle size	% pass
					0.037	83.86
9.5	0	0	0	100	0.027	80.32
4.75	0.4	0.04	0.04	99.96	0.017	75.01
2	4.2	0.42	0.46	99.54	0.010	72.36
0.85	12.8	1.28	1.74	98.26	0.007	72.01
0.425	10.5	1.05	2.79	97.21	0.005	71.12
0.300	14.7	1.47	4.26	95.74	0.004	70.24
0.150	16.3	1.63	5.89	94.11	0.003	69.35
0.075	36.6	3.66	9.55	90.45	0.002	67.94
Pass	904.5	90.45	100	0	0.001	66.70



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.76

Time min	A/ Hydr Rdg	Temp	Correction For Hydrometer Reading					Corr. factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj. % finer
			T° corr	meni scus corr.	zero corr.	Comp Corr.	Corr. Hydr. Rdg						
1	51	22	0.4	1	-5	-3.6	47.4	0.978	7.9	0.01321	0.037	92.71	83.86
2	49	22	0.4	1	-5	-3.6	45.4	0.978	8.3	0.01321	0.027	88.80	80.32
5	46	22	0.4	1	-5	-3.6	42.4	0.978	8.8	0.01321	0.017	82.93	75.01
15	44.5	22	0.4	1	-5	-3.6	40.9	0.978	9.0	0.01321	0.010	80.00	72.36
30	44	23	0.7	1	-5	-3.3	40.7	0.978	9.1	0.01321	0.007	79.61	72.01
60	43.5	23	0.7	1	-5	-3.3	40.2	0.978	9.2	0.01321	0.005	78.63	71.12
120	43	23	0.7	1	-5	-3.3	39.7	0.978	9.2	0.01306	0.004	77.65	70.24
240	42.5	23	0.7	1	-5	-3.3	39.2	0.978	9.3	0.01306	0.003	76.68	69.35
480	42	22	0.4	1	-5	-3.6	38.4	0.978	9.4	0.01306	0.002	75.11	67.94
1440	41.5	21	0.2	1	-5	-3.8	37.7	0.978	9.5	0.01321	0.001	73.74	66.70

Table B2: Determination of particle size distribution for TP2 @ 2m

TEST METHOD: ASTM D 422 – 63			
Sample preparation : Oven-dried sample			
Method of sieving:	Wet sieving		☑
	Dry sieving		☐
Mass dry soil (before wash)		1000	gm
Mass pass 0.075 mm,		887.30	gm
%age of pass 0.075 mm		88.73	%

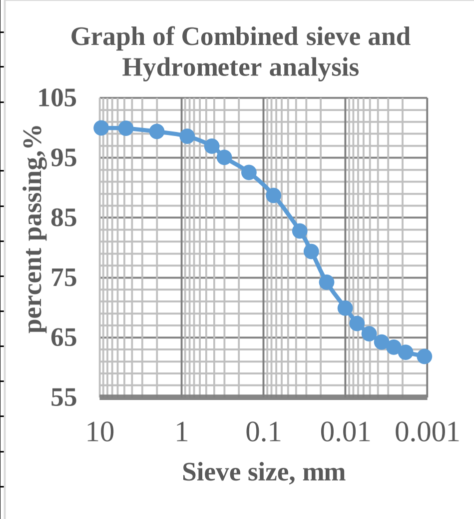
A) Sieve Analysis

Total mass, gm	1000			
Sieve Size, mm	Wt. R	% R	% Cum. Retained	% P
9.5	0	0	0	100
4.75	0.8	0.08	0.08	99.92
2	5.3	0.53	0.61	99.39
0.85	7.9	0.79	1.4	98.6
0.425	16.4	1.64	3.04	96.96
0.300	18.7	1.87	4.91	95.09
0.150	25.4	2.54	7.45	92.55
0.075	38.2	3.82	11.27	88.73
Pass	887.30	88.73	100	0

C) Combined sieve and hydrometer analysis

particle size	% of pass
9.5	100
4.75	99.92
2	99.39
0.85	98.6
0.4250	96.96
0.300	95.09
0.150	92.55
0.075	**88.73**
0.0360	82.80
0.0260	79.36
0.0169	74.21
0.0100	69.91
0.0072	67.34
0.0051	65.62
0.0036	64.25
0.0026	63.39
0.0018	62.53
0.0011	61.84

	AASHTO	USCS
% of gravel	0.61	0.08
% of Sand	10.66	11.19
% of Silt	26.20	26.20
% of Clay	62.53	62.53



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.86

Time min	Hydr Rdg	Temp	Temp corr.	meniscus corr	Zero corr.	Comp Corr	corr. Hydr Rdg	Corr factor (a)	Effe. Depth (L)	Value of K	D (mm)	% finer, P	Adj. % of finer, P
1	52	21	0.2	1	-5	-3.8	48.2	0.968	7.8	0.01287	0.0360	93.32	82.80
2	50	21	0.2	1	-5	-3.8	46.2	0.968	8.2	0.01287	0.0260	89.44	79.36
5	47	21	0.2	1	-5	-3.8	43.2	0.968	8.6	0.01287	0.0169	83.64	74.21
15	44.5	21	0.2	1	-5	-3.8	40.7	0.968	9.0	0.01287	0.0100	78.80	69.91
30	43	21	0.2	1	-5	-3.8	39.2	0.968	9.3	0.01287	0.0072	75.89	67.34
60	42	21	0.2	1	-5	-3.8	38.2	0.968	9.5	0.01287	0.0051	73.96	65.62
120	41	22	0.4	1	-5	-3.6	37.4	0.968	9.6	0.01272	0.0036	72.41	64.25
240	40.5	22	0.4	1	-5	-3.6	36.9	0.968	9.7	0.01272	0.0026	71.44	63.39
480	40.2	21	0.2	1	-5	-3.8	36.4	0.968	9.7	0.01287	0.0018	70.47	62.53
1440	40	20	0	1	-5	-4	36	0.968	9.8	0.01303	0.0011	69.70	61.84

Table B3: Determination of Particle Size Distribution for TP3 @3m

TEST METHOD: ASTM D 422 – 63		
Sample preparation : Oven-dried sample		
Method of sieving: Wet sieving		☑
Method of sieving: Dry sieving		☐
Mass dry soil (before wash)	1000	gm
Mass pass 0.075 mm	879	gm
%age of pass 0.075 mm	87.90	%

A) Sieve Analysis

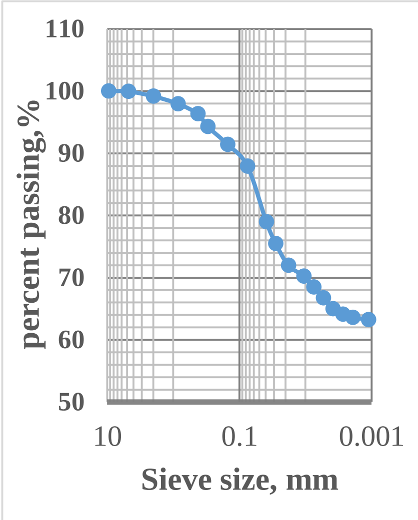
Total mass, gm 1000

Sieve Size mm	Wt. of Retained	% of Retained	% Cum. Retained	% of Pass
9.5	0	0	0	100
4.75	0.4	0.04	0.04	99.96
2	7.8	0.78	0.82	99.18
0.85	12.1	1.21	2.03	97.97
0.425	16.3	1.63	3.66	96.34
0.300	20.5	2.05	5.71	94.29
0.150	28.6	2.86	8.57	91.43
0.075	35.3	3.53	12.1	87.9
Pan	879.00	87.9	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	99.96
2	99.18
0.85	97.97
0.4250	96.34
0.300	94.29
0.150	91.43
0.075	**87.9**
0.0390	78.98
0.0281	75.49
0.0181	72.00
0.0106	70.25
0.0075	68.50
0.0054	66.75
0.0038	65.01
0.0027	64.13
0.0019	63.61
0.0011	63.26

	AASHTO	USCS
% of gravel	0.82	0.04
% of Sand	11.28	12.06
% of Silt	21.15	24.29
% of Clay	66.75	63.61



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.68

Time min	A/ Hydr Rdg	Temp	Correction For Hydrometer Reading: T° Corr	meniscus corr.	zero corr.	Comp Corr.	Corr H. Rdg	Corr. factor (a)	Effe. Depth (L)	Value of K	D (mm)	% finer, P	Adj. % of finer
1	49	21	0.2	1	-5	-3.8	45.2	0.994	8.3	0.01353	0.0390	89.86	78.98
2	47	21	0.2	1	-5	-3.8	43.2	0.994	8.6	0.01353	0.0281	85.88	75.49
5	45	21	0.2	1	-5	-3.8	41.2	0.994	9.0	0.01353	0.0181	81.91	72.00
15	44	21	0.2	1	-5	-3.8	40.2	0.994	9.1	0.01353	0.0106	79.92	70.25
30	43	21	0.2	1	-5	-3.8	39.2	0.994	9.3	0.01353	0.0075	77.93	68.50
60	42.5	21	0.2	1	-5	-3.8	38.2	0.994	9.5	0.01353	0.0054	75.94	66.75
120	41.5	21	0.2	1	-5	-3.8	37.2	0.994	9.6	0.01353	0.0038	73.95	65.01
240	40.5	21	0.2	1	-5	-3.8	36.7	0.994	9.7	0.01353	0.0027	72.96	64.13
480	40.2	21	0.2	1	-5	-3.8	36.4	0.994	9.7	0.01353	0.0019	72.36	63.61
1440	40	21	0.2	1	-5	-3.8	36.2	0.994	9.8	0.01353	0.0011	71.97	63.26

Table B4: Determination of Particle Size Distribution for TP4 @3m

TEST METHOD: ASTM D 422 – 63			
Sample preparation : Oven-dried sample			
Method of sieving	Wet sieving		☑
	Dry sieving		☐
Mass dry soil (before wash)		1000	gm
Mass pass 0.075 mm		858.90	gm
%age of pass 0.075 mm		85.89	%

A) Sieve Analysis

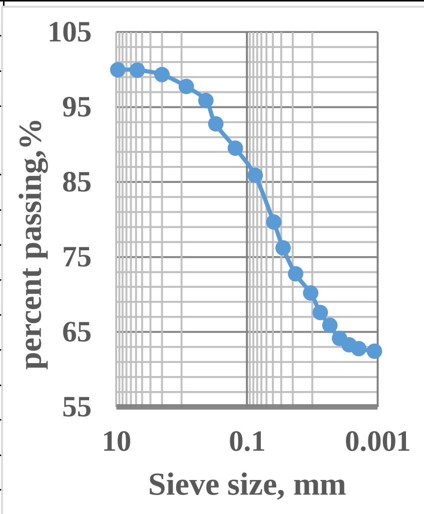
Total mass, gm 1000

Sieve Size, mm	Mass of Retain, gm	% Retain	% Cum. Retain	% of Pass
9.5	0	0	0	100
4.75	0.4	0.04	0.04	99.96
2	6.0	0.6	0.64	99.36
0.85	15.9	1.59	2.23	97.77
0.425	18.7	1.87	4.1	95.9
0.300	31.4	3.14	7.24	92.76
0.150	32.1	3.21	10.45	89.55
0.075	36.6	3.66	14.11	85.89
Pan	858.90	85.89	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	99.96
2	99.36
0.85	97.77
0.425	95.9
0.300	92.76
0.150	89.55
0.075	85.89
0.039	79.68
0.028	76.23
0.018	72.78
0.011	70.19
0.008	67.61
0.005	65.88
0.004	64.16
0.003	63.30
0.002	62.78
0.001	62.43

	AASHTO	USCS
% of gravel	0.64	0.04
% of Sand	13.47	14.07
% of Silt	20.01	23.11
% of Clay	65.88	62.78



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.65

Time min	Act. Hydr Rdg	Temp	correction for hydrometer reading: T° Corr	meniscus corr.	zero corr.	Comp Corr.	Corr H.Rdg	Corr factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj. % of finer, P
1	50	21	0.2	1	-5	-3.8	46.2	1.004	8.2	0.01357	0.039	92.77	79.68
2	48	21	0.2	1	-5	-3.8	44.2	1.004	8.5	0.01357	0.028	88.75	76.23
5	46	21	0.2	1	-5	-3.8	42.2	1.004	8.8	0.01357	0.018	84.74	72.78
15	44.5	21	0.2	1	-5	-3.8	40.7	1.004	9.0	0.01357	0.011	81.73	70.19
30	43.5	21	0.2	1	-5	-3.8	39.2	1.004	9.3	0.01357	0.008	78.71	67.61
60	42.5	21	0.2	1	-5	-3.8	38.2	1.004	9.5	0.01357	0.005	76.71	65.88
120	41.5	21	0.2	1	-5	-3.8	37.2	1.004	9.6	0.01357	0.004	74.70	64.16
240	40.5	21	0.2	1	-5	-3.8	36.7	1.004	9.7	0.01357	0.003	73.69	63.30
480	40.2	21	0.2	1	-5	-3.8	36.4	1.004	9.7	0.01357	0.002	73.09	62.78
1440	40	21	0.2	1	-5	-3.8	36.2	1.004	9.8	0.01357	0.001	72.69	62.43

Table B5: Determination of Particle Size Distribution for TP5 @1m

TEST METHOD: AASHTO T 11, T27

Sample preparation : Oven-dried sample

Method of sieving:	Wet sieving	☑
	Dry sieving	☐
Mass dry soil (before wash)	1000	gm
mass pass 0.075 mm	914.9	gm
percentage of pass 0.075 mm	91.49	%

A) Sieve Analysis

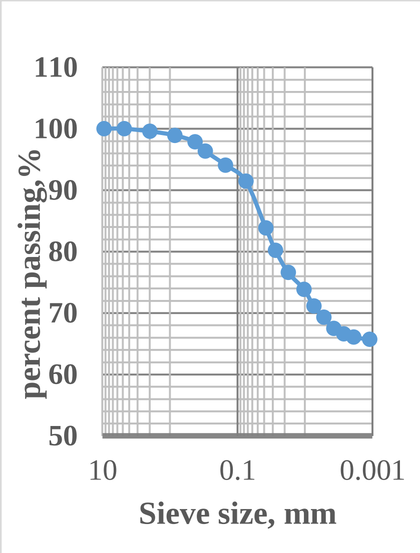
Total mass, gm = 1000

Sieve Size mm	Mass of Retained, gm	% Retained	% Cum. Retained	% of Pass
9.5	0	0	0	100
4.75	0	0	0	100
2	4.2	0.42	0.42	99.58
0.85	6.5	0.65	1.07	98.93
0.425	10.4	1.04	2.11	97.89
0.300	15.2	1.52	3.63	96.37
0.150	22.7	2.27	5.9	94.1
0.075	26.1	2.61	8.51	91.49
Pan	914.90	91.49	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	100
2	99.58
0.85	98.93
0.4250	97.89
0.300	96.37
0.150	94.1
0.075	91.49
0.0379	83.86
0.0273	80.23
0.0176	76.60
0.0103	73.88
0.0074	71.15
0.0053	69.34
0.0038	67.52
0.0027	66.62
0.0019	66.07
0.0011	65.71

	AASHTO	USCS
% of gravel	0.42	0.00
% of Sand	8.09	8.51
% of Silt	22.15	25.42
% of Clay	69.34	66.07



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.69

Time min	Hydr Rdg	Temp	Correction for Hydrometer Reading					Corr. factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj. % of finer
			T° Corr	Meni scus Corr.	Zero Corr.	Comp Corr.	Corr. Hydr Rdg						
1	50	21	0.2	1	-5	-3.8	46.2	0.992	8.1	0.01332	0.038	91.66	83.86
2	48	21	0.2	1	-5	-3.8	44.2	0.992	8.4	0.01332	0.027	87.69	80.23
5	46	21	0.2	1	-5	-3.8	42.2	0.992	8.8	0.01332	0.018	83.72	76.60
15	44.5	21	0.2	1	-5	-3.8	40.7	0.992	9.0	0.01332	0.010	80.75	73.88
30	43	21	0.2	1	-5	-3.8	39.2	0.992	9.2	0.01332	0.007	77.77	71.15
60	42	21	0.2	1	-5	-3.8	38.2	0.992	9.4	0.01332	0.005	75.79	69.34
120	41	21	0.2	1	-5	-3.8	37.2	0.992	9.6	0.01332	0.004	73.80	67.52
240	40.5	21	0.2	1	-5	-3.8	36.7	0.992	9.7	0.01332	0.003	72.81	66.62
480	40.2	21	0.2	1	-5	-3.8	36.4	0.992	9.7	0.01332	0.002	72.22	66.07
1440	40	21	0.2	1	-5	-3.8	36.2	0.992	9.7	0.01332	0.001	71.82	65.71

Table B6: Determination of Particle Size Distribution for TP6 @1m

TEST METHOD: ASTM D 422 – 63			
Sample preparation : Oven-dried sample			
Method of sieving:	Wet sieving	☑	
	Dry sieving	☐	
Mass dry soil (before wash)	1000	gm	
mass pass 0.075 mm	910.40	gm	
percentage of pass 0.075 mm	91.04	%	

A) Sieve Analysis

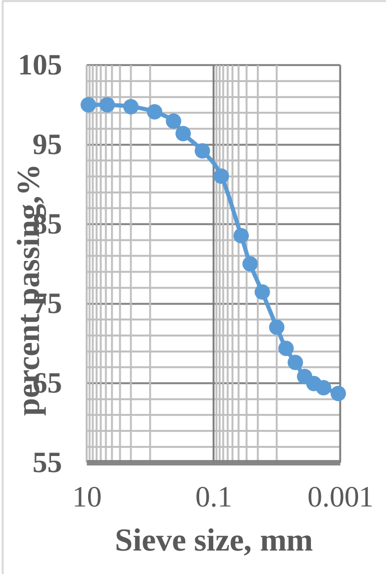
Total mass, gm: 1000

Sieve Size mm	Mas of Retained, gm	% Retained	% Cum. Retained	% of Pass
9.5	0	0	0	100
4.75	0	0	0	100
2	2.1	0.21	0.21	99.79
0.85	6.5	0.65	0.86	99.14
0.425	11.6	1.16	2.02	97.98
0.300	15.8	1.58	3.6	96.4
0.150	21.7	2.17	5.77	94.23
0.075	31.9	3.19	8.96	91.04
Pass	910.40	91.04	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	100
2	99.79
0.85	99.14
0.4250	97.98
0.300	96.4
0.150	94.23
0.075	91.04
0.036	83.54
0.026	80.00
0.017	76.46
0.010	72.03
0.007	69.38
0.005	67.61
0.004	65.84
0.003	64.95
0.002	64.42
0.001	63.71

	AASHTO	USCS
% of gravel	0.21	0.00
% of Sand	8.75	8.96
% of Silt	23.43	26.62
% of Clay	67.61	64.42



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.79

Time min	Hydr .Rdg	Temp	correction for hydrometer reading: T° corr	meniscus corr.	zero corr	Comp Corr.	Corr Hydr Rdg	Corr factor (a)	Eff. Depth (L)	Values of K	D (mm)	% finer P	Adj. % of finer
1	51	21	0.2	1	-5	-3.8	47.2	0.972	8.0	0.01295	0.037	91.76	83.54
2	49	21	0.2	1	-5	-3.8	45.2	0.972	8.3	0.01295	0.026	87.87	80.00
5	47	21	0.2	1	-5	-3.8	43.2	0.972	8.6	0.01295	0.017	83.98	76.46
15	44.5	21	0.2	1	-5	-3.8	40.7	0.972	9.0	0.01295	0.010	79.12	72.03
30	43	21	0.2	1	-5	-3.8	39.2	0.972	9.3	0.01295	0.007	76.20	69.38
60	42	21	0.2	1	-5	-3.8	38.2	0.972	9.5	0.01295	0.005	74.26	67.61
120	41	21	0.2	1	-5	-3.8	37.2	0.972	9.6	0.01295	0.004	72.32	65.84
240	40.5	21	0.2	1	-5	-3.8	36.7	0.972	9.7	0.01295	0.003	71.34	64.95
480	40.2	21	0.2	1	-5	-3.8	36.4	0.972	9.7	0.01295	0.002	70.76	64.42
1440	40	20	0	1	-5	-4	36	0.972	9.8	0.01310	0.001	69.98	63.71

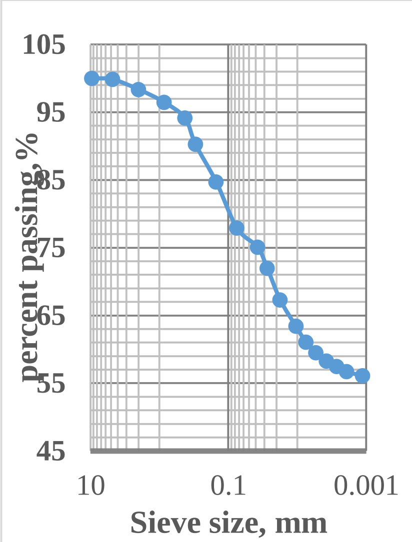
Table B7: Determination of Particle Size Distribution for TP7 @2m

TEST METHOD: ASTM D 422 – 63				
Sample preparation : Oven-dried sample				
Method of sieving	Wet Sieving	☑		
	Dry sieving	☐		
Mass dry soil (before wash)		1000	gm	
mass pass 0.075 mm,		779.00	gm	
%age of pass 0.075 mm		77.90	%	
A) Sieve Analysis				
Total mass, gm	1000			
Sieve Size, mm	Wt. R	% R	% Cum. Retained	% P
9.5	**0**	0	0	100
4.75	1.6	0.16	0.16	99.84
2	14.8	1.48	1.64	98.36
0.85	18.9	1.89	3.53	96.47
0.425	23.4	2.34	5.87	94.13
0.300	38.7	3.87	9.74	90.26
0.150	55.4	5.54	15.28	84.72
0.075	68.2	6.82	22.1	77.9
Pass	779.00	77.9	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	99.84
2	98.36
0.85	96.47
0.4250	94.13
0.300	90.26
0.150	84.72
0.075	77.9
0.038	75.10
0.027	71.98
0.018	67.31
0.010	63.41
0.008	61.07
0.005	59.52
0.004	58.27
0.003	57.49
0.002	56.71
0.001	56.09

	AASHTO	USCS
% of gravel	1.64	0.16
% of Sand	20.46	21.94
% of Silt	18.38	21.19
% of Clay	59.52	56.71



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

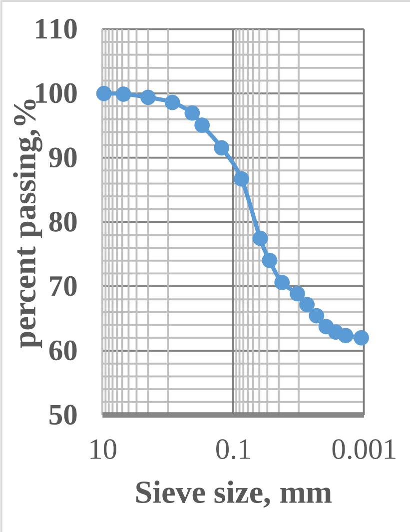
Specific gravity: 2.65

Time min	Hydr Rdg	Temp	Temp corr.	meniscus corr.	Zero corr.	Comp Corr.	Corr Hydr Rdg	Corr. Factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj % of finer
1	51	21	0.2	1	-5	-3.8	48.2	1.000	7.8	0.01348	0.038	96.40	75.10
2	48	21	0.2	1	-5	-3.8	46.2	1.000	8.2	0.01348	0.027	92.40	71.98
5	46	21	0.2	1	-5	-3.8	43.2	1.000	8.6	0.01348	0.018	86.40	67.31
15	44.5	21	0.2	1	-5	-3.8	40.7	1.000	9.0	0.01348	0.010	81.40	63.41
30	43	21	0.2	1	-5	-3.8	39.2	1.000	9.3	0.01348	0.008	78.40	61.07
60	42	21	0.2	1	-5	-3.8	38.2	1.000	9.5	0.01348	0.005	76.40	59.52
120	41.5	22	0.4	1	-5	-3.6	37.4	1.000	9.6	0.01332	0.004	74.80	58.27
240	40.5	22	0.4	1	-5	-3.6	36.9	1.000	9.7	0.01332	0.003	73.80	57.49
480	40	21	0.2	1	-5	-3.8	36.4	1.000	9.7	0.01348	0.002	72.80	56.71
1440	39.5	20	0	1	-5	-4	36	1.000	9.8	0.01365	0.001	72.00	56.09

Table B8: Determination of Particle Size Distribution for TP8 @3m

TEST METHOD: ASTM D 422 – 63				
Sample preparation : Oven-dried sample				
Method of sieving	Wet sieving	☑		
	Dry sieving	☐		
Mass dry soil (before wash)	1000	gm		
mass pass 0.075 mm	867	gm		
Percent of pass 0.075 mm	86.73	%		
A) Sieve Analysis				
Total mass, gm	1000			
Sieve Size, mm	Wt. of Retain	% of Retain	% Cum. Retain	% of Pass
9.5	0	0	0	100
4.75	0.8	0.08	0.08	99.92
2	5.3	0.53	0.61	99.39
0.85	7.9	0.79	1.4	98.6
0.425	16.4	1.64	3.04	96.96
0.300	18.7	1.87	4.91	95.09
0.150	35.4	3.54	8.45	91.55
0.075	48.2	4.82	13.27	86.73
Pan	867.30	86.73	100	0

C) Combined sieve and Hydrometer analysis				
particle size	% of pass		AASHTO	USCS
9.5	100	% of gravel	0.61	0.08
4.75	99.92	% of Sand	12.66	13.19
2	99.39	% of Silt	21.26	24.35
0.85	98.6	% of Clay	65.47	62.38
0.4250	96.96			
0.300	95.09			
0.150	91.55			
0.075	**86.73**			
0.0387	77.46			
0.0279	74.04			
0.0180	70.61			
0.0105	68.89			
0.0075	67.18			
0.0053	65.47			
0.0038	63.75			
0.0027	62.90			
0.0019	62.38			
0.0011	62.04			



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.71

Time min	Hydr Rdg	Temp	correction for hydrometer reading					Corr. factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj. % of finer
			T° Corr	meni scus corr.	zero corr	Comp Corr.	Corr. Hydr .Rdg						
1	49	21	0.2	1	-5	-3.8	45.2	0.988	8.3	0.01341	0.0387	89.32	77.46
2	47	21	0.2	1	-5	-3.8	43.2	0.988	8.6	0.01341	0.0279	85.36	74.04
5	45	21	0.2	1	-5	-3.8	41.2	0.988	9.0	0.01341	0.0180	81.41	70.61
15	44	21	0.2	1	-5	-3.8	40.2	0.988	9.1	0.01341	0.0105	79.44	68.89
30	43	21	0.2	1	-5	-3.8	39.2	0.988	9.3	0.01341	0.0075	77.46	67.18
60	42	21	0.2	1	-5	-3.8	38.2	0.988	9.5	0.01341	0.0053	75.48	65.47
120	41	21	0.2	1	-5	-3.8	37.2	0.988	9.6	0.01341	0.0038	73.51	63.75
240	40.5	21	0.2	1	-5	-3.8	36.7	0.988	9.7	0.01341	0.0027	72.52	62.90
480	40.2	21	0.2	1	-5	-3.8	36.4	0.988	9.7	0.01341	0.0019	71.93	62.38
1440	40	21	0.2	1	-5	-3.8	36.2	0.988	9.8	0.01341	0.0011	71.53	62.04

Table B9: Determination of Particle Size Distribution for TP9 @2m

TEST METHOD: ASTM D 422 – 63			
Sample preparation : Oven-dried sample			
Method of sieving:	Wet sieving	☐	
	Dry sieving	☑	
Mass dry soil (before wash)	1000	gm	
mass pass 0.075 mm	826	gm	
percentage of pass 0.075 mm	82.55	%	

A) Sieve Analysis

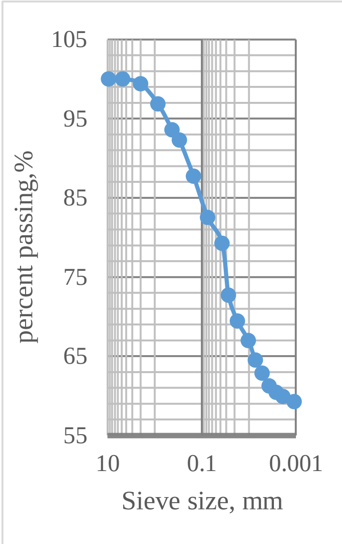
Total mass, gm: 1000

Sieve Size, mm	Mass of Retain, gm	% of Retain	% Cum. Retain	% of Pass
9.5	0	0	0	100
4.75	0.0	0	0	100
2	6.0	0.6	0.6	99.4
0.85	25.5	2.55	3.15	96.85
0.425	32.6	3.26	6.41	93.59
0.300	12.8	1.28	7.69	92.31
0.150	45.7	4.57	12.26	87.74
0.075	51.9	5.19	17.45	82.55
Pan	825.50	82.55	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	100
2	99.4
0.85	96.85
0.4250	93.59
0.300	92.31
0.150	87.74
0.075	**82.55**
0.037	79.27
0.027	72.72
0.017	69.44
0.010	66.99
0.007	64.53
0.005	62.89
0.004	61.25
0.003	60.43
0.002	59.94
0.001	59.29

	AASHTO	USCS
% of gravel	0.60	0.00
% of Sand	16.85	17.45
% of Silt	19.66	22.61
% of Clay	62.89	59.94



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.69

Time min	Hydr Rdg	Temp	correction for hydrometer reading: T° corr	meniscus corr	zero corr	Comp Corr	Corr Hydr Rdg	Corr factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj. % of finer
1	51	22	0.4	1	-5	-3.6	48.4	0.992	7.8	0.01317	0.037	96.03	79.27
2	48	22	0.4	1	-5	-3.6	44.4	0.992	8.4	0.01317	0.027	88.09	72.72
5	46	22	0.4	1	-5	-3.6	42.4	0.992	8.8	0.01317	0.017	84.12	69.44
15	44.5	22	0.4	1	-5	-3.6	40.9	0.992	9.0	0.01317	0.010	81.15	66.99
30	43	22	0.4	1	-5	-3.6	39.4	0.992	9.2	0.01317	0.007	78.17	64.53
60	42	22	0.4	1	-5	-3.6	38.4	0.992	9.4	0.01317	0.005	76.19	62.89
120	41	22	0.4	1	-5	-3.6	37.4	0.992	9.6	0.01317	0.004	74.20	61.25
240	40.5	22	0.4	1	-5	-3.6	36.9	0.992	9.7	0.01317	0.003	73.21	60.43
480	40.2	22	0.4	1	-5	-3.6	36.6	0.992	9.7	0.01317	0.002	72.61	59.94
1440	40	21	0.2	1	-5	-3.8	36.2	0.992	9.7	0.01332	0.001	71.82	59.29

Table B10: Determination of Particle Size Distribution for TP10 @3m

TEST METHOD: ASTM D 422 – 63			
Sample preparation : Oven-dried sample			
Method of sieving:	Wet sieving	☑	
	Dry sieving	☐	
Mass dry soil (before wash)	1000	gm	
mass pass 0.075 mm	882.50	gm	
percentage of pass 0.075 mm	88.25	%	

A) Sieve Analysis

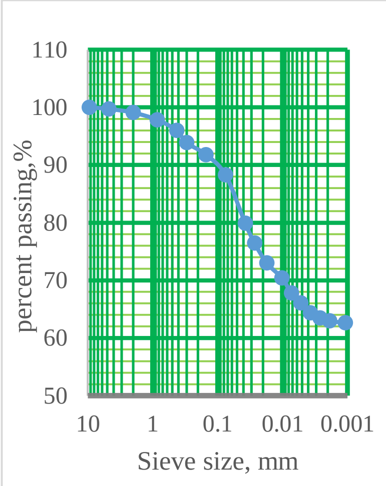
Total mass, gm: 1000

Sieve Size mm	Mass of Retain, gm	% of Retain	% Cum. Retain	% of Pass
9.5	0	0	0	100
4.75	2.8	0.28	0.28	99.72
2	6.4	0.64	0.92	99.08
0.85	12.5	1.25	2.17	97.83
0.425	18.5	1.85	4.02	95.98
0.300	21.2	2.12	6.14	93.86
0.150	20.7	2.07	8.21	91.79
0.075	35.4	3.54	11.75	88.25
Pan	882.50	88.25	100	0

C) Combined sieve and Hydrometer analysis

particle size	% of pass
9.5	100
4.75	99.72
2	99.08
0.85	97.83
0.4250	95.98
0.300	93.86
0.150	91.79
0.075	**88.25**
0.0374	79.91
0.0269	76.45
0.0173	72.99
0.0101	70.40
0.0073	67.80
0.0052	66.07
0.0037	64.34
0.0026	63.48
0.0019	62.96
0.0011	62.62

	AASHTO	USCS
% of gravel	0.92	0.28
% of Sand	10.83	11.47
% of Silt	22.18	25.29
% of Clay	66.07	62.96



B) Hydrometer Analysis

Data: Total oven dry sample: 50 gm

Specific gravity: 2.75

Time min	Hydr Rdg	Temp	correction for hydrometer reading: T° Corr	meniscus corr.	zero corr.	Comp Corr	Corr Hydr Rdg	Corr. factor (a)	Effe. Depth (L)	Values of K	D (mm)	% finer, P	Adj. % of finer
1	51	21	0.2	1	-5	-3.8	46.2	0.98	8.2	0.01309	0.0374	90.55	79.91
2	48	21	0.2	1	-5	-3.8	44.2	0.98	8.4	0.01309	0.0269	86.63	76.45
5	46	21	0.2	1	-5	-3.8	42.2	0.98	8.8	0.01309	0.0173	82.71	72.99
15	44.5	21	0.2	1	-5	-3.8	40.7	0.98	9.0	0.01309	0.0101	79.77	70.40
30	43	21	0.2	1	-5	-3.8	39.2	0.98	9.2	0.01309	0.0073	76.83	67.80
60	42	21	0.2	1	-5	-3.8	38.2	0.98	9.4	0.01309	0.0052	74.87	66.07
120	41	21	0.2	1	-5	-3.8	37.2	0.98	9.6	0.01309	0.0037	72.91	64.34
240	40.5	21	0.2	1	-5	-3.8	36.7	0.98	9.7	0.01309	0.0026	71.93	63.48
480	40.2	21	0.2	1	-5	-3.8	36.4	0.98	9.7	0.01309	0.0019	71.34	62.96
1440	40	21	0.2	1	-5	-3.8	36.2	0.98	9.7	0.01309	0.0011	70.95	62.62

APPENDIX C: Swelling Pressure test Result of the Study Area

Table C1: Deformation reading of Odometer consolidation test for Tp1 @2m

Time (min)	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.642	0.675	0.885	1.104	1.456
0.10	…..	0.294	0.718	0.904	1.222	1.502
0.25	…..	0.308	0.732	0.916	1.234	1.514
0.50	…..	0.340	0.742	0.934	1.242	1.522
1	…..	0.382	0.760	0.956	1.256	1.538
2	…..	0.446	0.784	0.974	1.284	1.544
4	…..	0.500	0.808	0.996	1.314	1.556
8	…..	0.546	0.828	1.012	1.352	1.568
15	…..	0.566	0.838	1.022	1.380	1.584
30	…..	0.576	0.846	1.038	1.406	1.592
60	…..	0.582	0.852	1.050	1.422	1.608
120	…..	0.586	0.854	1.066	1.434	1.622
240	…..	0.588	0.858	1.088	1.446	2.634
480	…..	0.596	0.866	1.096	1.452	1.650
1440	2.642	0.675	0.885	1.104	1.456	1.656

Determination of dry unit weight and Height of solids		
Specimen wet mass + ring	(g)	133.05
Specimen dry mass + ring	(g)	119.30
Mass of ring	(g)	68
Mass of dry specimen	(g)	51.302
Specimen Height, L	(cm)	2
Specimen diameter, D	(cm)	5
Area of ring	cm^2	19.625
Volume of ring	cm^3	39.25
Bulk density,	(g/cm^2)	1.657
Water Content,	%	32.968
Dry density,	(g/cm^2)	1.25
Height of solid	(mm)	9.47
Initial void ratio, eo		1.112
Swelling Potential		
Initial dial reading (adjusted to Zero Reading)	mm	0.0
Final Dial Reading	mm	2.642
Specimen Height	mm	20
Free swell index	(%)	13.21
Swelling pressure (Sp)	kPa	215

Pressure (KPa)	Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	ef = (Hf-Hs)/Hs
7	0	0	20.000	1.112
7	2.642	-2.642	22.642	1.391
50	0.675	-1.967	21.967	1.319
100	0.885	-1.082	21.082	1.226
200	1.104	0.022	19.978	1.109
400	1.456	1.478	18.522	0.956
800	1.656	3.134	16.866	0.781

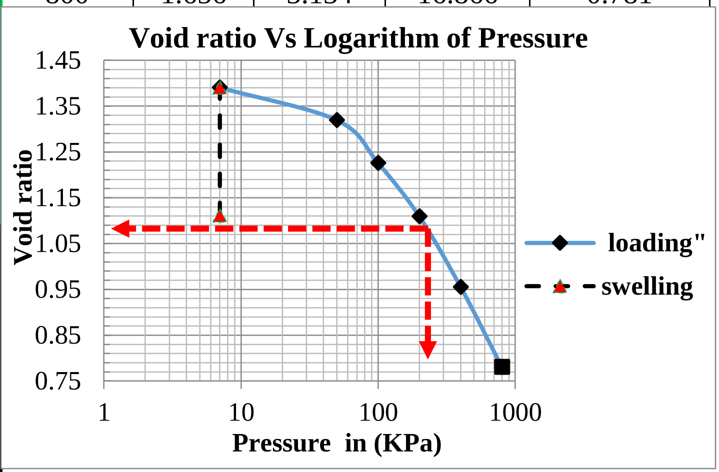


Table C2: Deformation reading of Odometer consolidation test for Tp1 @3m

Time (min)	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.248	0.703	1.287	1.617	1.756
0.10	…..	0.394	0.978	1.394	1.632	1.762
0.25	…..	0.418	1.002	1.426	1.644	1.774
0.50	…..	0.434	1.132	1.442	1.652	1.782
1	…..	0.482	1.154	1.466	1.660	1.798
2	…..	0.546	1.174	1.484	1.672	1.804
4	…..	0.602	1.198	1.506	1.684	1.816
8	…..	0.646	1.218	1.522	1.692	1.828
15	…..	0.666	1.232	1.534	1.698	1.834
30	…..	0.676	1.246	1.548	1.706	1.842
60	…..	0.682	1.252	1.562	1.722	1.848
120	…..	0.686	1.254	1.576	1.734	1.856
240	…..	0.688	1.258	1.592	1.746	1.864
480	…..	0.696	1.266	1.604	1.752	1.868
1440	2.248	0.703	1.287	1.617	1.756	1.872

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cum. ∆H (mm)	Hf = Hi - ∑∆H (mm)	ef = (Hf-Hs) / Hs
Specimen wet mass + ring (g)	131.05	7	0	0	20.000	1.1334
Specimen dry mass + can (g)	117.674	7	2.248	-2.248	22.248	1.3732
Mass of ring (g)	68	50	0.703	-1.545	21.545	1.2982
Specimen Height, L (cm)	2	100	1.287	-0.258	20.258	1.1609
Specimen diameter, D (cm)	5	200	1.617	1.359	18.641	0.9884
Area of ring cm^2	19.625	400	1.756	3.115	16.885	0.8011
Volume of ring cm^3	39.25	800	1.872	4.987	15.013	0.6014

Bulk density, (g/cm^2)	1.61
Water Content %	32.968
Dry density (g/cm^2)	1.21
Height of solid (cm)	0.937
Initial void ratio, eo	1.133
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.248
Specimen Height mm	20
Free swell index (%)	11.24
Swelling pressure (Sp) kPa	120

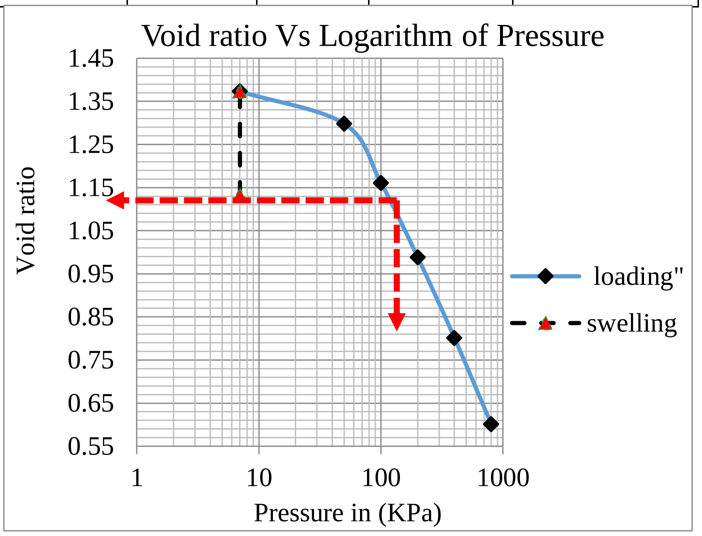


Table C3: Deformation reading of Odometer consolidation test for Tp2 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.916	0.558	0.893	1.004	1.214
0.10	…..	0.294	0.618	0.908	1.062	2.252
0.25	…..	0.308	0.732	0.912	1.084	2.266
0.5	…..	0.312	0.752	0.926	1.098	2.282
1.0	…..	0.352	0.768	0.936	1.112	2.298
2	…..	0.376	0.784	0.944	1.122	2.302
4	…..	0.394	0.802	0.956	1.134	2.314
8	…..	0.406	0.828	0.962	1.142	2.328
15	…..	0.436	0.842	0.976	1.150	2.334
30	…..	0.476	0.848	0.982	1.166	2.342
60	…..	0.492	0.854	0.986	1.172	2.358
120	…..	0.506	0.862	0.992	1.184	2.362
240	…..	0.528	0.874	0.996	1.194	2.364
480	…..	0.546	0.886	1.002	1.202	2.366
1440	2.916	0.558	0.893	1.004	1.214	1.368

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	136.05
Specimen dry mass + can (g)	118.029
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.73
Water Content, %	36.021
Dry density, (g/cm2)	1.27
Height of solid (cm)	0.891
Initial void ratio, eo	1.244
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	
Final Dial Reading mm	0.0
Specimen Height mm	2.916
Free swell index (%)	14.58
Swelling pressure (Sp) kPa	285

Height of solid (mm)				8.91
Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	ef = (Hf-Hs) / Hs
7	0	0	20.000	1.244
7	2.916	-2.916	22.916	1.571
50	0.558	-2.358	22.358	1.508
100	0.893	-1.465	21.465	1.408
200	1.004	-0.461	20.461	1.296
400	1.214	0.753	19.247	1.159
800	1.368	2.121	17.879	1.006

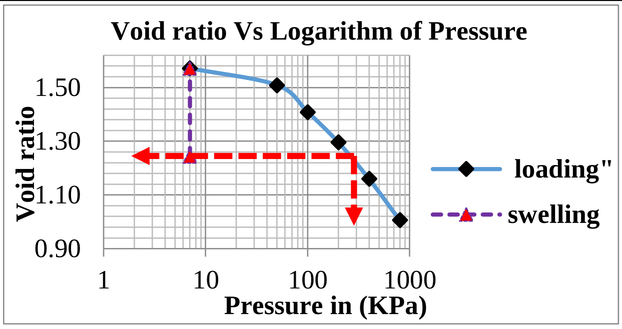


Table C4: Deformation reading of Odometer consolidation test for Tp2 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.508	0.618	0.916	1.289	1.426
0.10	…..	0.394	0.668	0.968	1.302	1.442
0.25	…..	0.418	0.686	0.982	1.308	1.448
0.5	…..	0.452	0.705	1.012	1.316	1.454
1.0	…..	0.482	0.720	1.026	1.322	1.458
2	…..	0.506	0.732	1.044	1.330	1.462
4	…..	0.524	0.746	1.066	1.336	1.474
8	…..	0.546	0.764	1.072	1.344	1.482
15	…..	0.554	0.782	1.086	1.352	1.494
30	…..	0.576	0.788	1.102	1.364	1.498
60	…..	0.572	0.854	1.136	1.372	1.502
120	…..	0.586	0.872	1.158	1.394	1.502
240	…..	0.598	0.884	1.276	1.404	1.504
480	…..	0.606	0.896	1.282	1.422	1.504
1440	2.508	0.618	0.916	1.289	1.426	1.506

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring,(g)	132.34
Specimen dry mass + can, (g)	115.827
Mass of ring (g)	68
Mass of dry sample (g)	47.827
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.64
Water Content, %	34.527
Dry density, (g/cm^2)	1.22
Height of solid (cm)	0.867
Initial void ratio, eo	1.306
Height of solid (mm)	8.67
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.508
Specimen Height mm	20
Free swell index (%)	12.54
Swelling pressure (Sp) kPa	195

Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void ef = (Hf-Hs)/ Hs
7	0	0	20.000	1.306
7	2.508	-2.508	22.508	1.595
50	0.618	-1.89	21.890	1.524
100	0.916	-0.974	20.974	1.418
200	1.289	0.315	19.685	1.270
400	1.426	1.741	18.259	1.105
800	1.506	3.247	16.753	0.932

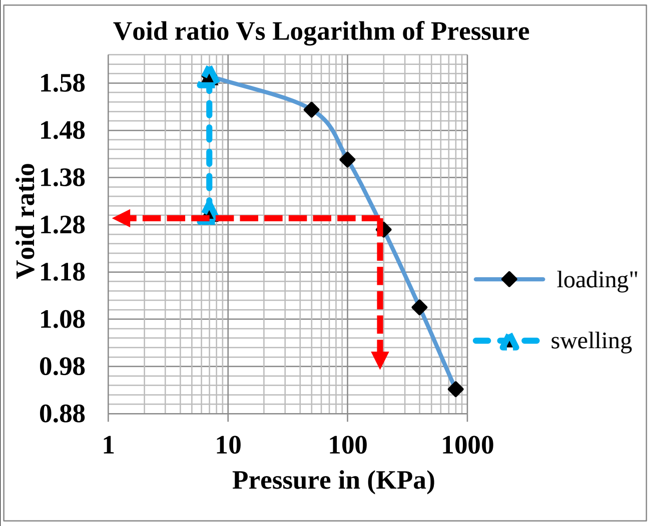


Table C5: Deformation reading of Odometer consolidation test for Tp2 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.014	0.424	0.656	1.012	1.298
0.10	…..	0.194	0.508	0.758	1.102	1.306
0.25	…..	0.218	0.526	0.774	1.108	1.308
0.5	…..	0.252	0.535	0.788	1.116	1.314
1.0	…..	0.282	0.542	0.808	1.122	1.318
2	…..	0.306	0.552	0.824	1.130	1.322
4	…..	0.324	0.576	0.836	1.136	1.324
8	…..	0.346	0.594	0.842	1.144	1.328
15	…..	0.354	0.602	0.856	1.152	1.334
30	…..	0.376	0.612	0.962	1.164	1.338
60	…..	0.372	0.624	0.976	1.172	1.342
120	…..	0.386	0.634	0.988	1.194	1.348
240	…..	0.398	0.646	0.992	1.288	1.352
480	…..	0.406	0.654	1.008	1.294	1.355
1440	2.014	0.424	0.656	1.012	1.298	1.357

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void ef = (Hf-Hs)/Hs
Specimen wet mass + ring (g)	131.64	7	0	0	20.000	1.3575
Specimen dry mass + can (g)	114.117	7	2.014	-2.014	22.014	1.5949
Mass of ring (g)	68	50	0.424	-1.59	21.590	1.5449
Specimen Height, L (cm)	2	100	0.656	-0.934	20.934	1.4676
Specimen diameter, D (cm)	5	200	1.012	0.078	19.922	1.3483
Area of ring cm^2	19.625	400	1.298	1.376	18.624	1.1953
Volume of ring cm^3	39.25	800	1.357	2.733	17.267	1.0354

Bulk density, (g/cm^2)	1.62
Water Content, %	37.996
Dry density, (g/cm2)	1.17
Height of solid (cm)	0.848
Initial void ratio, eo	1.358
Height of Solids in mm	8.48
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.014
Specimen Height mm	20
Free swell (%)	10.07
Swelling pressure (Sp) kPa	200

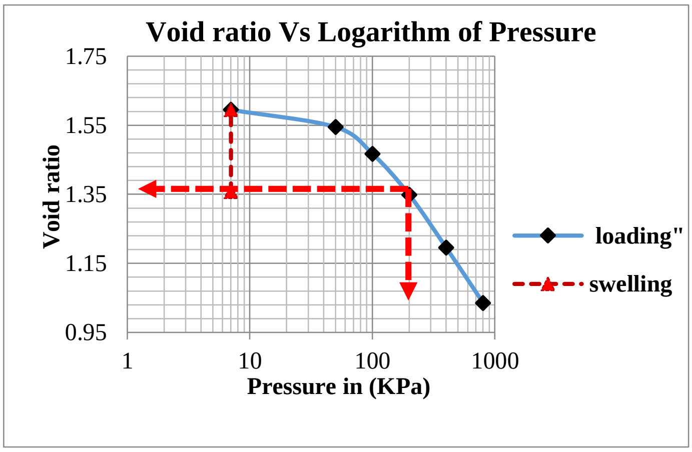


Table C6: Deformation reading of Odometer consolidation test for Tp3 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.282	0.512	0.706	0.811	0.968
0.10	…..	0.294	0.548	0.728	0.882	0.996
0.25	…..	0.308	0.562	0.732	0.894	1.006
0.50	…..	0.340	0.574	0.746	0.898	1.012
1	…..	0.382	0.592	0.752	0.906	1.026
2	…..	0.396	0.604	0.764	0.914	1.032
4	…..	0.412	0.618	0.772	0.924	1.042
8	…..	0.446	0.628	0.778	0.932	1.054
15	…..	0.466	0.638	0.782	0.942	1.082
30	…..	0.476	0.646	0.788	0.948	1.096
60	…..	0.482	0.652	0.796	0.954	1.008
120	…..	0.860	0.674	0.802	0.958	1.118
240	…..	0.498	0.688	0.806	0.962	1.122
480	…..	0.506	0.702	0.808	0.966	1.124
1440	2.282	0.512	0.706	0.811	0.968	1.126

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring, (g)	132.69	7	0	0	20.000	1.299
Specimen dry mass + ring (g)	114.786	7	2.282	-2.282	22.282	1.561
Mass of ring (g)	68	50	0.512	-1.77	21.770	1.502
Specimen Height, L (cm)	2	100	0.706	-1.064	21.064	1.421
Specimen diameter, D (cm)	5	200	0.811	-0.253	20.253	1.328
Area of ring cm^2	19.625	400	0.968	0.715	19.285	1.216
Volume of ring cm^3	39.25	800	1.126	1.841	18.159	1.087
Bulk density, (g/cm^2)	1.65					
Water Content, %	38.268					
Dry density, (g/cm^2)	1.19					
Height of solid (cm)	0.870					
Initial void ratio, eo	1.299					
Height of solid (mm)	8.701					
Swelling Potential						
Initial dial reading (adjusted to Zero Reading) mm	0.0					
Final Dial Reading mm	2.282					
Specimen Height mm	20					
Free swell index (%)	11.41					
Swelling Pressure (Sp) kPa	245					

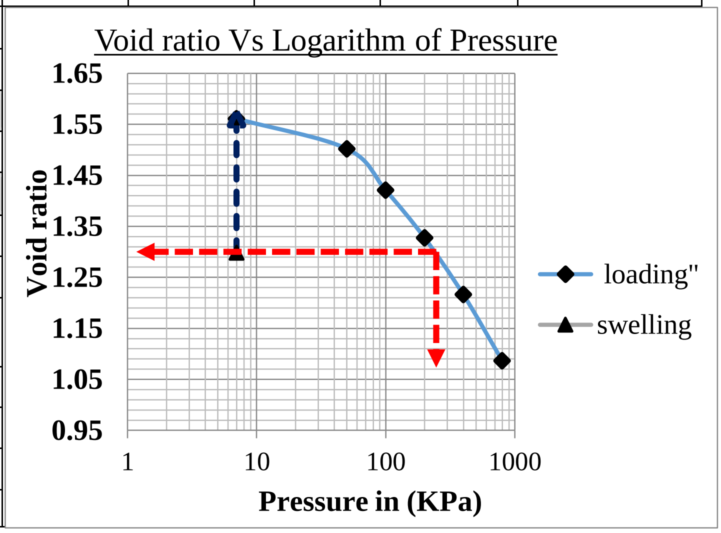


Table C7: Deformation reading of Odometer consolidation test for Tp3 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.573	0.394	0.507	0.894	1.036
0.10	…..	0.294	0.448	0.618	0.922	1.048
0.25	…..	0.308	0.456	0.632	0.934	1.052
0.50	…..	0.314	0.464	0.676	0.942	1.058
1	…..	0.322	0.472	0.692	0.966	1.062
2	…..	0.336	0.478	0.714	0.984	1.066
4	…..	0.342	0.482	0.732	0.994	1.072
8	…..	0.356	0.486	0.778	1.002	1.084
15	…..	0.366	0.490	0.792	1.012	1.088
30	…..	0.376	0.494	0.818	1.018	1.096
60	…..	0.382	0.498	0.836	1.022	1.008
120	…..	0.388	0.500	0.862	1.028	1.102
240	…..	0.390	0.502	0.878	1.032	1.104
480	…..	0.392	0.504	0.888	1.034	1.106
1440	1.573	0.394	0.507	0.894	1.036	1.108

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cum.. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
Specimen wet mass + ring (g)	135.28	7	0	0	20.000	1.198
Specimen dry mass + can (g)	116.57 2	7	1.573	-1.573	21.573	1.371
Mass of ring (g)	68	50	0.394	-1.179	21.179	1.328
Specimen Height, L (cm)	2	100	0.507	-0.672	20.672	1.272
Specimen diameter, D (cm)	5	200	0.894	0.222	19.778	1.174
Area of ring cm^2	19.625	400	1.036	1.258	18.742	1.060
Volume of ring cm^3	39.25	800	1.108	2.366	17.634	0.938

Bulk density, (g/cm^2)	1.71
Water Content %	38.515
Dry density, (g/cm^2)	1.24
Height of solid (cm)	0.9099
Initial void ratio, eo	1.1980
Height of solid (mm)	9.10
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.573
Specimen Height mm	20
Free swell index (%)	7.87
Swelling pressure (Sp) kPa	190

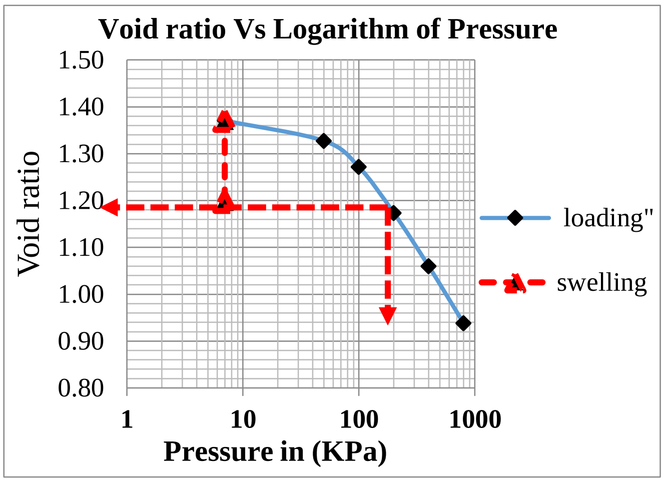


Table C8: Deformation reading of Odometer consolidation test for Tp3 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.497	0.532	0.954	1.438	1.657
0.10	…..	0.392	0.628	1.098	0.982	1.678
0.25	…..	0.406	0.656	1.124	0.494	1.682
0.50	…..	0.415	0.678	1.146	0.502	1.684
1	…..	0.423	0.696	1.182	0.516	1.686
2	…..	0.432	0.718	1.214	0.524	1.688
4	…..	0.444	0.732	1.242	0.544	1.69
8	…..	0.452	0.756	1.288	1.562	1.692
15	…..	0.464	0.778	1.314	1.582	1.694
30	…..	0.480	0.794	1.348	1.598	1.696
60	…..	0.502	0.818	1.386	1.612	1.698
120	…..	0.518	0.838	1.402	1.632	1.700
240	…..	0.522	0.846	1.418	1.648	1.702
480	…..	0.528	0.850	1.432	1.654	1.702
1440	1.497	0.532	0.954	1.438	1.657	1.704

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring, (g)	133.52	7	0	0	20.000	1.226
Specimen dry mass + can, (g)	115.247	7	1.497	-1.497	21.497	1.393
Mass of ring (g)	68	50	0.532	-0.965	20.965	1.334
Specimen Height, L (cm)	2	100	0.954	-0.011	20.011	1.228
Specimen diameter, D (cm)	5	200	1.438	1.427	18.573	1.068
Area of ring cm^2	19.625	400	1.657	3.084	16.916	0.883
Volume of ring cm^3	39.25	800	1.704	4.788	15.212	0.693

Bulk density, (g/cm^2)	1.669
Water Content, %	38.675
Dry density, (g/cm2)	1.204
Height of solid (cm)	0.8983
Initial void ratio, eo	1.226
Height of solid (cm)	8.9832
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.497
Specimen Height mm	20
Free swell index (%)	7.49
Swelling pressure (Sp) kPa	115

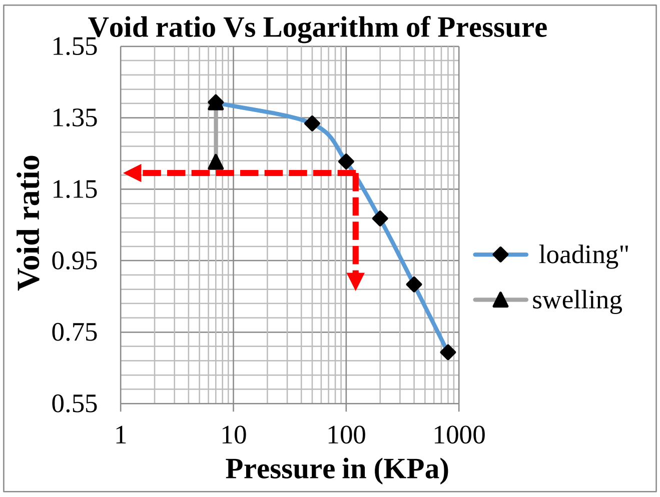


Table C9: Deformation reading of Odometer consolidation test for Tp4 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.974	0.387	0.559	0.868	1.256
0.10	…..	0.254	0.458	0.658	0.952	1.296
0.25	…..	0.268	0.472	0.672	0.974	1.306
0.50	…..	0.280	0.482	0.692	0.992	1.312
1	…..	0.292	0.492	0.708	1.006	1.318
2	…..	0.306	0.504	0.724	1.124	1.324
4	…..	0.318	0.518	0.756	1.144	1.334
8	…..	0.326	0.526	0.784	1.162	1.342
15	…..	0.336	0.532	0.806	1.188	1.356
30	…..	0.346	0.538	0.818	1.206	1.364
60	…..	0.352	0.542	0.828	1.222	1.372
120	…..	0.366	0.546	0.846	1.234	1.378
240	…..	0.378	0.552	0.854	1.246	1.382
480	…..	0.382	0.556	0.862	1.252	1.384
1440	1.974	0.387	0.559	0.868	1.256	1.386

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring,(g)	136.19	7	0	0	20.000	1.044
Specimen dry mass + can (g)	119.283	7	1.974	-1.974	21.974	1.245
Mass of ring (g)	68	50	0.387	-1.587	21.587	1.206
Specimen Height, L (cm)	2	100	0.559	-1.028	21.028	1.149
Specimen diameter, D (cm)	5	200	0.868	-0.16	20.160	1.060
Area of ring cm^2	19.625	400	1.256	1.096	18.904	0.932
Volume of ring cm^3	39.25	800	1.386	2.482	17.518	0.790

Bulk density, (g/cm^2)	1.737
Water Content, %	32.968
Dry density, (g/cm2)	1.307
Height of solid (cm)	0.9787
Initial void ratio, eo	1.044
Height of solid (cm)	9.79
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.974
Specimen Height mm	20
Free swell index (%)	9.87
Swelling pressure (Sp) kPa	240

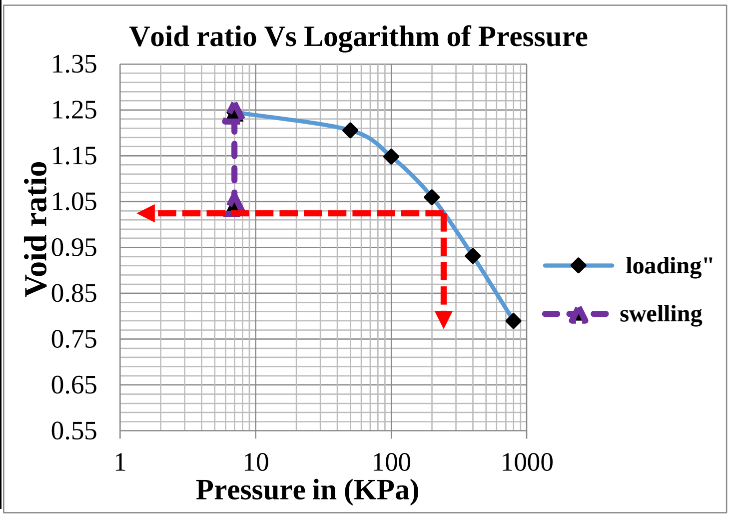


Table C10: Deformation reading of Odometer consolidation test for Tp4 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.662	0.592	0.702	1.095	1.268
0.10	…..	0.454	0.638	0.758	1.152	1.296
0.25	…..	0.466	0.646	0.772	1.164	1.302
0.50	…..	0.484	0.652	0.792	1.172	1.308
1	…..	0.492	0.658	0.808	1.186	1.312
2	…..	0.506	0.664	0.824	1.194	1.318
4	…..	0.518	0.668	0.856	1.204	1.324
8	…..	0.526	0.672	0.884	1.212	1.338
15	…..	0.536	0.676	0.906	1.218	1.344
30	…..	0.546	0.680	0.918	1.226	1.348
60	…..	0.552	0.682	0.938	1.232	1.352
120	…..	0.565	0.688	0.966	1.244	1.352
240	…..	0.577	0.692	0.998	1.254	1.354
480	…..	0.585	0.698	1.085	1.262	1.354
1440	1.662	0.592	0.702	1.095	1.268	1.356

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring,(g)	136.96	7	0	0	20.000	1.118
Specimen dry mass + can, (g)	117.10	7	1.662	-1.662	21.662	1.294
Mass of ring (g)	68	50	0.592	-1.07	21.070	1.232
Specimen Height, L (cm)	2	100	0.702	-0.368	20.368	1.157
Specimen diameter, D (cm)	5	200	1.095	0.727	19.273	1.041
Area of ring cm^2	19.625	400	1.268	1.995	18.005	0.907
Volume of ring cm^3	39.25	800	1.356	3.351	16.649	0.763

Bulk density, (g/cm^2)	1.76
Water Content, %	40.449
Dry density, (g/cm2)	1.25
Height of solid (cm)	0.944
Initial void ratio, eo	1.118
Height of solid (mm)	9.44
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.662
Specimen Height mm	20
Free swell index (%)	8.31
Swelling pressure (Sp) kPa	150

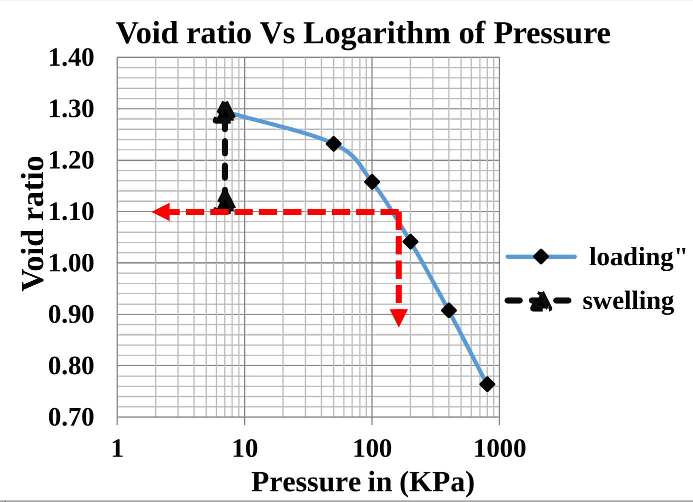


Table C11: Deformation reading of Odometer consolidation test for Tp4 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.513	0.702	0.914	1.198	1.286
0.10	…..	0.552	0.768	0.974	1.222	1.292
0.25	…..	0.564	0.776	0.982	1.226	1.298
0.50	…..	0.586	0.788	0.992	1.232	1.306
1	…..	0.594	0.798	0.908	1.240	1.310
2	…..	0.608	0.804	0.924	1.246	1.316
4	…..	0.618	0.818	0.956	1.252	1.322
8	…..	0.624	0.832	0.984	1.258	1.334
15	…..	0.632	0.846	1.097	1.262	1.342
30	…..	0.644	0.860	1.108	1.266	1.346
60	…..	0.652	0.872	1.138	1.272	1.350
120	…..	0.665	0.888	1.176	1.278	1.352
240	…..	0.677	0.892	1.188	1.282	1.354
480	…..	0.698	0.898	1.195	1.284	1.354
1440	1.513	0.702	0.914	1.198	1.286	1.356

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring, (g)	132.98	7	0	0	20.000	1.217
Specimen dry mass + can, (g)	114.572	7	1.513	-1.513	21.513	1.384
Mass of ring (g)	68	50	0.702	-0.811	20.811	1.306
Specimen Height, L (cm)	2	100	0.914	0.103	19.897	1.205
Specimen diameter, D (cm)	5	200	1.198	1.301	18.699	1.072
Area of ring cm^2	19.625	400	1.286	2.587	17.413	0.930
Volume of ring cm^3	39.25	800	1.356	3.943	16.057	0.780
Bulk density, (g/cm^2)	1.656					
Water Content, %	39.527					
Dry density, (g/cm2)	**1.187**					
Height of solid (cm)	0.902					
Initial void ratio, eo	**1.217**					
Height of solid (cm)	9.02					
Swelling Potential						
Initial dial reading (adjusted to Zero Reading) mm	0.0					
Final Dial Reading mm	1.513					
Specimen Height mm	20					
Free swell index (%)	7.57					
Swelling pressure (Sp) kPa	90					

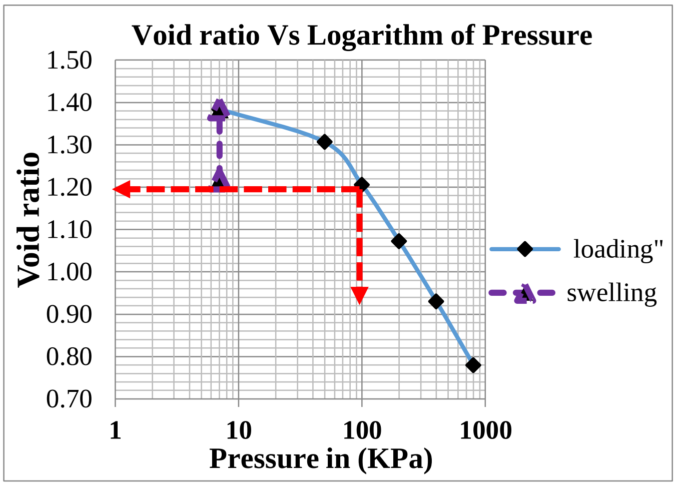


Table C12: Deformation reading of Odometer consolidation test for Tp5 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.763	0.324	0.529	0.914	1.096
0.10	…..	0.224	0.348	0.638	0.957	1.153
0.25	…..	0.238	0.452	0.662	0.962	1.156
0.50	…..	0.246	0.458	0.686	0.968	1.160
1	…..	0.252	0.464	0.708	0.970	1.164
2	…..	0.264	0.472	0.724	0.972	1.168
4	…..	0.272	0.478	0.766	0.980	1.174
8	…..	0.278	0.484	0.798	0.992	1.178
15	…..	0.286	0.488	0.816	1.002	1.180
30	…..	0.296	0.496	0.838	1.028	1.184
60	…..	0.302	0.492	0.864	1.058	1.186
120	…..	0.306	0.506	0.886	1.074	1.188
240	…..	0.316	0.518	0.904	1.086	1.190
480	…..	0.320	0.526	0.908	1.094	1.192
1440	1.763	0.324	0.529	0.914	1.096	1.194

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	130.15
Specimen dry mass + can (g)	113.035
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.58
Water Content, %	38.005
Dry density, (g/cm2)	1.147
Height of solid (cm)	0.853
Initial void ratio, eo	1.344
Height of solid (mm)	8.53
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.763
Specimen Height mm	20
Free swell index (%)	8.82
Swelling pressure (Sp) kPa	210

Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio: ef = (Hf-Hs) / Hs
7	0	0	20.000	1.344
7	1.763	-1.763	21.763	1.551
50	0.324	-1.439	21.439	1.513
100	0.529	-0.91	20.910	1.451
200	0.914	0.004	19.996	1.344
400	1.096	1.1	18.900	1.216
800	1.194	2.294	17.706	1.076

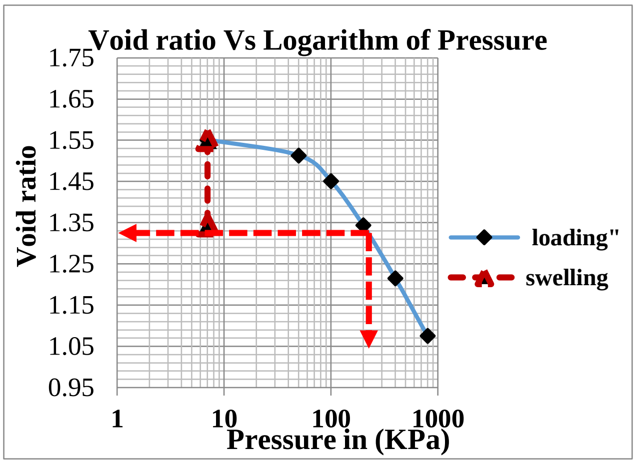


Table C13: Deformation reading of Odometer consolidation test for Tp5 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.587	0.584	0.745	1.208	1.387
0.10	…..	0.454	0.648	0.852	1.274	1.423
0.25	…..	0.468	0.652	0.872	1.282	1.436
0.50	…..	0.476	0.658	0.896	1.294	1.442
1	…..	0.482	0.664	0.918	1.298	1.454
2	…..	0.494	0.672	0.934	1.302	1.468
4	…..	0.502	0.678	0.966	1.314	1.474
8	…..	0.518	0.684	0.988	1.322	1.478
15	…..	0.526	0.692	1.006	1.334	1.480
30	…..	0.536	0.706	1.118	1.348	1.484
60	…..	0.542	0.714	1.154	1.358	1.486
120	…..	0.556	0.726	1.182	1.364	1.488
240	…..	0.568	0.738	1.194	1.376	1.474
480	…..	0.576	0.741	1.202	1.384	1.482
1440	1.587	0.584	0.745	1.208	1.387	1.489

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	138.58
Specimen dry mass + can (g)	119.094
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.80
Water Content %	38.137
Dry density, (g/cm^2)	1.302
Height of solid (cm)	0.975
Initial void ratio, eo	1.051
Height of solid (mm)	9.75
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.587
Specimen Height mm	20
Free swell index (%)	7.94
Swelling pressure (Sp) kPa	125

Pressure (KPa)	Final Df. Rdg (mm)	Cumu lΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
7	0	0	20.000	1.051
7	1.587	-1.587	21.587	1.214
50	0.584	-1.003	21.003	1.154
100	0.745	-0.258	20.258	1.078
200	1.208	0.95	19.050	0.954
400	1.387	2.337	17.663	0.811
800	1.489	3.826	16.174	0.659

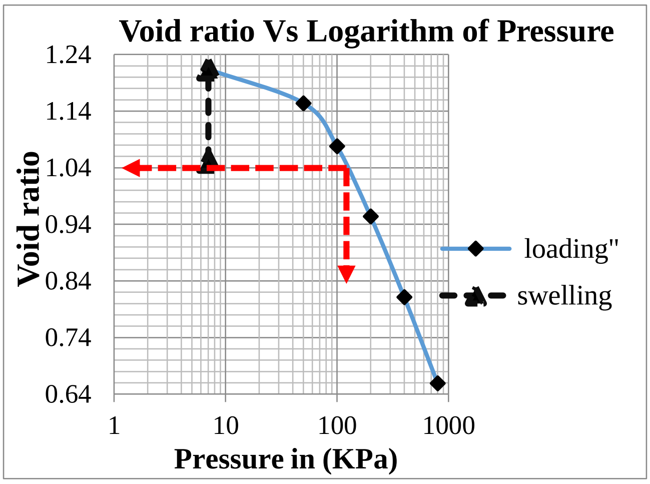


Table C14: Deformation reading of Odometer consolidation test for Tp5 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.496	0.684	0.915	1.151	1.256
0.10	…..	0.458	0.758	0.962	1.194	1.302
0.25	…..	0.462	0.762	0.968	1.198	1.306
0.50	…..	0.476	0.778	0.972	1.204	1.312
1	…..	0.584	0.784	0.978	1.218	1.324
2	…..	0.592	0.792	0.984	1.222	1.328
4	…..	0.608	0.808	0.992	1.232	1.334
8	…..	0.616	0.824	1.006	1.236	1.348
15	…..	0.624	0.852	1.016	1.240	1.350
30	…..	0.632	0.876	1.128	1.244	1.364
60	…..	0.644	0.884	1.134	1.248	1.374
120	…..	0.658	0.896	1.142	1.250	1.386
240	…..	0.664	0.902	1.144	1.252	1.384
480	…..	0.678	0.912	1.148	1.254	1.386
1440	1.496	0.684	0.915	1.151	1.256	1.389

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	131.76
Specimen dry mass + can (g)	114.699
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^3)	1.62
Water Content, %	36.535
Dry density, (g/cm2)	**1.190**
Height of solid (cm)	0.895
Initial void ratio, eo	**1.236**
Height of solid (mm)	8.946
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.496
Specimen Height mm	20
Free swell index (%)	7.48
Swelling pressure (Sp) kPa	105

Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
7	0	0	20.000	1.236
7	1.496	-1.496	21.496	1.403
50	0.684	-0.812	20.812	1.326
100	0.915	0.103	19.897	1.224
200	1.151	1.254	18.746	1.096
400	1.256	2.51	17.490	0.955
800	1.389	3.899	16.101	0.800

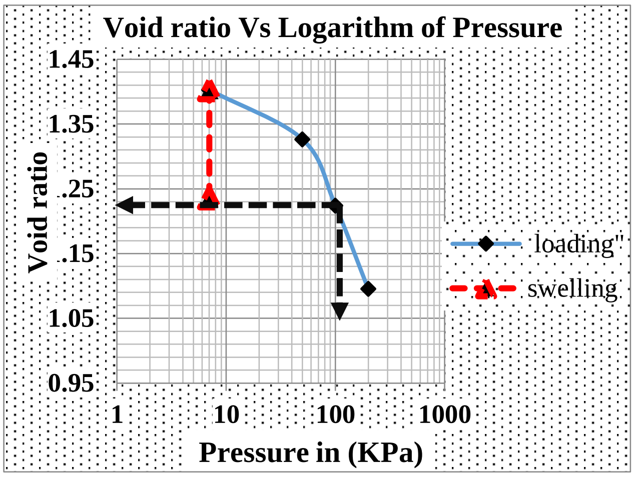


Table C15: Deformation reading of Odometer consolidation test for Tp6 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	3.172	0.485	0.773	0.994	1.156
0.10	…..	0.264	0.538	0.844	1.104	1.162
0.25	…..	0.376	0.562	0.852	1.108	1.168
0.50	…..	0.384	0.594	0.864	1.112	1.170
1	…..	0.392	0.612	0.872	1.116	1.172
2	…..	0.406	0.634	0.878	1.120	1.174
4	…..	0.412	0.658	0.886	1.124	1.176
8	…..	0.426	0.678	0.898	1.128	1.182
15	…..	0.436	0.688	0.916	1.132	1.186
30	…..	0.446	0.696	0.928	1.136	1.190
60	…..	0.452	0.712	0.942	1.138	1.194
120	…..	0.466	0.734	0.966	1.142	1.198
240	…..	0.478	0.748	0.981	1.148	1.202
480	…..	0.484	0.764	0.988	1.152	1.206
1440	3.172	0.485	0.773	0.994	1.156	1.209

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring (g)	137.705	7	0	0	20.000	1.146
Specimen dry mass + can (g)	119.035	7	3.172	-3.172	23.172	1.486
Mass of ring (g)	68	50	0.485	-2.687	22.687	1.434
Specimen Height, L (cm)	2	100	0.773	-1.914	21.914	1.351
Specimen diameter, D (cm)	5	200	0.994	-0.92	20.920	1.244
Area of ring cm^2	19.625	400	1.156	0.236	19.764	1.120
Volume of ring cm^3	39.25	800	1.209	1.445	18.555	0.991

Bulk density, (g/cm^2)	1.78
Water Content, %	36.582
Dry density, (g/cm2)	**1.300**
Height of solid (cm)	0.932
Initial void ratio, eo	**1.146**
Height of solid (cm)	9.32
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	3.172
Specimen Height mm	20
Free swell index (%)	15.86
Swelling pressure (Sp) kPa	325

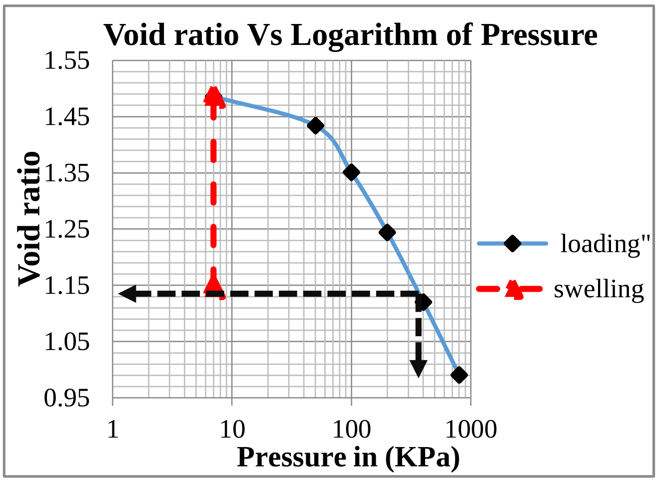


Table C16: Deformation reading of Odometer consolidation test for Tp6 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.857	0.615	0.743	1.014	1.216
0.10	…..	0.474	0.648	0.814	1.104	1.262
0.25	…..	0.486	0.652	0.822	1.108	1.288
0.50	…..	0.494	0.660	0.834	1.112	1.302
1	…..	0.502	0.664	0.842	1.126	1.312
2	…..	0.516	0.670	0.864	1.130	1.334
4	…..	0.522	0.678	0.872	1.144	1.356
8	…..	0.536	0.688	0.892	1.158	1.372
15	…..	0.546	0.698	0.912	1.162	1.396
30	…..	0.566	0.706	0.928	1.176	1.412
60	…..	0.572	0.712	0.952	1.188	1.424
120	…..	0.586	0.724	0.976	1.198	1.438
240	…..	0.598	0.734	0.992	1.206	1.442
480	…..	0.608	0.740	1.004	1.212	1.444
1440	2.857	0.615	0.743	1.014	1.216	1.446

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	132.705
Specimen dry mass + can (g)	115.813
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.65
Water Content, %	35.329
Dry density, (g/cm^2)	**1.218**
Height of solid (cm)	0.889
Initial void ratio, eo	**1.249**
Height of solid (mm)	8.89
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.857
Specimen Height mm	20
Free swell index (%)	14.29
Swelling pressure (Sp) kPa	290

Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
7	0	0	20	1.249
7	2.857	-2.857	22.857	1.571
50	0.615	-2.242	22.242	1.501
100	0.743	-1.499	21.499	1.418
200	1.014	-0.485	20.485	1.304
400	1.216	0.731	19.269	1.167
800	1.446	2.177	17.823	1.004

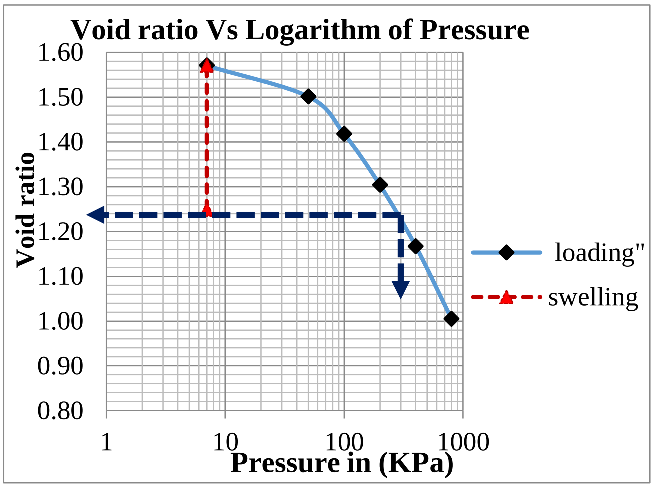


Table C17: Deformation reading of Odometer consolidation test for Tp6 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.088	0.385	0.648	0.958	1.256
0.10	…..	0.274	0.448	0.764	1.064	1.282
0.25	…..	0.276	0.462	0.782	1.078	1.286
0.50	…..	0.284	0.484	0.804	1.092	1.292
1	…..	0.292	0.498	0.822	1.106	1.298
2	…..	0.306	0.512	0.844	1.124	1.306
4	…..	0.312	0.538	0.862	1.144	1.318
8	…..	0.326	0.558	0.874	1.156	1.332
15	…..	0.336	0.578	0.882	1.162	1.346
30	…..	0.346	0.596	0.898	1.176	1.362
60	…..	0.352	0.602	0.912	1.188	1.380
120	…..	0.366	0.614	0.936	1.198	1.388
240	…..	0.378	0.624	0.946	1.206	1.392
480	…..	0.388	0.634	0.954	1.252	1.394
1440	2.088	0.385	0.648	0.958	1.256	1.396

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring ,(g)	130.56
Specimen dry mass + can (g)	114.507
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.59
Water Content, %	34.518
Dry density, (g/cm2)	**1.185**
Height of solid (cm)	0.871
Initial void ratio, eo	**1.296**
Height of solid (mm)	8.712
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.088
Specimen Height mm	20
Free swell index (%)	10.44
Swelling pressure (Sp) kPa	210

Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
7	0	0	20.000	1.296
7	2.088	-2.088	22.088	1.535
50	0.385	-1.703	21.703	1.491
100	0.648	-1.055	21.055	1.417
200	0.958	-0.097	20.097	1.307
400	1.256	1.159	18.841	1.163
800	1.396	2.555	17.445	1.002

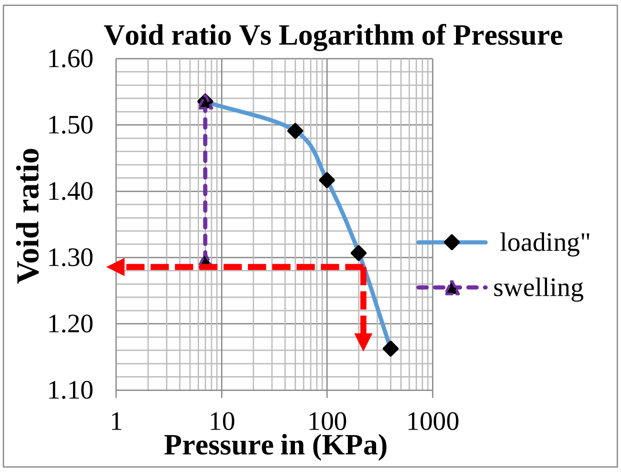


Table C18: Deformation reading of Odometer consolidation test for Tp7 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.649	0.552	0.883	1.124	1.296
0.10	…..	0.421	0.607	0.925	1.162	1.332
0.25	…..	0.435	0.623	0.932	1.175	1.334
0.50	…..	0.443	0.655	0.942	1.193	1.336
1	…..	0.451	0.687	0.948	1.209	1.342
2	…..	0.467	0.711	0.956	1.215	1.352
4	…..	0.473	0.739	0.982	1.223	1.358
8	…..	0.487	0.757	1.002	1.235	1.362
15	…..	0.495	0.779	1.024	1.243	1.368
30	…..	0.505	0.797	1.054	1.257	1.374
60	…..	0.513	0.813	1.074	1.268	1.380
120	…..	0.525	0.837	1.092	1.277	1.378
240	…..	0.537	0.857	1.106	1.285	1.382
480	…..	0.549	0.877	1.118	1.293	1.384
1440	1.649	0.552	0.883	1.124	1.296	1.386

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring (g)	131.96	7	0	0	20.000	1.201
Specimen dry mass + can (g)	115.624	7	1.649	-1.649	21.649	1.382
Mass of ring (g)	68	50	0.552	-1.097	21.097	1.321
Specimen Height, L (cm)	2	100	0.883	-0.214	20.214	1.224
Specimen diameter, D (cm)	5	200	1.124	0.91	19.090	1.100
Area of ring cm^2	19.625	400	1.296	2.206	17.794	0.958
Volume of ring cm^3	39.25	800	1.386	3.592	16.408	0.805

Bulk density, (g/cm^2)	1.63
Water Content, %	34.302
Dry density, (g/cm2)	**1.21**
Height of solid (cm)	0.909
Initial void ratio, eo	**1.201**
Height of solid (mm)	9.09
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.649
Specimen Height mm	20
Free swell index (%)	8.25
Swelling pressure (Sp) kPa	125

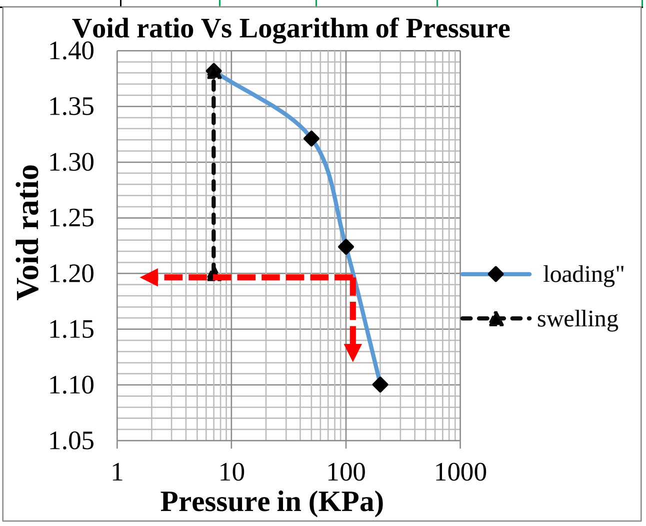


Table C19: Deformation reading of Odometer consolidation test for Tp7 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.007	0.392	0.573	0.875	1.016
0.10	…..	0.271	0.487	0.675	0.922	1.082
0.25	…..	0.284	0.493	0.692	0.933	1.084
0.50	…..	0.293	0.505	0.712	0.943	1.092
1	…..	0.302	0.517	0.738	0.949	1.099
2	…..	0.317	0.524	0.756	0.955	1.102
4	…..	0.323	0.532	0.782	0.963	1.104
8	…..	0.336	0.537	0.802	0.975	1.108
15	…..	0.345	0.542	0.834	0.983	1.112
30	…..	0.354	0.549	0.844	0.987	1.116
60	…..	0.363	0.555	0.852	0.992	1.118
120	…..	0.375	0.562	0.862	0.977	1.120
240	…..	0.384	0.567	0.866	1.005	1.122
480	…..	0.388	0.570	0.871	1.013	1.144
1440	1.007	0.392	0.573	0.875	1.016	1.126

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring (g)	135.96	7	0	0	20.000	1.089
Specimen dry mass + can (g)	117.785	7	1.007	-1.007	21.007	1.194
Mass of ring (g)	68	50	0.392	-0.615	20.615	1.153
Specimen Height, L (cm)	2	100	0.573	-0.042	20.042	1.094
Specimen diameter, D (cm)	5	200	0.875	0.833	19.167	1.002
Area of ring cm^2	19.625	400	1.016	1.849	18.151	0.896
Volume of ring cm^3	39.25	800	1.126	2.975	17.025	0.778

Bulk density, (g/cm^2)	1.73
Water Content, %	36.508
Dry density, (g/cm2)	**1.27**
Height of solid (cm)	0.957
Initial void ratio, eo	**1.089**
Height of solid (mm)	9.57
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.007
Specimen Height mm	20
Free swell index (%)	5.04
Swelling pressure (Sp) kPa	105

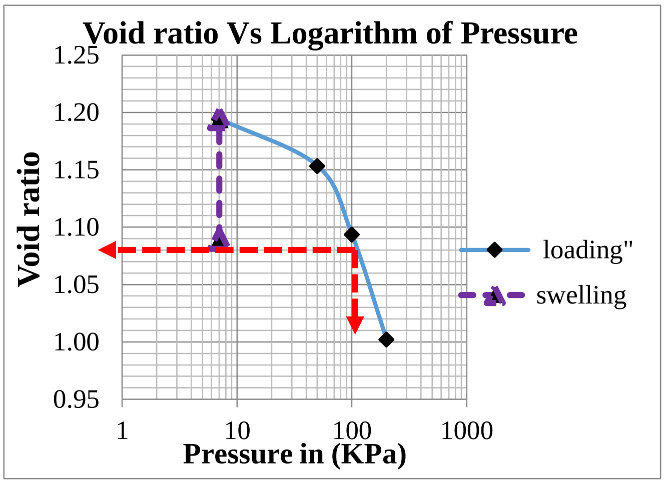


Table C20: Deformation reading of Odometer consolidation test for Tp7 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	0.946	0.779	0.868	1.009	1.196
0.10	…..	0.651	0.817	0.915	1.052	1.212
0.25	…..	0.662	0.821	0.912	1.073	1.216
0.50	…..	0.674	0.824	0.918	1.093	1.220
1	…..	0.682	0.828	0.926	1.104	1.224
2	…..	0.695	0.832	0.934	1.110	1.228
4	…..	0.703	0.838	0.942	1.113	1.232
8	…..	0.715	0.842	0.952	1.125	1.236
15	…..	0.724	0.848	0.964	1.133	1.238
30	…..	0.734	0.852	0.974	1.147	1.240
60	…..	0.745	0.858	0.982	1.152	1.242
120	…..	0.756	0.862	0.992	1.167	1.242
240	…..	0.764	0.864	0.998	1.175	1.244
480	…..	0.772	0.866	1.005	1.183	1.244
1440	0.946	0.779	0.868	1.009	1.196	1.246

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
Specimen wet mass + ring (g)	133.87	7	0	0	20.000	1.092
Specimen dry mass + can (g)	117.336	7	0.946	-0.946	20.946	1.191
Mass of ring (g)	68	50	0.779	-0.167	20.167	1.110
Specimen Height, L (cm)	2	100	0.868	0.701	19.299	1.019
Specimen diameter, D (cm)	5	200	1.009	1.71	18.290	0.913
Area of ring cm^2	19.625	400	1.196	2.906	17.094	0.788
Volume of ring cm^3	39.25	800	1.246	4.152	15.848	0.658
Bulk density, (g/cm^2)	1.68					
Water Content, %	33.512					
Dry density (g/cm2)	**1.26**					
Height of solid (cm)	0.956					
Initial void ratio, eo	**1.092**					
Height of solid (mm)	9.559					
Swelling Potential						
Initial dial reading (adjusted to Zero Reading) mm	0.0					
Final Dial Reading mm	0.946					
Specimen Height mm	20					
Free swell index (%)	4.73					
Swelling pressure (Sp) kPa	65					

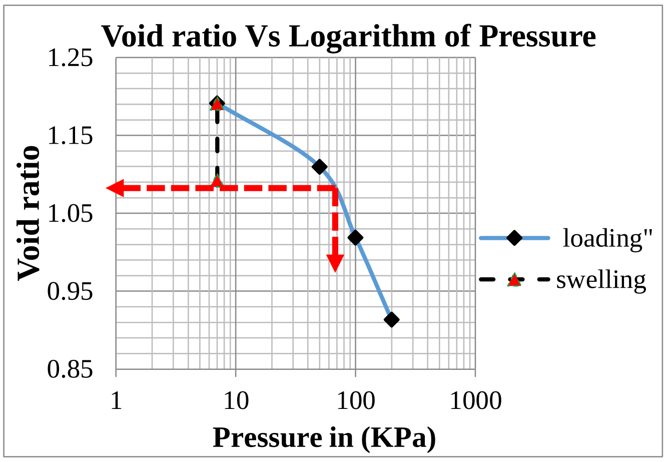


Table C21: Deformation reading of Odometer consolidation test for Tp8 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.987	0.685	0.816	1.058	1.156
0.10	…..	0.582	0.718	0.933	1.109	1.195
0.25	…..	0.597	0.722	0.945	1.114	1.190
0.50	…..	0.609	0.728	0.957	1.116	1.182
1	…..	0.617	0.734	0.963	1.120	1.184
2	…..	0.624	0.742	0.975	1.124	1.194
4	…..	0.633	0.753	0.983	1.127	1.204
8	…..	0.641	0.764	0.989	1.130	1.218
15	…..	0.647	0.771	0.995	1.133	1.226
30	…..	0.653	0.782	1.008	1.138	1.232
60	…..	0.659	0.788	1.023	1.142	1.238
120	…..	0.665	0.795	1.039	1.148	1.242
240	…..	0.677	0.805	1.045	1.152	1.250
480	…..	0.682	0.812	1.052	1.154	1.254
1440	2.987	0.685	0.816	1.058	1.156	1.256

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	129.985
Specimen dry mass + can (g)	113.155
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.58
Water Content, %	37.272
Dry density, (g/cm^2)	**1.15**
Height of solid (cm)	0.807
Initial void ratio, eo	**1.477**
Height of solid (mm)	8.07
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.987
Specimen Height mm	20
Free swell index (%)	14.94
Swelling pressure (Sp) kPa	280

Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
7	0	0	20.000	1.477
7	2.987	-2.987	22.987	1.847
50	0.685	-2.302	22.302	1.762
100	0.816	-1.486	21.486	1.661
200	1.058	-0.428	20.428	1.530
400	1.156	0.728	19.272	1.387
800	1.256	1.984	18.016	1.232

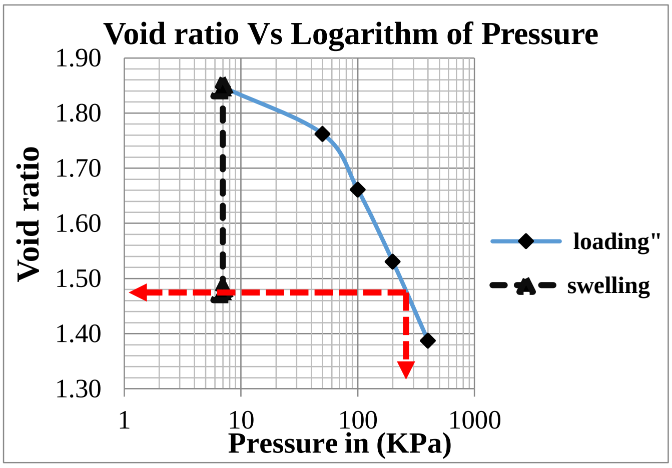


Table C22: Deformation reading of Odometer consolidation test for Tp8 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.492	0.592	0.707	0.907	1.196
0.10	…..	0.465	0.625	0.792	0.985	1.215
0.25	…..	0.474	0.630	0.803	0.989	1.219
0.50	…..	0.489	0.634	0.810	0.996	1.224
1	…..	0.507	0.639	0.816	1.012	1.228
2	…..	0.514	0.644	0.822	1.032	1.231
4	…..	0.523	0.653	0.831	1.073	1.237
8	…..	0.531	0.664	0.844	1.093	1.242
15	…..	0.542	0.673	0.857	1.113	1.247
30	…..	0.557	0.680	0.869	1.138	1.252
60	…..	0.565	0.685	0.874	1.152	1.255
120	…..	0.573	0.689	0.888	1.178	1.259
240	…..	0.579	0.695	0.897	1.182	1.262
480	…..	0.587	0.702	0.904	1.194	1.265
1440	2.492	0.592	0.707	0.907	1.196	1.267

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul . ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring (g)	130.58	7	0	0	20.000	1.366
Specimen dry mass + can (g)	113.951	7	2.492	-2.492	22.492	1.661
Mass of ring (g)	68	50	0.592	-1.9	21.900	1.591
Specimen Height, L (cm)	2	100	0.707	-1.193	21.193	1.507
Specimen diameter, D (cm)	5	200	0.907	-0.286	20.286	1.400
Area of ring cm^2	19.625	400	1.196	0.91	19.090	1.258
Volume of ring cm^3	39.25	800	1.267	2.177	17.823	1.109

Bulk density, (g/cm^3)	1.59
Water Content, %	36.190
Dry density, (g/cm2)	**1.17**
Height of solid (cm)	0.845
Initial void ratio, eo	**1.366**
Height of solid (mm)	8.45
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.492
Specimen Height mm	20
Free swell index (%)	12.46
Swelling pressure (Sp) kPa	260

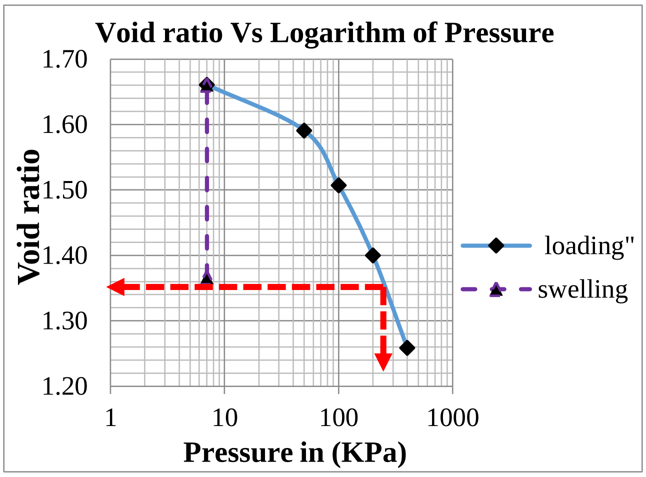


Table C23: Deformation reading of Odometer consolidation test for Tp8 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg
0.00	0.00	2.015	0.622	0.879	1.181
0.10	…..	0.415	0.753	0.932	1.205
0.25	…..	0.424	0.762	0.943	1.207
0.50	…..	0.439	0.779	0.951	1.210
1	…..	0.547	0.789	0.966	1.213
2	…..	0.554	0.794	0.972	1.217
4	…..	0.563	0.803	0.981	1.221
8	…..	0.571	0.814	0.994	1.224
15	…..	0.582	0.823	1.104	1.228
30	…..	0.587	0.830	1.119	1.232
60	…..	0.595	0.845	1.134	1.237
120	…..	0.603	0.859	1.158	1.243
240	…..	0.609	0.865	1.167	1.248
480	…..	0.617	0.872	1.178	1.254
1440	2.015	0.622	0.879	1.181	1.256

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cum. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
Specimen wet mass + ring (g)	136.58	7	0	0	20.000	1.128
Specimen dry mass + can (g)	117.977	7	2.015	-2.015	22.015	1.343
Mass of ring (g)	68	50	0.622	-1.393	21.393	1.277
Specimen Height, L (cm)	2	100	0.879	-0.514	20.514	1.183
Specimen diameter, D (cm)	5	200	1.181	0.667	19.333	1.057
Area of ring cm^2	19.625	400	1.256	1.923	18.077	0.924
Volume of ring cm^3	39.25	800	1.398	3.321	16.679	0.775
Bulk density, (g/cm^2)	1.75					
Water Content, %	37.223					
Dry density, (g/cm2)	**1.27**					
Height of solid (cm)	0.940					
Initial void ratio, eo	**1.128**					
Height of solid (cm)	9.40					
SWELLING POTENTIAL						
Initial dial reading (adjusted to Zero Reading) mm	0.0					
Final Dial Reading mm	2.015					
Specimen Height mm	20					
Free swell index (%)	10.08					
Swelling pressure (Sp) kPa	155					

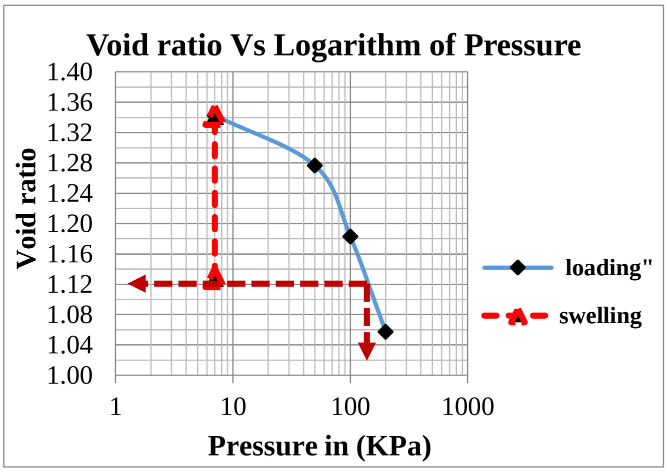


Table C24: Deformation reading of Odometer consolidation test for Tp9 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.892	0.402	0.579	0.867	1.151
0.10	…..	0.254	0.458	0.628	0.932	1.192
0.25	…..	0.268	0.462	0.632	0.944	1.206
0.50	…..	0.275	0.472	0.646	0.952	1.222
1	…..	0.282	0.486	0.665	0.966	1.244
2	…..	0.296	0.494	0.684	0.984	1.264
4	…..	0.312	0.508	0.716	1.014	1.288
8	…..	0.346	0.528	0.750	1.052	1.298
15	…..	0.366	0.538	0.776	1.089	1.306
30	…..	0.376	0.546	0.788	1.106	1.312
60	…..	0.382	0.552	0.798	1.122	1.328
120	…..	0.386	0.554	0.816	1.128	1.332
240	…..	0.388	0.558	0.834	1.134	1.344
480	…..	0.396	0.566	0.852	1.142	1.348
1440	1.892	0.402	0.579	0.867	1.151	1.352

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	131.357
Specimen dry mass + can (g)	115.458
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.61
Water Content, %	33.501
Dry density, (g/cm2)	**1.21**
Height of solid (cm)	0.886
Initial void ratio, eo	**1.258**
Height of solid (mm)	8.86
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.892
Specimen Height mm	20
Free swell index (%)	9.46
Swelling pressure (Sp) kPa	205

Pressure (KPa)	Final Df. Rdg (mm)	Cumul ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
7	0	0	20.000	1.258
7	1.892	-1.892	21.892	1.471
50	0.402	-1.49	21.490	1.426
100	0.579	-0.911	20.911	1.361
200	0.867	-0.044	20.044	1.263
400	1.151	1.107	18.893	1.133
800	1.352	2.459	17.541	0.980

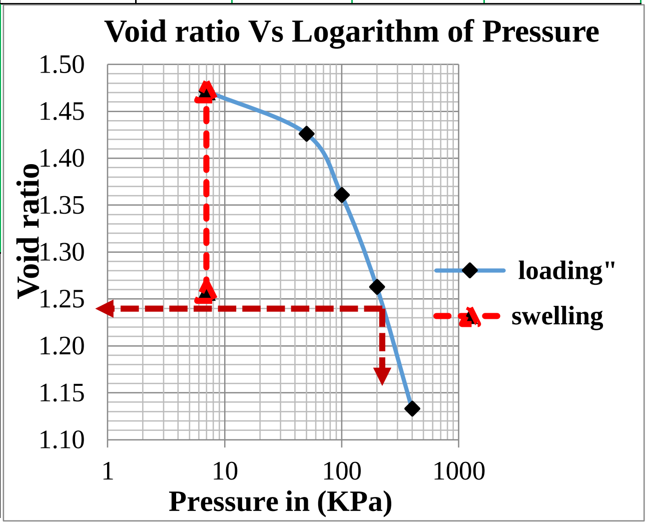


Table C25: Deformation reading of Odometer consolidation test for Tp9 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	1.753	0.432	0.707	0.918	1.142
0.10	…..	0.284	0.518	0.753	0.955	1.197
0.25	…..	0.292	0.542	0.762	0.963	1.203
0.50	…..	0.305	0.562	0.779	0.972	1.208
1	…..	0.322	0.586	0.787	0.979	1.213
2	…..	0.346	0.605	0.799	0.988	1.218
4	…..	0.352	0.638	0.816	1.014	1.223
8	…..	0.366	0.647	0.837	1.052	1.228
15	…..	0.376	0.653	0.849	1.095	1.233
30	…..	0.386	0.665	0.863	1.107	1.237
60	…..	0.392	0.673	0.878	1.114	1.240
120	…..	0.406	0.687	0.892	1.122	1.242
240	…..	0.418	0.695	0.904	1.130	1.244
480	…..	0.426	0.702	0.912	1.137	1.246
1440	1.753	0.432	0.707	0.918	1.142	1.248

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	130.876
Specimen dry mass + can (g)	113.682
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^3)	1.60
Water Content, %	37.640
Dry density, (g/cm2)	**1.16**
Height of solid (cm)	0.865
Initial void ratio, eo	**1.311**
Height of solid (mm)	8.65
SWELLING POTENTIAL	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	1.753
Specimen Height mm	20
Free swell index (%)	8.77
Swelling pressure (Sp) kPa	170

Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
7	0	0	20.000	1.311
7	1.753	-1.753	21.753	1.514
50	0.432	-1.321	21.321	1.464
100	0.707	-0.614	20.614	1.382
200	0.918	0.304	19.696	1.276
400	1.142	1.446	18.554	1.144
800	1.248	2.694	17.306	1.000

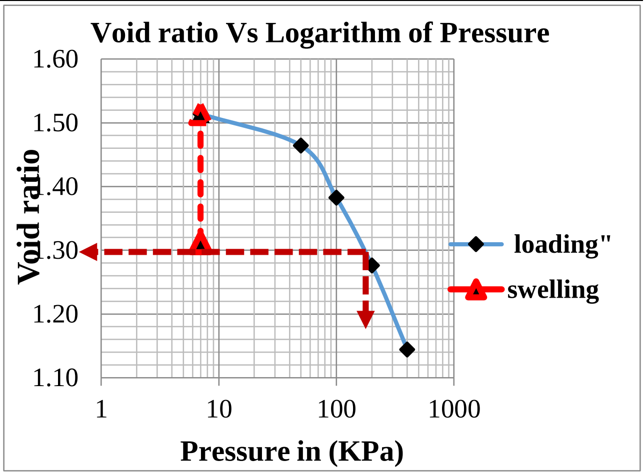


Table C26: Deformation reading of Odometer consolidation test for Tp9 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg
0.00	0.00	1.585	0.682	0.856	1.064
0.10	…..	0.487	0.743	0.908	1..092
0.25	…..	0.495	0.755	0.913	1.097
0.50	…..	0.508	0.767	0.925	1.102
1	…..	0.527	0.783	0.937	1.109
2	…..	0.345	0.802	0.949	1.112
4	…..	0.567	0.832	0.956	1.115
8	…..	0.586	0.847	0.967	1.119
15	…..	0.606	0.853	0.979	1.123
30	…..	0.625	0.865	0.983	1.127
60	…..	0.637	0.873	1.007	1.130
120	…..	0.649	0.827	1.022	1.132
240	…..	0.663	0.838	1.044	1.134
480	…..	0.676	0.847	1.052	1.136
1440	1.585	0.682	0.856	1.064	1.138

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul . ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
Specimen wet mass + ring (g)	135.865	7	0	0	20.000	1.108
Specimen dry mass + can (g)	118.078	7	1.585	-1.585	21.585	1.275
Mass of ring (g)	68	50	0.682	-0.903	20.903	1.204
Specimen Height, L (cm)	2	100	0.856	-0.047	20.047	1.113
Specimen diameter, D (cm)	5	200	1.064	1.017	18.983	1.001
Area of ring cm^2	19.625	400	1.138	2.155	17.845	0.881
Volume of ring cm^3	39.25	800	1.206	3.361	16.639	0.754
Bulk density, (g/cm^2)	1.73					
Water Content, %	35.519					
Dry density, (g/cm2)	**1.28**					
Height of solid (cm)	0.949					
Initial void ratio, eo	**1.108**					
Height of solid (cm)	9.49					
Swelling Potential						
Initial dial reading (adjusted to Zero Reading) mm	0.0					
Final Dial Reading mm	1.585					
Specimen Height mm	20					
Free swell index (%)	7.93					
Swelling pressure (Sp) kPa	105					

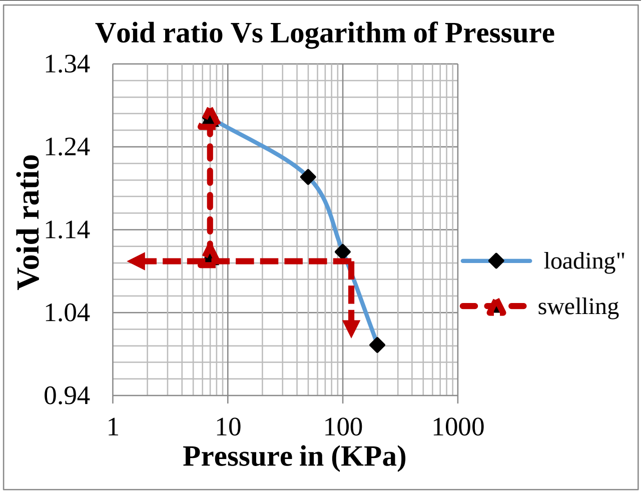


Table C27: Deformation reading of Odometer consolidation test for Tp10 @1m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	3.137	0.592	0.802	1.114	1.364
0.10	…..	0.367	0.628	0.865	1.207	1.412
0.25	…..	0.385	0.632	0.882	1.214	1.426
0.50	…..	0.407	0.642	0.904	1.242	1.432
1	…..	0.422	0.656	0.926	1.256	1.444
2	…..	0.446	0.684	0.944	1.264	1.454
4	…..	0.467	0.708	0.966	1.274	1.464
8	…..	0.486	0.718	0.985	1.289	1.478
15	…..	0.506	0.728	1.006	1.297	1.486
30	…..	0.526	0.736	1.018	1.308	1.492
60	…..	0.542	0.742	1.038	1.320	1.508
120	…..	0.566	0.754	1.066	1.332	1.522
240	…..	0.578	0.764	1.084	1.345	1.534
480	…..	0.584	0.786	1.102	1.353	1.545
1440	3.137	0.592	0.802	1.114	1.364	1.554

Determination of dry unit weight and Height of solids	
Specimen wet mass + ring (g)	138.61
Specimen dry mass + can (g)	117.814
Mass of ring (g)	68
Specimen Height, L (cm)	2
Specimen diameter, D (cm)	5
Area of ring cm^2	19.625
Volume of ring cm^3	39.25
Bulk density, (g/cm^2)	1.80
Water Content, %	41.748
Dry density, (g/cm2)	**1.27**
Height of solid (cm)	0.900
Initial void ratio, eo	**1.222**
Height of solid (cm)	9.00
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	3.137
Specimen Height mm	20
Free swell index (%)	15.69
Swelling pressure (Sp) kPa	300

Pressure (KPa)	Final Df. Rdg (mm)	Cumul ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs) / Hs
7	0	0	20.000	1.222
7	3.137	-3.137	23.137	1.570
50	0.592	-2.545	22.545	1.505
100	0.802	-1.743	21.743	1.416
200	1.114	-0.629	20.629	1.292
400	1.364	0.735	19.265	1.140
800	1.554	2.289	17.711	0.968

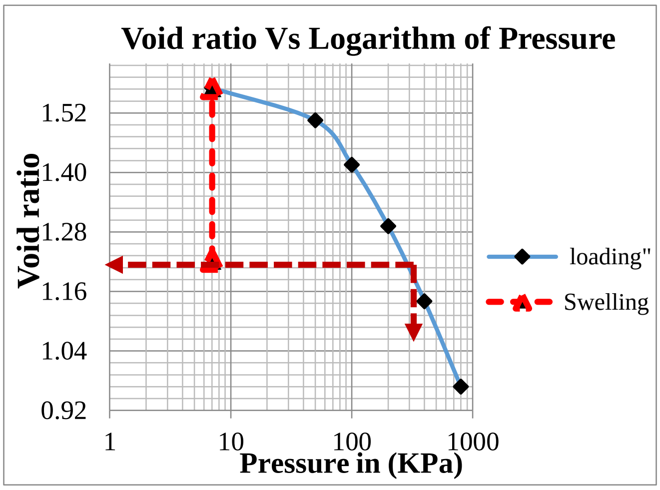


Table C28: Deformation reading of Odometer consolidation test for Tp10 @2m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.695	0.412	0.707	1.084	1.196
0.10	…..	0.277	0.468	0.852	1.127	1.222
0.25	…..	0.289	0.487	0.852	1.134	1.228
0.50	…..	0.303	0.499	0.884	1.139	1.232
1	…..	0.312	0.516	0.906	1.143	1.238
2	…..	0.325	0.534	0.924	1.147	1.242
4	…..	0.337	0.558	0.946	1.152	1.247
8	…..	0.343	0.578	0.965	1.157	1.253
15	…..	0.352	0.598	0.986	1.163	1.258
30	…..	0.365	0.616	1.008	1.170	1.262
60	…..	0.372	0.632	1.018	1.175	1.267
120	…..	0.383	0.658	1.036	1.182	1.271
240	…..	0.397	0.679	1.054	1.187	1.273
480	…..	0.404	0.696	1.072	1.193	1.275
1440	2.695	0.412	0.707	1.084	1.196	1.277

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul . ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
Specimen wet mass + ring (g)	135.68	7	0	0	20.000	1.298
Specimen dry mass + can (g)	115.478	7	2.695	-2.695	22.695	1.608
Mass of ring (g)	68	50	0.412	-2.283	22.283	1.561
Specimen Height, L (cm)	2	100	0.707	-1.576	21.576	1.479
Specimen diameter, D (cm)	5	200	1.084	-0.492	20.492	1.355
Area of ring cm^2	19.625	400	1.196	0.704	19.296	1.217
Volume of ring cm^3	39.25	800	1.277	1.981	18.019	1.071

Bulk density, (g/cm^2)	1.72
Water Content, %	42.549
Dry density, (g/cm2)	**1.21**
Height of solid (cm)	0.870
Initial void ratio, eo	**1.298**
Height of solid (cm)	8.70
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.695
Specimen Height mm	20
Free swell index (%)	13.48
Swelling pressure (Sp) kPa	285

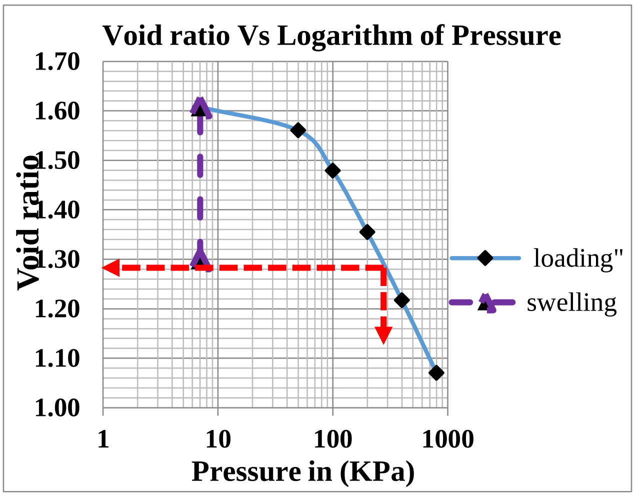
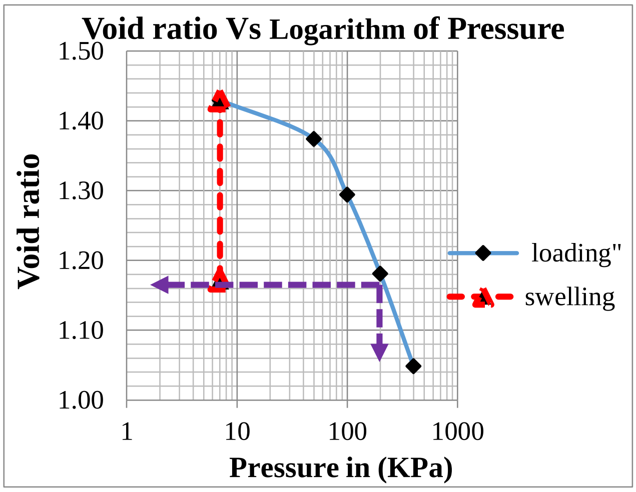


Table C29: Deformation reading of Odometer consolidation test for Tp10 @3m

Time	Swelling @ 0.14kg	Deformation @ 1kg	Deformation @ 2kg	Deformation @ 4kg	Deformation @ 8kg	Deformation @ 16kg
0.00	0.00	2.376	0.512	0.735	1.044	1.217
0.10	…..	0.365	0.594	0.822	1.107	1.242
0.25	…..	0.387	0.609	0.832	1.114	1.248
0.50	…..	0.405	0.617	0.844	1.129	1.252
1	…..	0.416	0.628	0.856	1.133	1.258
2	…..	0.428	0.638	0.864	1.147	1.262
4	…..	0.439	0.643	0.876	1.152	1.267
8	…..	0.448	0.655	0.885	1.167	1.273
15	…..	0.459	0.667	0.896	1.173	1.278
30	…..	0.467	0.688	1.008	1.182	1.280
60	…..	0.473	0.695	1.019	1.195	1.282
120	…..	0.487	0.702	1.028	1.202	1.282
240	…..	0.495	0.715	1.035	1.207	1.283
480	…..	0.504	0.726	1.040	1.212	1.284
1440	2.376	0.512	0.735	1.044	1.217	1.285

Determination of dry unit weight and Height of solids		Pressure (KPa)	Final Df. Rdg (mm)	Cumul. ΔH (mm)	Hf = Hi - ∑ΔH (mm)	Final Void Ratio ef = (Hf-Hs)/Hs
Specimen wet mass + ring (g)	135.61	7	0	0	20.000	1.172
Specimen dry mass + can (g)	117.706	7	2.376	-2.376	22.376	1.430
Mass of ring (g)	68	50	0.512	-1.864	21.864	1.374
Specimen Height, L (cm)	2	100	0.735	-1.129	21.129	1.294
Specimen diameter, D (cm)	5	200	1.044	-0.085	20.085	1.181
Area of ring cm^2	19.625	400	1.217	1.132	18.868	1.049
Volume of ring cm^3	39.25	800	1.285	2.417	17.583	0.909

Bulk density, (g/cm^2)	1.72
Water Content, %	36.021
Dry density, (g/cm2)	**1.27**
Height of solid (cm)	0.921
Initial void ratio, eo	**1.172**
Height of solid (cm)	9.21
Swelling Potential	
Initial dial reading (adjusted to Zero Reading) mm	0.0
Final Dial Reading mm	2.376
Specimen Height mm	20
Free swell index (%)	11.88
Swelling pressure (Sp) kPa	210



APPENDIX D: Specific Gravity test Results of the Study Area

Table F1: Specific test results Test Pit 2

Test Method: D 854	**TEST PIT 2**					
Depth	1m		2m		3m	
Pycnometer No.	O7	O8	O9	10	11	12
Wt of dry, clean pycnometer, w_p (g)	31.519	30.884	31.977	30.786	26.863	30.408
Wt of pycnometer + water, w_{pw} (g)	126.205	127.712	126.379	125.962	123.022	126.456
Observed Temp. of water, T_i (oc)	23	23	23	23	23	23
Wt of pycno. + soil + water, W_{pws} (g)	132.731	134.242	132.841	132.442	129.44	132.876
Temperature, T_x(°c)	22	22	22	22	22	22
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	126.23	127.73	126.40	125.98	123.04	126.48
Wt of dry soil ,(gm)	10	10	10	10	10	10
Conversion factor , K	1.0001	1.0001	1.0001	1.0001	1.0001	1.0001
Gs of soil at 20°c.	2.859	2.862	2.808	2.822	2.773	2.775
Average Gs of soil.	**2.86**		**2.81**		**2.77**	

Table F2: Specific test results Test Pit 3

Test Method: D 854	TEST PIT 3					
Depth	1m		2m		3m	
Pycnometer No.	13	14	15	16	17	18
Wt of dry, clean pycnometer, w_p (g)	29.752	30.248	28.746	31.076	30.249	29.324
Wt of pycnometer + water, w_{pw} (g)	125.625	126.642	125.086	125.872	124.682	123.056
Observed Temp. of water, T_i (oc)	23	23	23	23	23	23
Wt of pycno. + soil + water, W_{pws} (g)	131.997	133.018	131.407	132.201	130.972	129.344
Temperature, T_x(°c)	22	22	22	22	22	22
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	125.65	126.66	125.11	125.89	124.70	123.08
Wt of dry soil ,(gm)	10	10	10	10	10	10
Conversion factor , K	1.0001	1.0001	1.0001	1.0001	1.0001	1.0001
Gs of soil at 20°c.	2.738	2.741	2.701	2.707	2.679	2.677
Average Gs of soil.	2.74		2.70		2.68	

Table F3: Specific test results Test Pit 4

Test Method: D 854	**TEST PIT 4**					
Depth	**1m**		**2m**		**3m**	
Pycnometer No.	**o1**	***o2***	**o3**	**o4**	**o5**	**o6**
Wt of dry, clean pycnometer, w_p (g)	28.514	29.429	29.715	29.567	30.179	29.976
Wt of pycnometer + water, w_{pw} (g)	124.509	123.826	124.871	126.658	125.542	122.256
Observed Temp. of water, T_i (oc)	22	22	22	22	22	22
Wt of pycno. + soil + water, W_{pws} (g)	130.788	130.107	131.117	132.922	131.764	128.479
Temperature, T_x(°c)	21	21	21	21	21	21
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	124.53	123.85	124.89	126.68	125.56	122.28
Wt of dry soil ,(gm)	10.011	9.992	10.000	10.000	10.000	10.000
Conversion factor , K	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
Gs of soil at 20°c.	2.667	2.677	2.648	2.661	2.632	2.633
Average Gs of soil	**2.67**		**2.65**		**2.63**	

Table F4: Specific test results Test Pit 5

Test Method: D 854	**TEST PIT 5**					
Depth	**1m**		**2m**		**3m**	
Pycnometer No.	**o7**	**o8**	**o9**	**10**	**11**	**12**
Wt of dry, clean pycnometer, w_p (g)	30.928	30.985	31.727	30.767	27.063	30.408
Wt of pycnometer + water, w_{pw} (g)	126.187	127.712	126.229	125.922	122.922	126.456
Observed Temp. of water, T_i (oc)	22	22	22	22	22	22
Wt of pycno. + soil + water, W_{pws} (g)	132.495	134.012	132.499	132.197	129.188	132.712
Temperature, T_x(°c)	21	21	21	21	21	21
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	126.21	127.73	126.25	125.94	122.94	126.48
Wt of dry soil ,(gm)	10.000	10.000	10.000	10.000	10.000	10.000
Conversion factor , K	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
Gs of soil at 20°c.	2.693	2.687	2.665	2.669	2.662	2.655
Average Gs of soil	**2.69**		**2.67**		**2.66**	

Table F5: Specific test results Test Pit 6

Test Method: D 854	**TEST PIT 6**					
Depth	**1m**		**2m**		**3m**	
Pycnometer No.	**13**	**14**	**15**	**16**	**17**	**18**
Wt of dry, clean pycnometer, w_p (g)	29.725	30.749	29.546	31.076	30.249	29.324
Wt of pycnometer + water, w_{pw} (g)	125.205	126.512	125.166	125.992	124.692	122.829
Observed Temp. of water, T_i (oc)	22	22	22	22	22	22
Wt of pycno. + soil + water, W_{pws} (g)	131.637	132.948	131.545	132.358	131.039	129.171
Temperature, T_x(°c)	21	21	21	21	21	21
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	125.23	126.53	125.19	126.01	124.71	122.85
Wt of dry soil ,(gm)	10.000	10.000	10.000	10.000	10.000	10.000
Conversion factor , K	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998
Gs of soil at 20°c.	2.786	2.789	2.745	2.735	2.721	2.718
Average Gs of soil	**2.79**		**2.74**		**2.72**	

Table F6: Specific test results Test Pit 7

Test Method: D 854	TEST PIT 7					
Depth	1m		2m		3m	
Pycnometer No.	o1	o2	o3	o4	o5	o6
Wt of dry, clean pycnometer, w_p (g)	28.511	29.442	28.515	29.46	30.069	29.964
Wt of pycnometer + water, w_{pw} (g)	124.498	123.572	124.851	126.338	125.342	121.856
Observed Temp. of water, T_i (oc)	24	24	24	24	24	24
Wt of pycno. + soil + water, W_{pws} (g)	130.797	129.868	131.131	132.612	131.588	128.089
Temperature, T_x(°c)	22	22	22	22	22	22
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	124.54	123.62	124.90	126.38	125.39	121.90
Wt of dry soil ,(gm)	10	10	10	10	10	10
Conversion factor , K	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
Gs of soil at 20°c.	2.668	2.667	2.654	2.650	2.631	2.623
Average Gs of soil	2.67		2.65		2.63	

Table F7: Specific test results Test Pit 8

Test Method: D 854	**TEST PIT 8**					
Depth	**1m**		**2m**		**3m**	
Pycnometer No.	**o7**	**o8**	**o9**	**10**	**11**	**12**
Wt of dry, clean pycnometer, w_p (g)	31.519	30.884	31.977	30.786	26.863	30.408
Wt of pycnometer + water, w_{pw} (g)	126.205	127.712	126.379	125.962	123.022	126.456
Observed Temp. of water, T_i (oc)	24	24	24	24	24	24
Wt of pycno. + soil + water, W_{pws} (g)	132.746	134.252	132.816	132.398	129.382	132.822
Temperature, T_x(°c)	22	22	22	22	22	22
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	126.25	127.76	126.42	126.01	123.07	126.50
Wt of dry soil ,(gm)	10	10	10	10	10	10
Conversion factor , K	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
Gs of soil at 20°c.	2.853	2.851	2.771	2.770	2.712	2.717
Average Gs of soil	**2.85**		**2.77**		**2.71**	

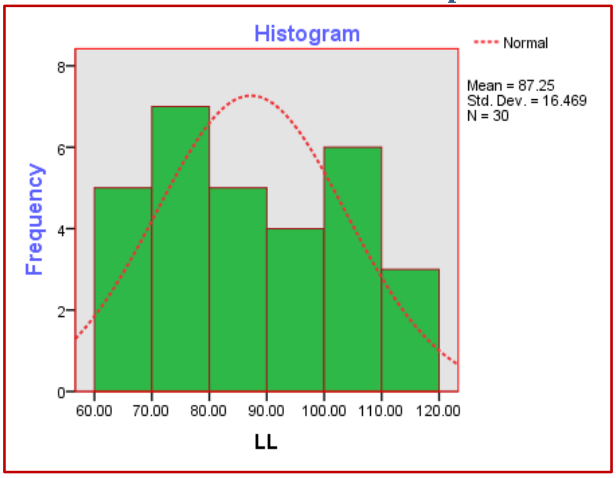
Table F8: Specific test results Test Pit 9

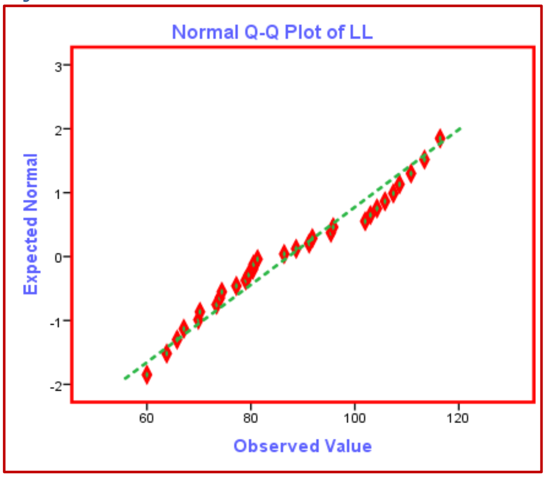
Test Method: D 854	**TEST PIT 9**					
Depth	**1m**		**2m**		**3m**	
Pycnometer No.	**13**	**14**	**15**	**16**	**17**	**18**
Wt of dry, clean pycnometer, w_p (g)	29.752	30.248	28.746	31.076	30.249	29.324
Wt of pycnometer + water, w_{pw} (g)	125.625	126.642	125.086	125.872	124.682	123.056
Observed Temp. of water, T_i (oc)	24	24	24	24	24	24
Wt of pycno. + soil + water, W_{pws} (g)	132.014	133.021	131.414	132.206	131.014	129.394
Temperature, T_x(°c)	22	22	22	22	22	22
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	125.67	126.69	125.13	125.92	124.73	123.10
Wt of dry soil ,(gm)	10	10	10	10	10	10
Conversion factor , K	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
Gs of soil at 20°c.	2.734	2.726	2.689	2.694	2.692	2.697
Average Gs of soil	**2.73**		**2.69**		**2.69**	

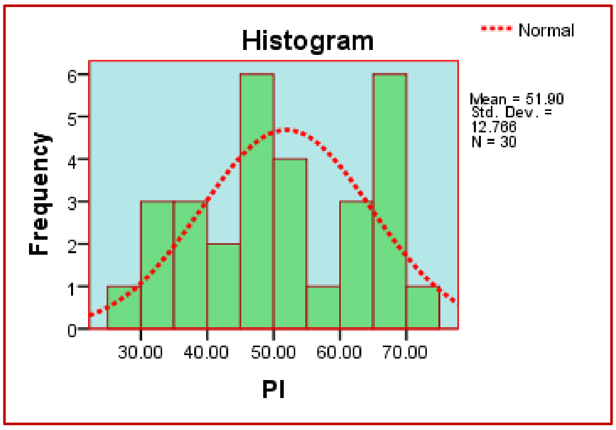
Table F9: Specific test results Test Pit 10

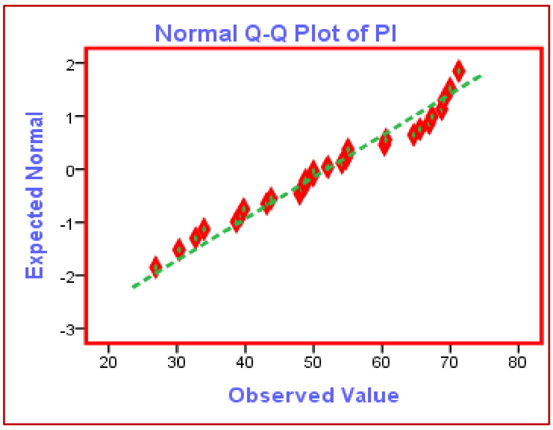
Test Method: D 854	**TEST PIT 10**					
Depth	**1m**		**2m**		**3m**	
Pycnometer No.	**13**	**14**	**15**	**16**	**17**	**18**
Wt of dry, clean pycnometer, w_p (g)	31.357	30.298	29.875	30.025	31.256	30.258
Wt of pycnometer + water, w_{pw} (g)	126.123	125.752	122.667	124.011	126.629	126.001
Observed Temp. of water, T_i (oc)	24	24	24	24	24	24
Wt of pycno. + soil + water, W_{pws} (g)	132.621	132.248	129.121	130.458	133.042	132.409
Temperature, T_x(°c)	22	22	22	22	22	22
Wt of pycno. + water at T_x , $W_{pw}(atT_x)$ (g)	126.17	125.80	122.71	124.06	126.67	126.05
Wt of dry soil ,(gm)	10	10	10	10	10	10
Conversion factor , K	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996
Gs of soil at 20°c.	2.818	2.816	2.784	2.779	2.752	2.748
Average Gs of soil	**2.82**		**2.78**		**2.75**	

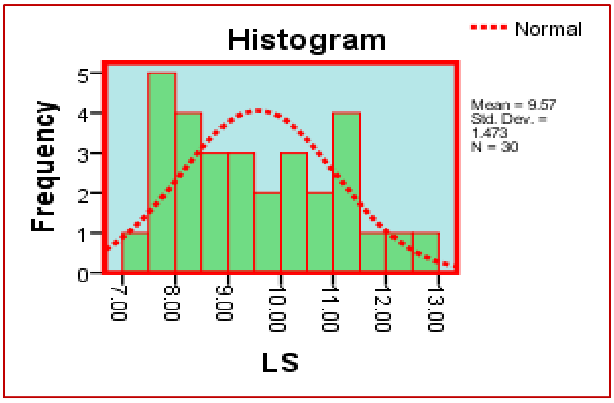
APPENDIX E: Graph of Normality test for each Variables

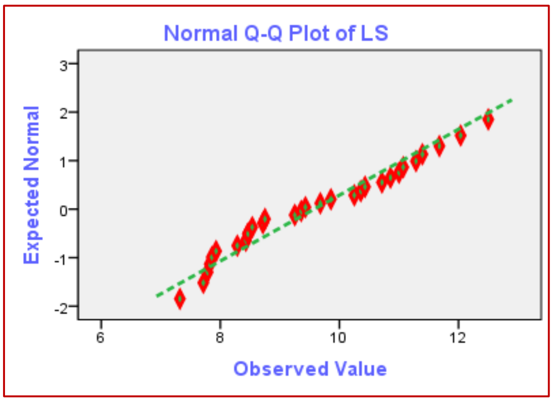


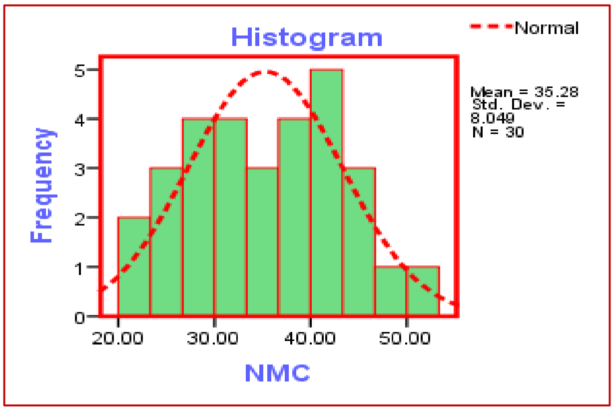


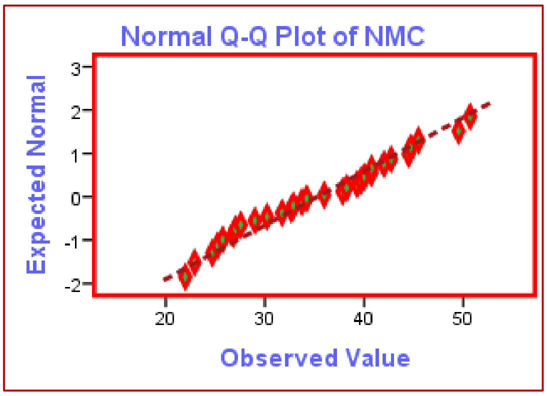


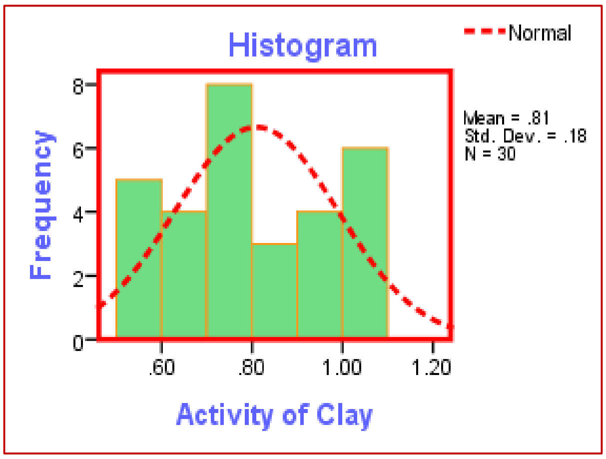








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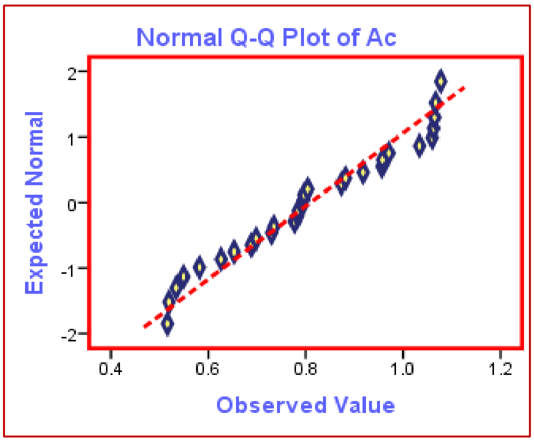
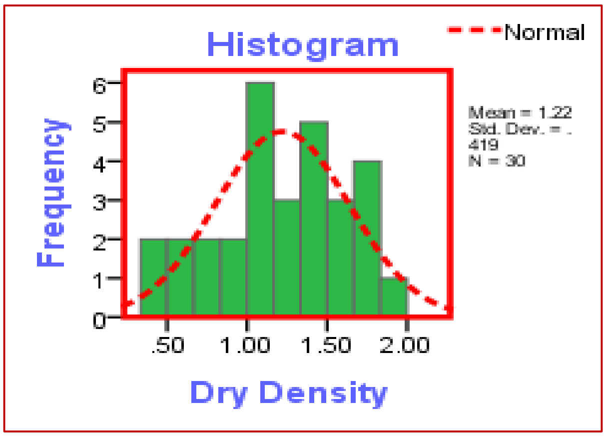
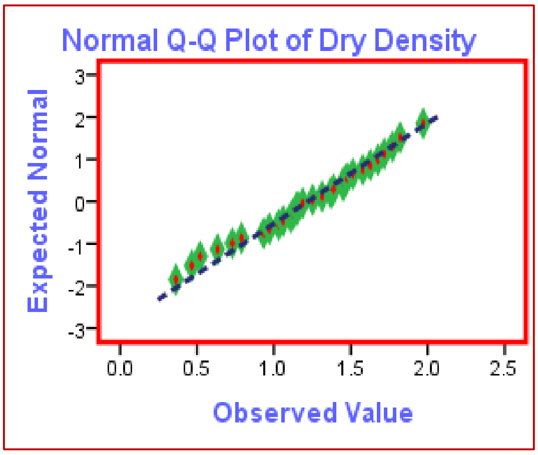
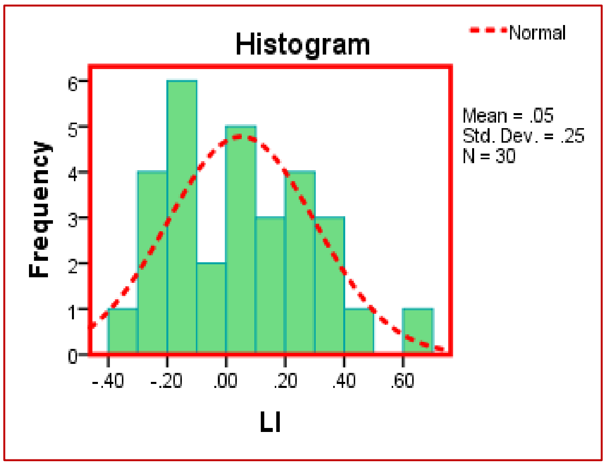
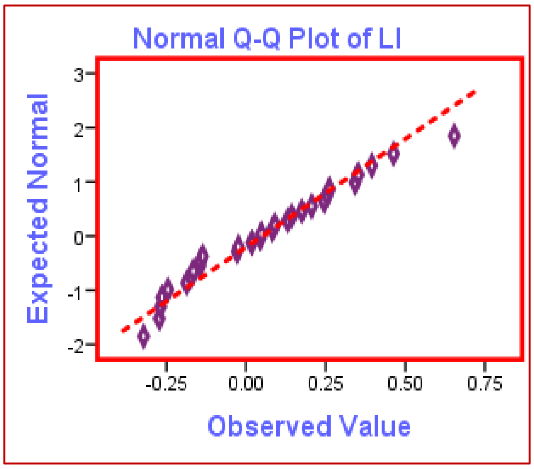
Std. Dev. = .18
N = 30
Frequency
Activity of Clay

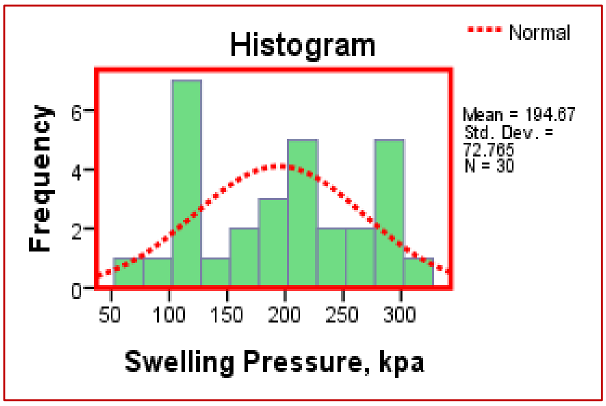

Normal Q-Q Plot of Ac
Expected Normal
Observed Value

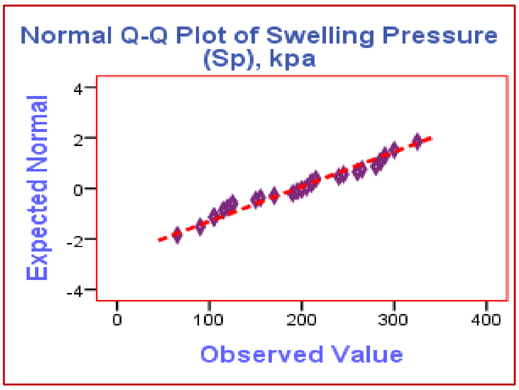

Histogram
Normal
Mean = 1.22
Std. Dev. = .419
N = 30
Frequency
Dry Density


Normal Q-Q Plot of Dry Density
Expected Normal
Observed Value


Histogram
Normal
Mean = .05
Std. Dev. = .25
N = 30
Frequency
LI


Normal Q-Q Plot of LI
Expected Normal
Observed Value


Histogram
Normal
Mean = 194.67
Std. Dev. = 72.765
N = 30
Frequency
Swelling Pressure, kpa


Normal Q-Q Plot of Swelling Pressure (Sp), kpa
Expected Normal
Observed Value

APPENDIX F: SPSS 20 Output of Correlation Analysis

Descriptive Statistics

	Mean	Std. Deviation	N
LL	87.2536	16.46916	30
PI	51.9016	12.76625	30
LS	9.5738	1.47349	30
NMC	35.2810	8.04943	30
γd	1.2198	.41909	30
Ac	.8097	.17967	30
LI	.0510	.25030	30
Swelling Pressure (Sp), kpa	194.67	72.765	30

Correlations

		LL	PI	LS	NMC	Dd	Ac	LI	Swelling Pressure (Sp), kpa
LL	Pearson Correlation	1	.977**	.920**	-.823**	-.947**	.968**	-.898**	.859**
	Sig. (2-tailed)		.000	.000	.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
PI	Pearson Correlation	.977**	1	.865**	-.822**	-.930**	.981**	-.880**	.857**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
LS	Pearson Correlation	.920**	.865**	1	-.740**	-.868**	.845**	-.822**	.826**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
NMC	Pearson Correlation	-.823**	-.822**	-.740**	1	.846**	-.765**	.959**	-.861**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000
	N	30	30	30	30	30	30	30	30
γ_d	Pearson Correlation	-.947**	-.930**	-.868**	.846**	1	-.883**	.889**	-.911**
	Sig. (2-tailed)	.000	.000	.000	.000		.000	.000	.000
	N	30	30	30	30	30	30	30	30
Ac	Pearson Correlation	.968**	.981**	.845**	-.765**	-.883**	1	-.842**	.791**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.000
	N	30	30	30	30	30	30	30	30
LI	Pearson Correlation	-.898**	-.880**	-.822**	.959**	.889**	-.842**	1	-.871**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000		.000
	N	30	30	30	30	30	30	30	30
Swelling Pressure (Sp), kpa	Pearson Correlation	.859**	.857**	.826**	-.861**	-.911**	.791**	-.871**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	
	N	30	30	30	30	30	30	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

APPENDIX G: Representative SPSS 20 output of developed Regression Analysis

MODEL 1: REGRESSION ANALYSIS OUTPUT

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	NMC, γ_d [b]	.	Enter
a. Dependent Variable: Swelling Pressure (Sp), kpa			
b. All requested variables entered.			

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.926[a]	.858	.847	28.436	.858	81.449	2	27	.000	1.833
a. Predictors: (Constant), NMC, Dd										
b. Dependent Variable: Swelling Pressure (Sp), kpa										

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	131715.069	2	65857.535	81.449	.000[b]
	Residual	21831.597	27	808.578		
	Total	153546.667	29			
a. Dependent Variable: Swelling Pressure (Sp), kpa						
b. Predictors: (Constant), NMC, γ_d						

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	431.920	25.000		17.277	.000	380.625	483.215		
	γ_d	-111.420	23.631	-.642	-4.715	.000	-159.907	-62.933	.284	3.518
	NMC	-2.873	1.230	-.318	-2.335	.027	-5.397	-.348	.284	3.518
a. Dependent Variable: Swelling Pressure (Sp), kpa										

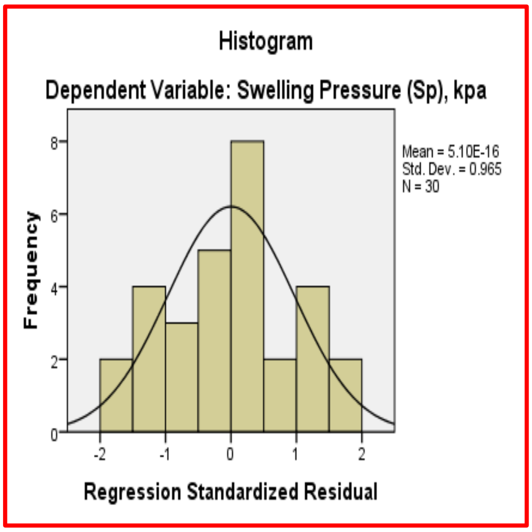
Coefficient Correlations[a]

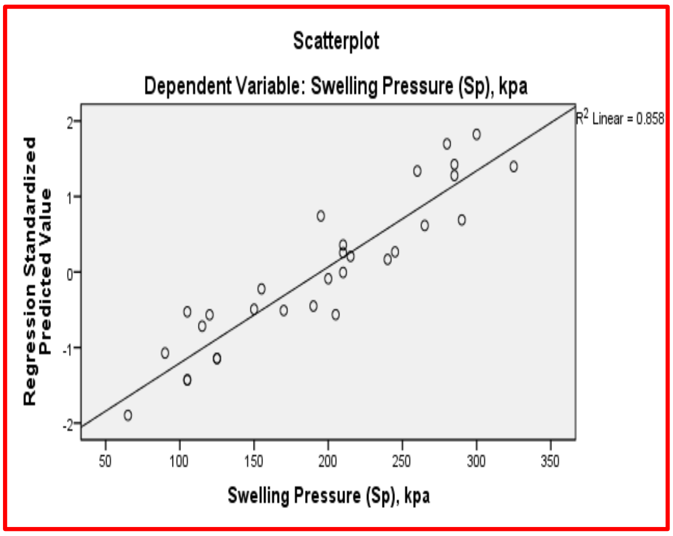
Model			NMC	Dd
1	Correlations	NMC	1.000	-.846
		γ_d	-.846	1.000
	Covariance's	NMC	1.514	-24.596
		γ_d	-24.596	558.419
a. Dependent Variable: Swelling Pressure (Sp), kpa				

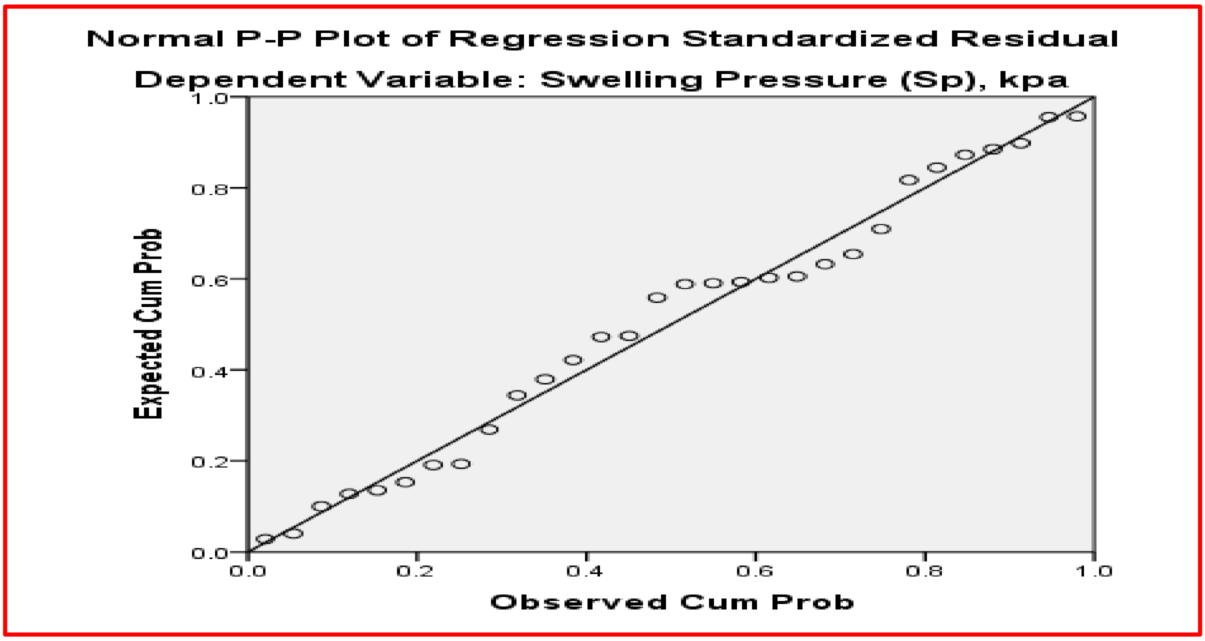
Collinearity Diagnostics[a]

Model	Dimension	Eigen value	Condition Index	Variance Proportions		
				(Constant)	Dd	NMC
1	1	2.938	1.000	.00	.00	.00
	2	.053	7.440	.45	.24	.00
	3	.009	18.121	.54	.76	1.00
a. Dependent Variable: Swelling Pressure (Sp), kpa						

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	66.81	317.52	194.67	67.394	30
Std. Predicted Value	-1.897	1.823	.000	1.000	30
Standard Error of Predicted Value	5.431	13.395	8.706	2.287	30
Adjusted Predicted Value	67.16	322.27	195.05	67.813	30
Residual	-54.195	48.845	.000	27.437	30
Std. Residual	-1.906	1.718	.000	.965	30
Stud. Residual	-2.080	1.762	-.006	1.011	30
Deleted Residual	-64.558	51.879	-.379	30.180	30
Stud. Deleted Residual	-2.228	1.838	-.009	1.039	30
Mahal. Distance	.091	5.468	1.933	1.513	30
Cook's Distance	.000	.276	.033	.053	30
Centered Leverage Value	.003	.189	.067	.052	30
a. Dependent Variable: Swelling Pressure (Sp), kpa					







MODEL 2: REGRESSION ANALYSIS OUTPUT

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
2	NMC, LS, γ_d [b]	.	Enter
a. Dependent Variable: Swelling Pressure (Sp), kpa			
b. All requested variables entered.			

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
2	.929[a]	.862	.846	28.517	.862	54.271	3	26	.000	1.914
a. Predictors: (Constant), NMC, LS, γd										
b. Dependent Variable: Swelling Pressure (Sp), kpa										

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	132403.030	3	44134.343	54.271	.000[b]
	Residual	21143.637	26	813.217		
	Total	153546.667	29			
a. Dependent Variable: Swelling Pressure (Sp), kpa						
b. Predictors: (Constant), NMC, LS, γd						

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	342.925	99.954		3.431	.002	137.468	548.383		
	γd	-91.456	32.137	-.527	-2.846	.009	-157.514	-25.398	.155	6.468
	LS	6.665	7.247	.135	.920	.366	-8.230	21.561	.246	4.066
	NMC	-2.849	1.234	-.315	-2.309	.029	-5.386	-.312	.284	3.519
a. Dependent Variable: Swelling Pressure (Sp), kpa										

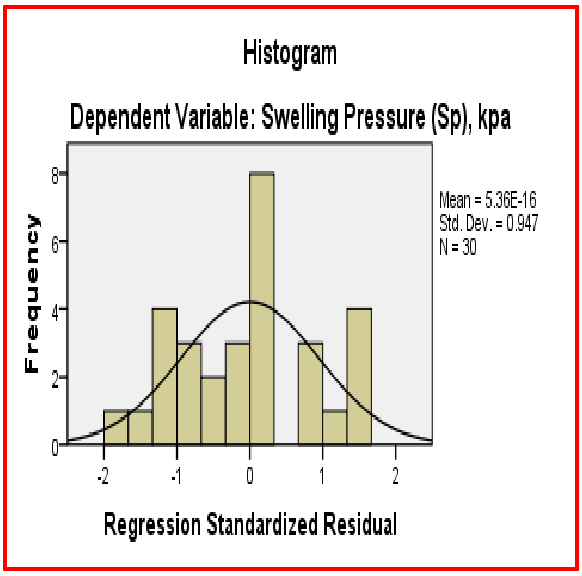
Coefficient Correlations[a]

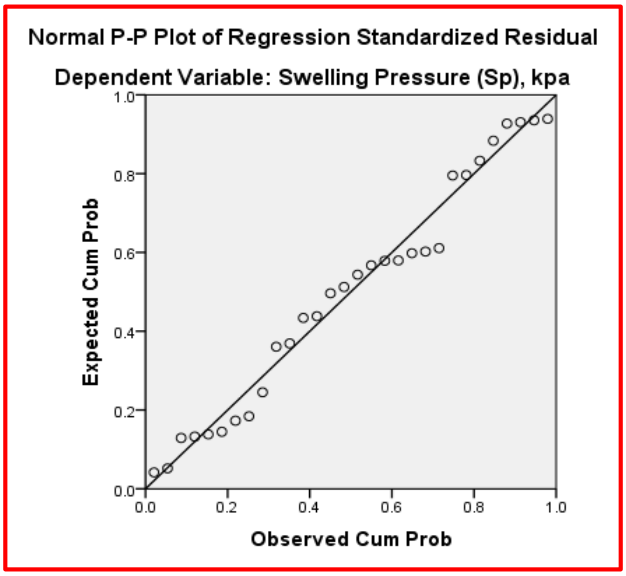
Model			NMC	LS	γd
1	Correlations	NMC	1.000	.021	-.610
		LS	.021	1.000	.675
		Dd	-.610	.675	1.000
	Covariance's	NMC	1.523	.186	-24.180
		LS	.186	52.512	157.292
		Dd	-24.180	157.292	1032.768
a. Dependent Variable: Swelling Pressure (Sp), kpa					

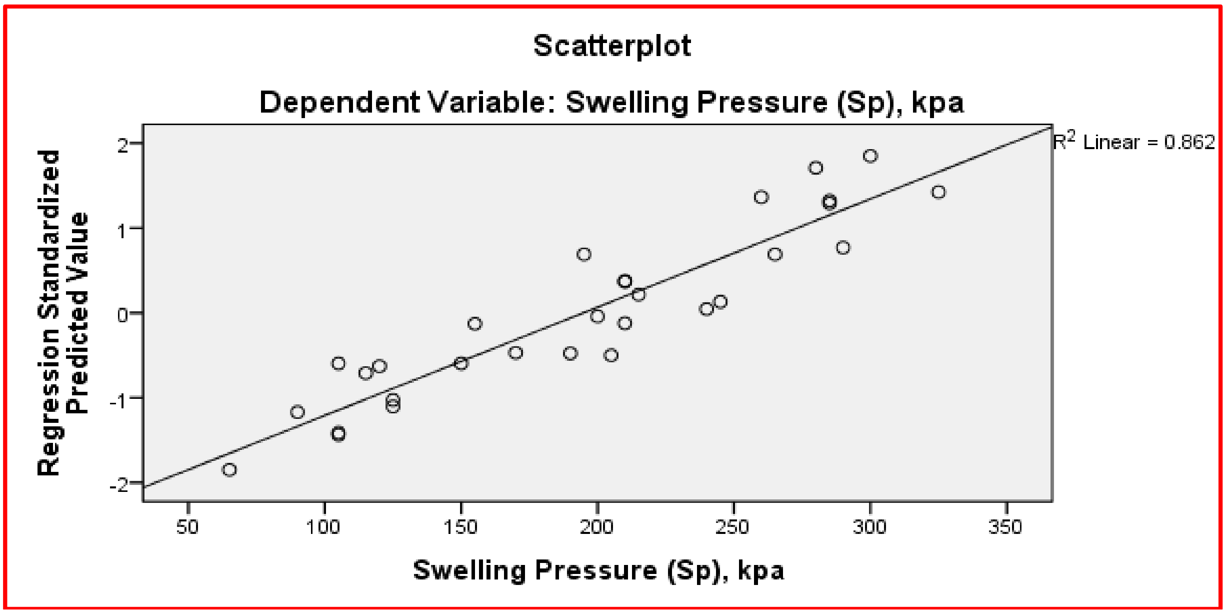
Collinearity Diagnostics[a]

Model	Dimension	Eigen value	Condition Index	Variance Proportions			
				(Constant)	γd	LS	NMC
1	1	3.866	1.000	.00	.00	.00	.00
	2	.123	5.607	.00	.05	.02	.01
	3	.009	20.494	.01	.51	.01	.98
	4	.002	46.934	.99	.44	.97	.01
a. Dependent Variable: Swelling Pressure (Sp), kpa							

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	69.76	319.69	194.67	67.569	30
Std. Predicted Value	-1.849	1.850	.000	1.000	30
Standard Error of Predicted Value	6.424	13.943	10.229	1.984	30
Adjusted Predicted Value	70.77	325.26	194.74	67.801	30
Residual	-49.397	44.106	.000	27.002	30
Std. Residual	-1.732	1.547	.000	.947	30
Stud. Residual	-1.929	1.625	-.001	1.014	30
Deleted Residual	-61.285	49.710	-.074	31.000	30
Stud. Deleted Residual	-2.044	1.682	-.001	1.038	30
Mahal. Distance	.505	5.966	2.900	1.440	30
Cook's Distance	.000	.224	.037	.048	30
Centered Leverage Value	.017	.206	.100	.050	30
a. Dependent Variable: Swelling Pressure (Sp), kpa					







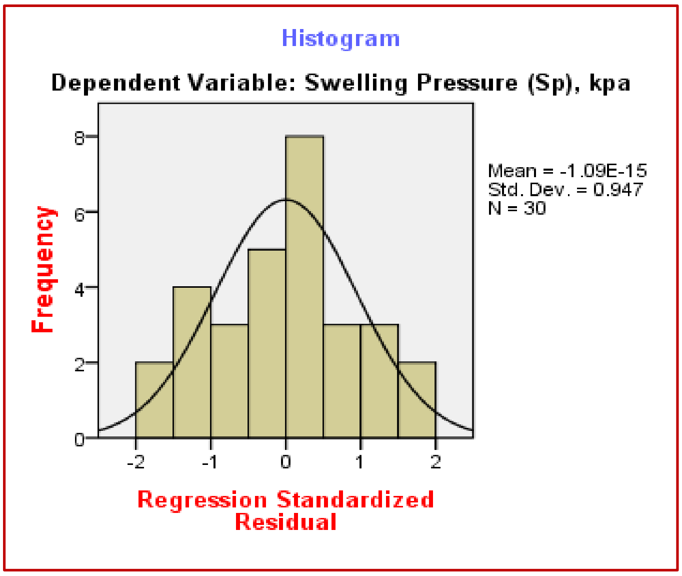
MODEL 3: REGRESSION ANALYSIS OUTPUT

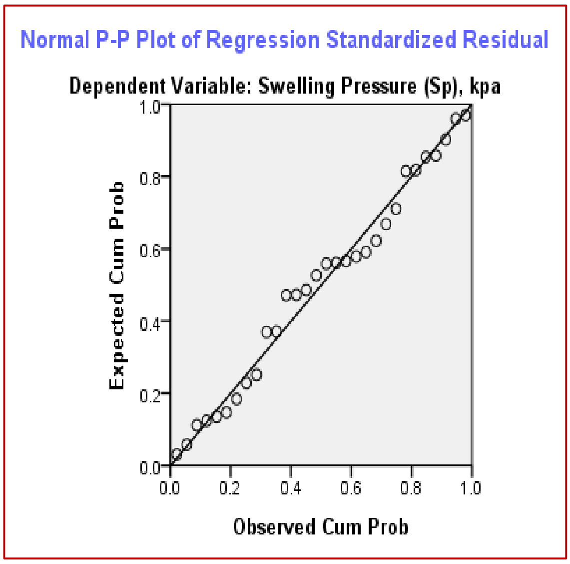
Model Summary[b]										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
3	.927[a]	.860	.843	28.803	.860	53.028	3	26	.000	1.727
a. Predictors: (Constant), Ac, NMC, γd										
b. Dependent Variable: Swelling Pressure (Sp), kpa										

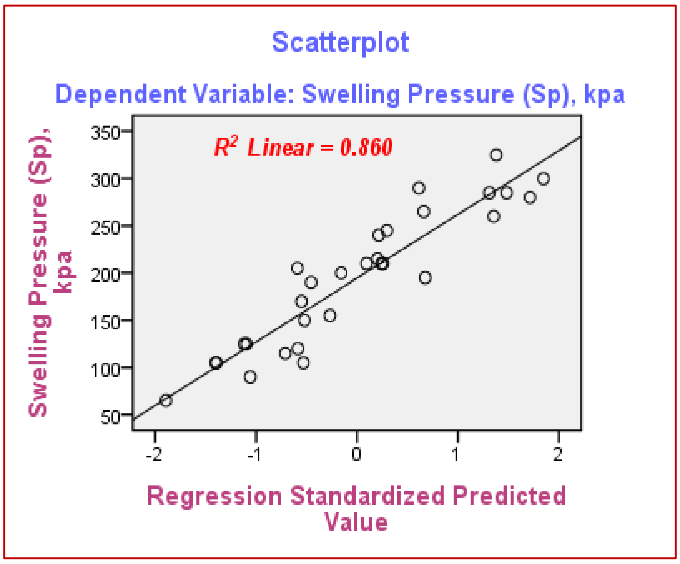
ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
3	Regression	131976.755	3	43992.252	53.028	.000[b]
	Residual	21569.912	26	829.612		
	Total	153546.667	29			
a. Dependent Variable: Swelling Pressure (Sp), kpa						
b. Predictors: (Constant), Ac, NMC, Dd						

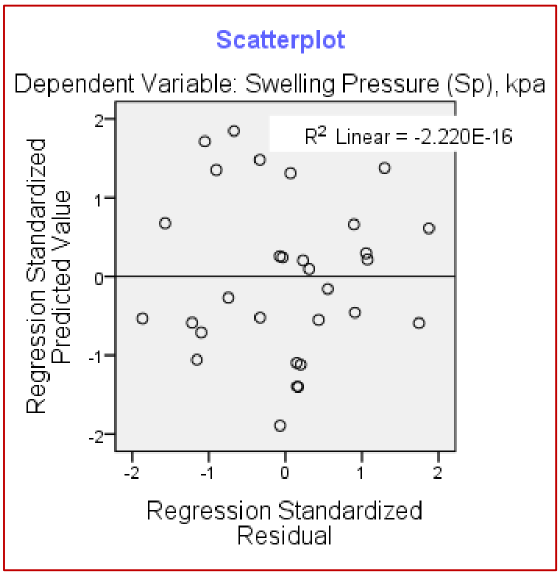
Coefficients[a]										
Model 3		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
3	Constant	478.171	86.156		5.550	.000	301.074	655.268		
	NMC	-2.924	1.250	-.323	-2.340	.027	-5.492	-.355	.283	3.536
	γd	-124.125	32.935	-.715	-3.769	.001	-191.823	-56.427	.150	6.659
	Ac	-35.751	63.655	-.088	-.562	.579	-166.596	95.094	.219	4.573
a. Dependent Variable: Swelling Pressure (Sp), kpa										

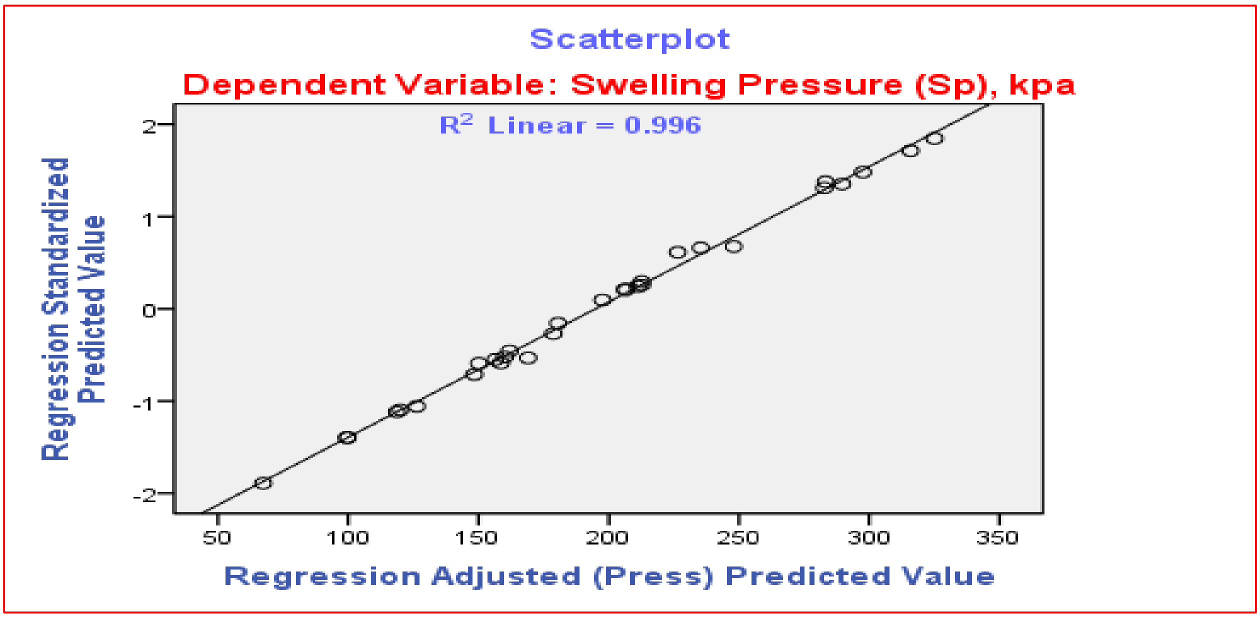
Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	66.98	319.32	194.67	67.461	30
Std. Predicted Value	-1.893	1.848	.000	1.000	30
Standard Error of Predicted Value	5.760	15.306	10.238	2.448	30
Adjusted Predicted Value	67.36	324.96	194.85	68.004	30
Residual	-53.706	53.984	.000	27.273	30
Std. Residual	-1.865	1.874	.000	.947	30
Stud. Residual	-2.036	2.034	-.003	1.010	30
Deleted Residual	-64.044	63.564	-.182	31.078	30
Stud. Deleted Residual	-2.178	2.175	-.003	1.042	30
Mahal. Distance	.193	7.222	2.900	1.794	30
Cook's Distance	.000	.200	.035	.051	30
Centered Leverage Value	.007	.249	.100	.062	30
a. Dependent Variable: Swelling Pressure (Sp), kpa					


Histogram
Dependent Variable: Swelling Pressure (Sp), kpa
Frequency
Mean = -1.09E-15
Std. Dev. = 0.947
N = 30
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Swelling Pressure (Sp), kpa
Expected Cum Prob
Observed Cum Prob


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R2 Linear = 0.860
Swelling Pressure (Sp), kpa
Regression Standardized Predicted Value


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R2 Linear = -2.220E-16
Regression Standardized Predicted Value
Regression Standardized Residual


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R2 Linear = 0.996
Regression Standardized Predicted Value
Regression Adjusted (Press) Predicted Value

MODEL 4: REGRESSION ANALYSIS OUTPUT

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
4	.927[a]	.859	.842	28.890	.859	52.658	3	26	.000	1.773

a. Predictors: (Constant), LL, NMC, γd

b. Dependent Variable: Swelling Pressure (Sp), kpa

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
4	Regression	131846.932	3	43948.977	52.658	.000[b]
	Residual	21699.735	26	834.605		
	Total	153546.667	29			

a. Dependent Variable: Swelling Pressure (Sp), kpa

b. Predictors: (Constant), LL, NMC, Dd

Coefficients[a]

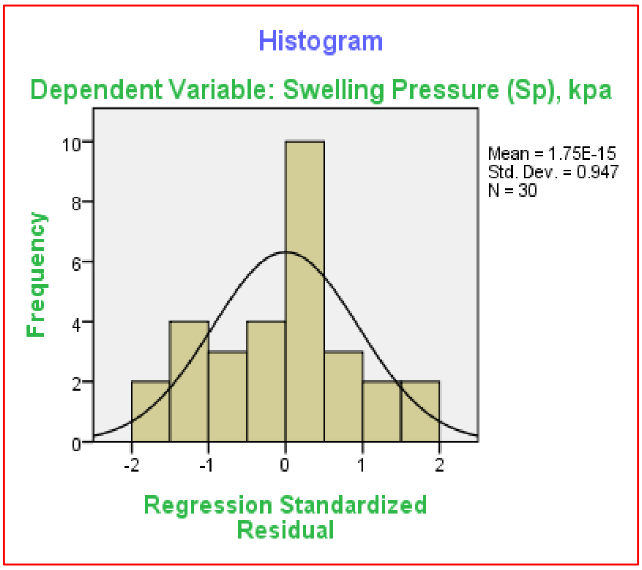
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
4	Constant	486.564	139.800		3.480	.002	199.202	773.926		
	NMC	-2.936	1.260	-.325	-2.330	.028	-5.526	-.346	.280	3.575
	Dd	-125.444	42.675	-.722	-2.940	.007	-213.162	-37.725	.090	11.114
	LL	-.405	1.018	-.092	-.397	.694	-2.497	1.688	.102	9.767

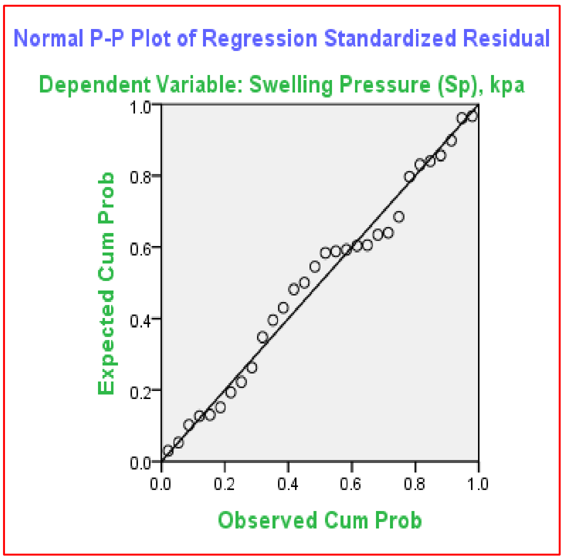
a. Dependent Variable: Swelling Pressure (Sp), kpa

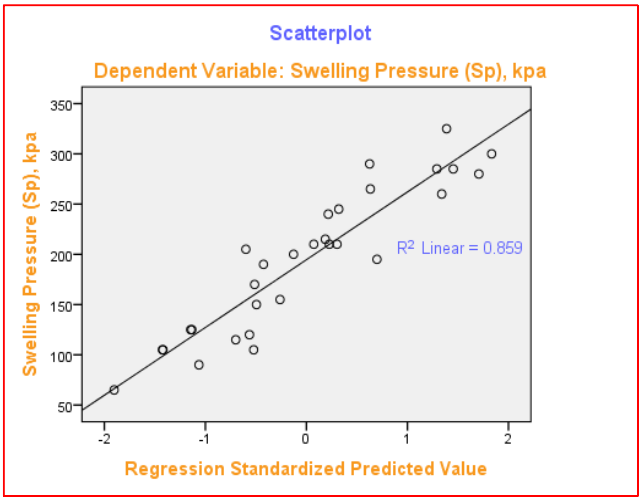
Residuals Statistics[a]

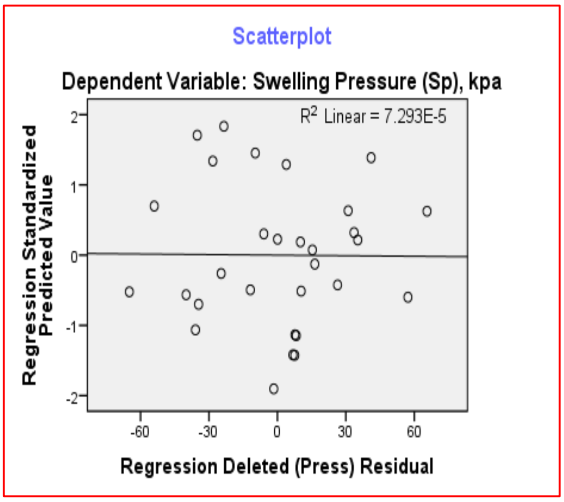
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	66.34	318.34	194.67	67.427	30
Std. Predicted Value	-1.903	1.834	.000	1.000	30
Standard Error of Predicted Value	6.183	16.412	10.304	2.300	30
Adjusted Predicted Value	66.60	323.48	194.46	67.844	30
Residual	-54.468	53.141	.000	27.354	30
Std. Residual	-1.885	1.839	.000	.947	30
Stud. Residual	-2.058	2.043	.003	1.017	30
Deleted Residual	-64.926	65.583	.210	31.593	30
Stud. Deleted Residual	-2.206	2.187	.003	1.051	30
Mahal. Distance	.362	8.393	2.900	1.739	30
Cook's Distance	.000	.244	.039	.059	30
Centered Leverage Value	.012	.289	.100	.060	30

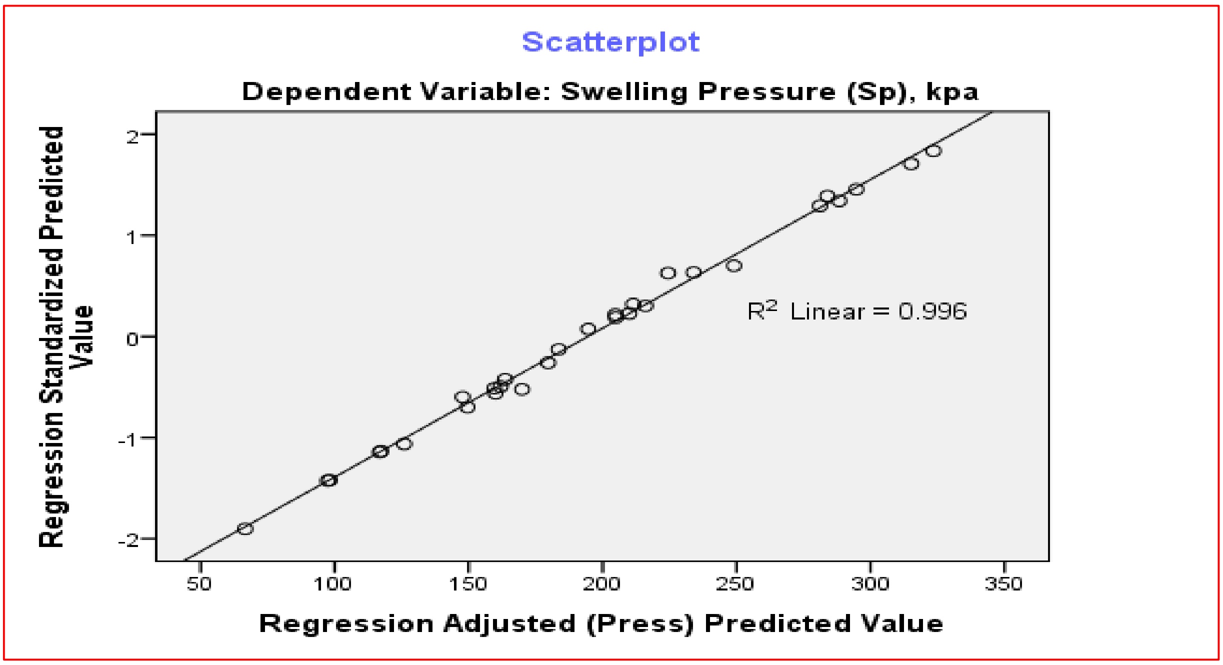
a. Dependent Variable: Swelling Pressure (Sp), kpa


Histogram
Dependent Variable: Swelling Pressure (Sp), kpa
Mean = 1.75E-15
Std. Dev. = 0.947
N = 30
Frequency
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Swelling Pressure (Sp), kpa
Expected Cum Prob
Observed Cum Prob


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R² Linear = 0.859
Swelling Pressure (Sp), kpa
Regression Standardized Predicted Value


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R² Linear = 7.293E-5
Regression Standardized Predicted Value
Regression Deleted (Press) Residual


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R² Linear = 0.996
Regression Standardized Predicted Value
Regression Adjusted (Press) Predicted Value

MODEL 6: REGRESSION ANALYSIS OUTPUT

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
6	.932[a]	.869	.848	28.403	.869	41.334	4	25	.000	1.710

a. Predictors: (Constant), Ac, NMC, γd, PI
b. Dependent Variable: Swelling Pressure (Sp), kpa

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
6	Regression	133378.757	4	33344.689	41.334	.000[b]
	Residual	20167.910	25	806.716		
	Total	153546.667	29			

a. Dependent Variable: Swelling Pressure (Sp), kpa
b. Predictors: (Constant), Ac, NMC, γd, PI

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
6	(Constant)	381.831	112.065		3.407	.002	151.028	612.634		
	NMC	-2.406	1.293	-.266	-1.860	.075	-5.070	.257	.257	3.896
	γd	-95.564	39.040	-.550	-2.448	.022	-175.969	-15.159	.104	9.623
	PI	4.134	3.136	.725	1.318	.199	-2.325	10.593	.017	57.619
	Ac	-247.366	172.358	-.611	-1.435	.164	-602.345	107.612	.029	34.475

a. Dependent Variable: Swelling Pressure (Sp), kpa

Collinearity Diagnostics[a]

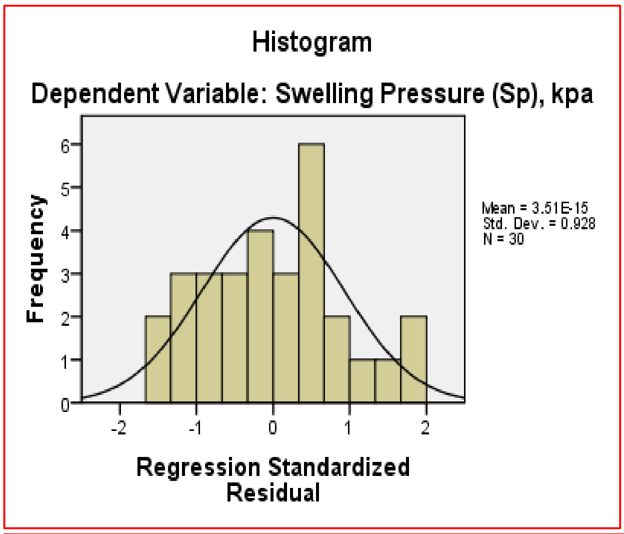
Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	NMC	γd	PI	Ac
6	1	4.759	1.000	.00	.00	.00	.00	.00
	2	.229	4.562	.00	.01	.02	.00	.00
	3	.009	22.620	.00	.85	.38	.00	.00
	4	.003	43.226	.56	.03	.30	.00	.13
	5	.001	96.063	.43	.11	.30	1.00	.87

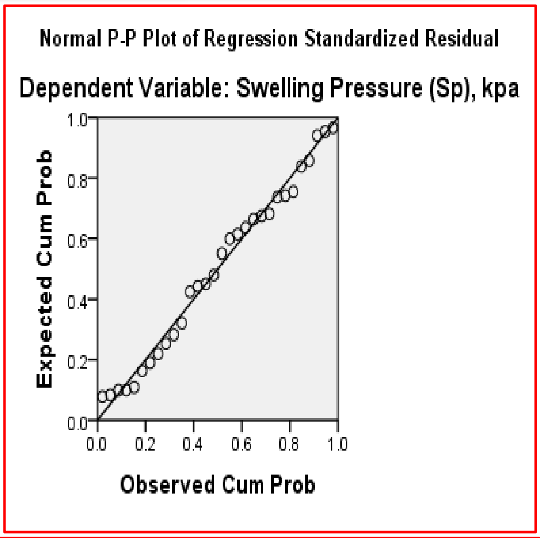
a. Dependent Variable: Swelling Pressure (Sp), kpa

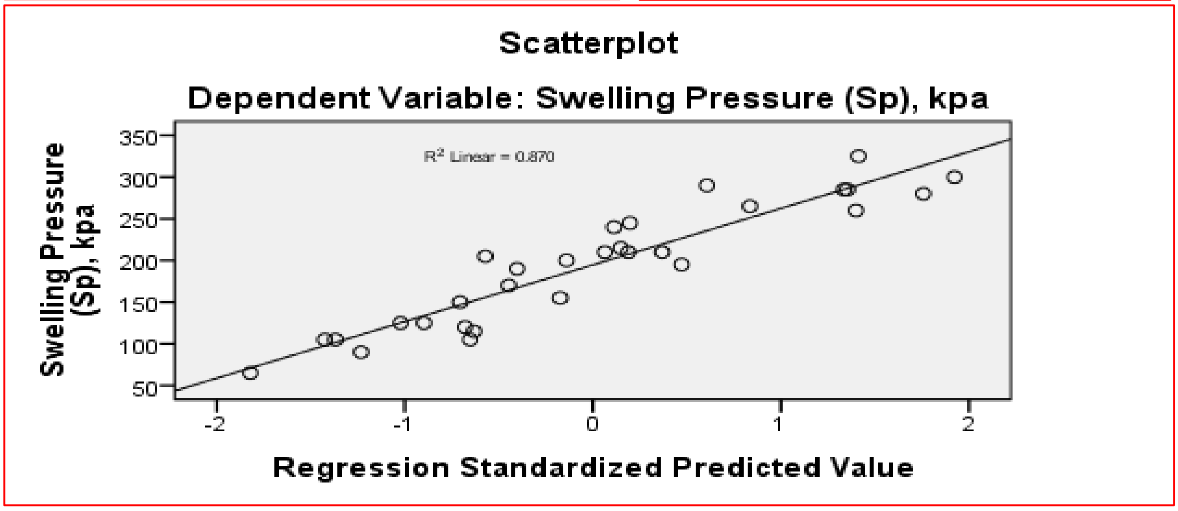
Residuals Statistics[a]

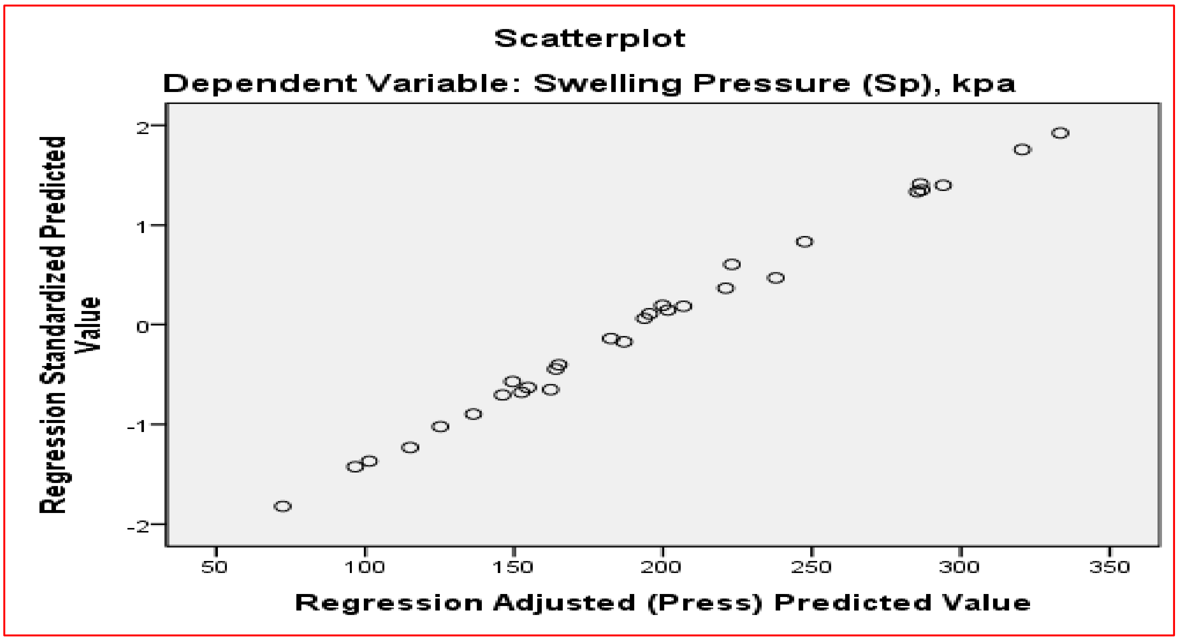
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	55.10	313.22	194.67	67.818	30
Std. Predicted Value	-2.058	1.748	.000	1.000	30
Standard Error of Predicted Value	6.683	17.385	11.263	2.802	30
Adjusted Predicted Value	51.54	317.69	195.24	68.367	30
Residual	-40.273	51.773	.000	26.371	30
Std. Residual	-1.418	1.823	.000	.928	30
Stud. Residual	-1.621	1.906	-.009	1.009	30
Deleted Residual	-58.233	58.054	-.577	31.315	30
Stud. Deleted Residual	-1.679	2.020	-.006	1.034	30
Mahal. Distance	.639	9.898	3.867	2.358	30
Cook's Distance	.000	.315	.038	.062	30
Centered Leverage Value	.022	.341	.133	.081	30

a. Dependent Variable: Swelling Pressure (Sp), kpa


Histogram
Dependent Variable: Swelling Pressure (Sp), kpa
Frequency
Mean = 3.51E-15
Std. Dev. = 0.928
N = 30
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Swelling Pressure (Sp), kpa
Expected Cum Prob
Observed Cum Prob


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R² Linear = 0.870
Swelling Pressure (Sp), kpa
Regression Standardized Predicted Value


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
Regression Standardized Predicted Value
Regression Adjusted (Press) Predicted Value

MODEL 7: REGRESSION ANALYSIS OUTPUT

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
7	.932[a]	.869	.848	28.403	.869	41.334	4	25	.000	1.710

a. Predictors: (Constant), PI, NMC, γd, Ac

b. Dependent Variable: Swelling Pressure (Sp), kpa

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
7	Regression	133378.757	4	33344.689	41.334	.000[b]
	Residual	20167.910	25	806.716		
	Total	153546.667	29			

a. Dependent Variable: Swelling Pressure (Sp), kpa

b. Predictors: (Constant), PI, NMC, γd, Ac

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
7	(Constant)	381.831	112.065		3.407	.002	151.028	612.634		
	Dd	-95.564	39.040	-.550	-2.448	.022	-175.969	-15.159	.104	9.623
	NMC	-2.406	1.293	-.266	-1.860	.075	-5.070	.257	.257	3.896
	Ac	-247.366	172.358	-.611	-1.435	.164	-602.345	107.612	.029	34.475
	PI	4.134	3.136	.725	1.318	.199	-2.325	10.593	.017	57.619

Coefficient Correlations[a]

Model			PI	NMC	γd	Ac
1	Correlations	PI	1.000	.304	.555	-.931
		NMC	.304	1.000	-.278	-.257
		γd	.555	-.278	1.000	-.309
		Ac	-.931	-.257	-.309	1.000
	Covariance's	PI	9.835	1.232	67.943	-503.400
		NMC	1.232	1.673	-14.024	-57.393
		γd	67.943	-14.024	1524.143	-2077.493
		Ac	-503.400	-57.393	-2077.493	29707.376

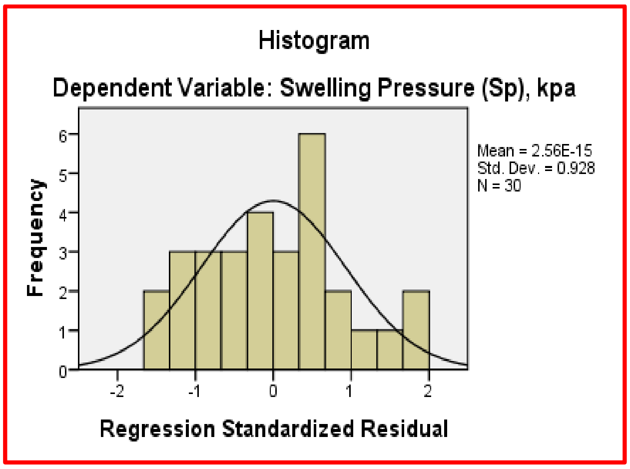
a. Dependent Variable: Swelling Pressure (Sp), kpa

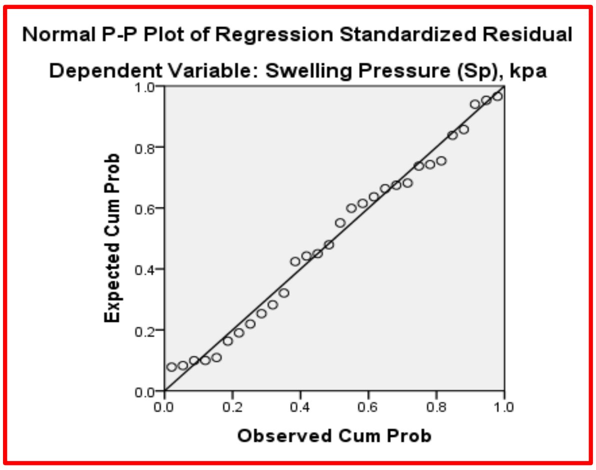
Collinearity Diagnostics[a]

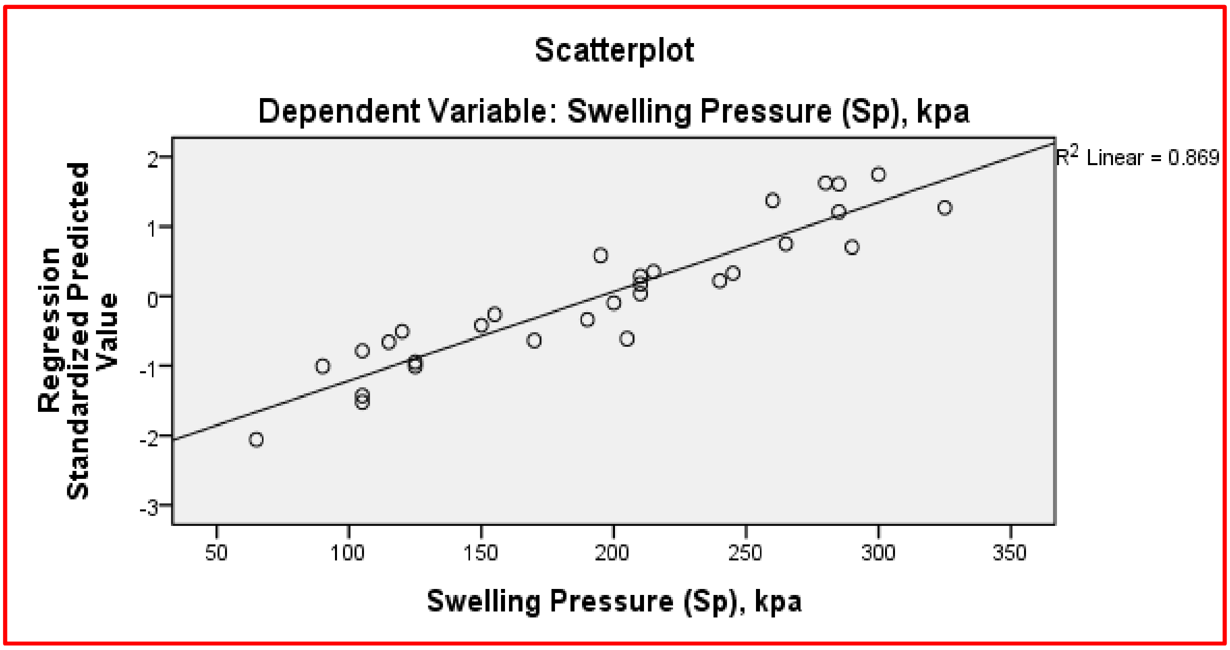
Model	Dimension	Eigen value	Condition Index	Variance Proportions				
				(Constant)	γd	NMC	Ac	PI
1	1	4.759	1.000	.00	.00	.00	.00	.00
	2	.229	4.562	.00	.02	.01	.00	.00
	3	.009	22.620	.00	.38	.85	.00	.00
	4	.003	43.226	.56	.30	.03	.13	.00
	5	.001	96.063	.43	.30	.11	.87	1.00

a. Dependent Variable: Swelling Pressure (Sp), kpa

Residuals Statistics[a]					
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	55.10	313.22	194.67	67.818	30
Std. Predicted Value	-2.058	1.748	.000	1.000	30
Standard Error of Predicted Value	6.683	17.385	11.263	2.802	30
Adjusted Predicted Value	51.54	317.69	195.24	68.367	30
Residual	-40.273	51.773	.000	26.371	30
Std. Residual	-1.418	1.823	.000	.928	30
Stud. Residual	-1.621	1.906	-.009	1.009	30
Deleted Residual	-58.233	58.054	-.577	31.315	30
Stud. Deleted Residual	-1.679	2.020	-.006	1.034	30
Mahal. Distance	.639	9.898	3.867	2.358	30
Cook's Distance	.000	.315	.038	.062	30
Centered Leverage Value	.022	.341	.133	.081	30
a. Dependent Variable: Swelling Pressure (Sp), kpa					







MODEL 8: REGRESSION ANALYSIS OUTPUT

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
8	.931[a]	.867	.846	28.593	.867	40.704	4	25	.000	1.735

a. Predictors: (Constant), Ac, NMC, LS, γd

b. Dependent Variable: Swelling Pressure (Sp), kpa

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
8	Regression	133108.297	4	33277.074	40.704	.000[b]
	Residual	20438.369	25	817.535		
	Total	153546.667	29			

a. Dependent Variable: Swelling Pressure (Sp), kpa

b. Predictors: (Constant), Ac, NMC, LS, γd

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
8	(Constant)	391.346	112.967		3.464	.002	158.686	624.005		
	NMC	-2.930	1.240	-.324	-2.362	.026	-5.485	-.375	.283	3.536
	γd	-106.379	36.006	-.613	-2.955	.007	-180.535	-32.224	.124	8.077
	LS	9.078	7.716	.184	1.176	.250	-6.814	24.969	.218	4.585
	Ac	-62.329	67.107	-.154	-.929	.362	-200.539	75.880	.194	5.157

a. Dependent Variable: Swelling Pressure (Sp), kpa

Collinearity Diagnostics[a]

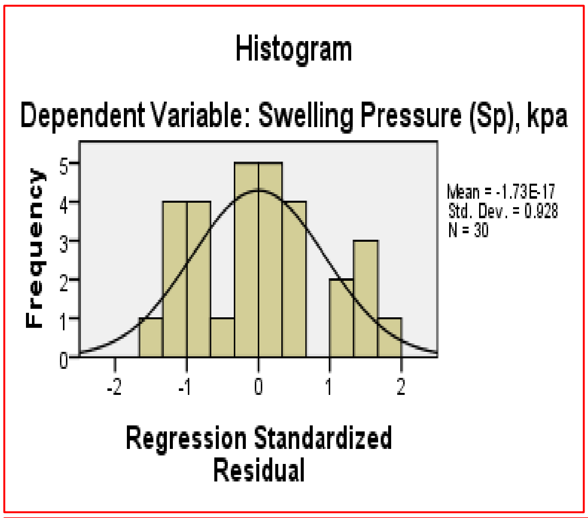
Model	Dimension	Eigenvalue	Condition Index	Variance Proportions				
				(Constant)	NMC	γd	LS	Ac
8	1	4.795	1.000	.00	.00	.00	.00	.00
	2	.189	5.031	.00	.01	.03	.00	.01
	3	.009	22.782	.01	.96	.43	.00	.00
	4	.005	30.764	.01	.01	.03	.45	.85
	5	.002	54.880	.98	.02	.51	.55	.13

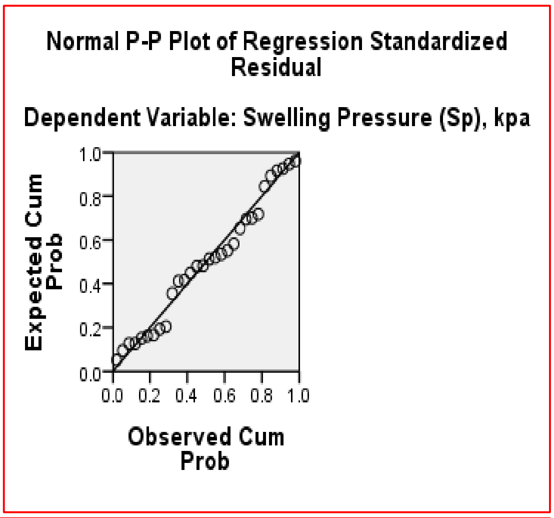
a. Dependent Variable: Swelling Pressure (Sp), kpa

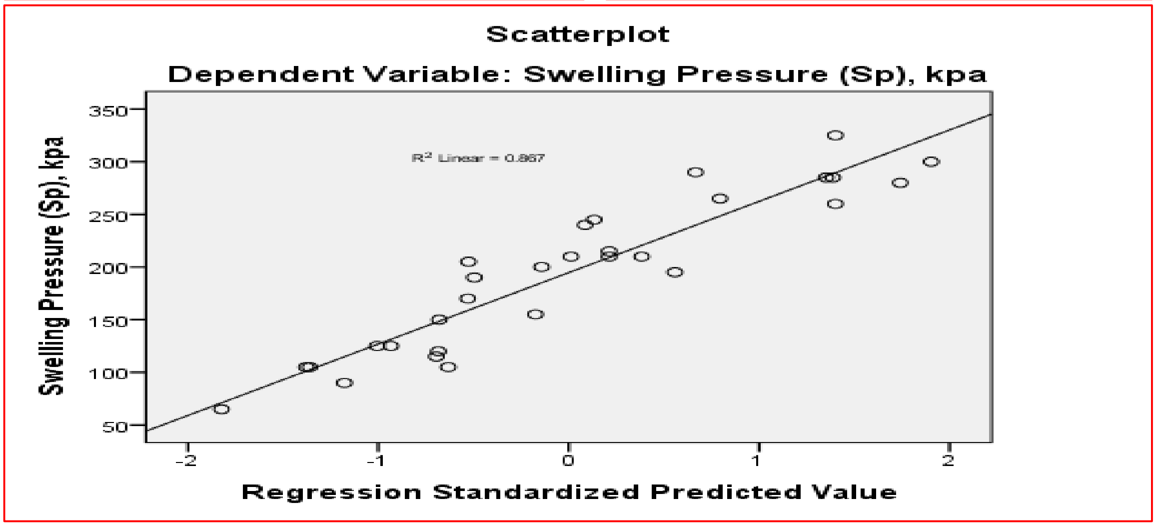
Residuals Statistics[a]

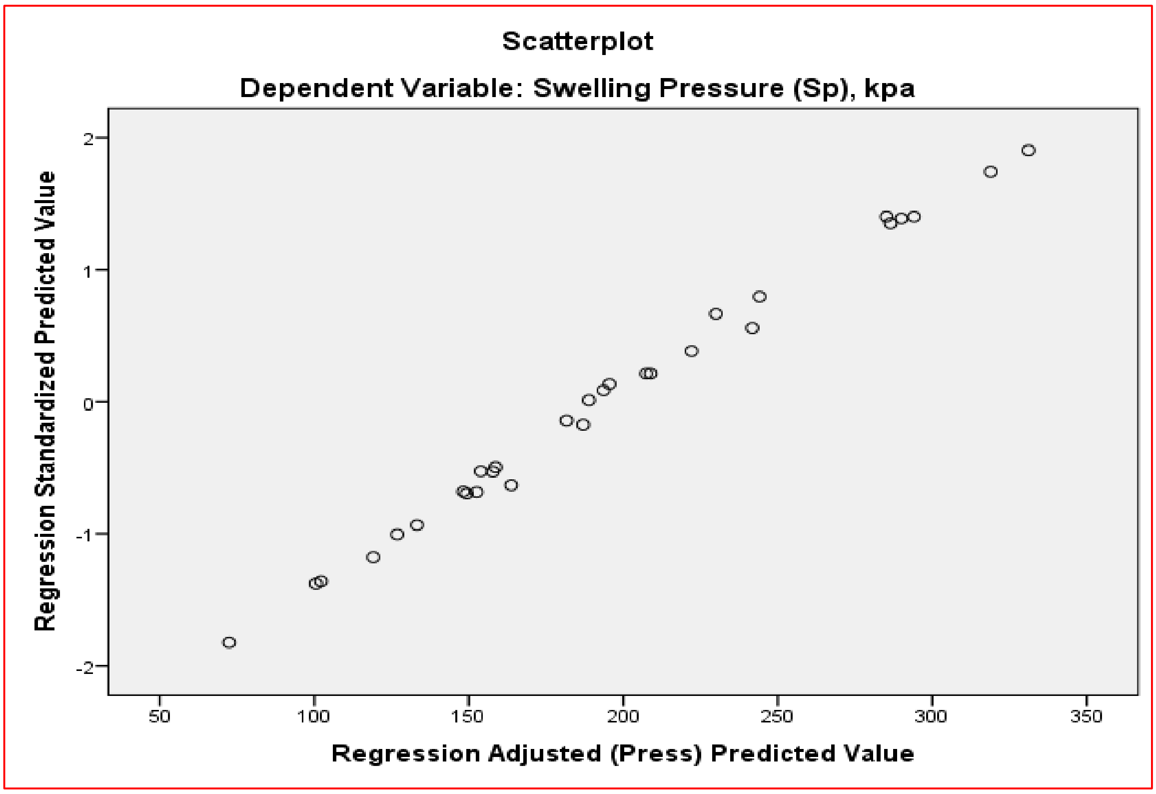
	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	71.12	323.62	194.67	67.749	30
Std. Predicted Value	-1.824	1.903	.000	1.000	30
Standard Error of Predicted Value	6.539	15.926	11.491	2.087	30
Adjusted Predicted Value	72.45	331.18	194.85	68.140	30
Residual	-46.806	50.226	.000	26.548	30
Std. Residual	-1.637	1.757	.000	.928	30
Stud. Residual	-1.834	1.920	-.003	1.008	30
Deleted Residual	-58.765	60.020	-.181	31.369	30
Stud. Deleted Residual	-1.932	2.038	.001	1.035	30
Mahal. Distance	.550	8.030	3.867	1.675	30
Cook's Distance	.000	.172	.036	.045	30
Centered Leverage Value	.019	.277	.133	.058	30

a. Dependent Variable: Swelling Pressure (Sp), kpa


Histogram
Dependent Variable: Swelling Pressure (Sp), kpa
Frequency
Mean = -1.73E-17
Std. Dev. = 0.928
N = 30
Regression Standardized Residual


Normal P-P Plot of Regression Standardized Residual
Dependent Variable: Swelling Pressure (Sp), kpa
Expected Cum Prob
Observed Cum Prob


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
R² Linear = 0.867
Swelling Pressure (Sp), kpa
Regression Standardized Predicted Value


Scatterplot
Dependent Variable: Swelling Pressure (Sp), kpa
Regression Standardized Predicted Value
Regression Adjusted (Press) Predicted Value

MODEL 9: REGRESSION ANALYSIS OUTPUT

Variables Entered/Removed[a]			
Model	Variables Entered	Variables Removed	Method
9	LS, NMC, Ac, γd, PI[b]	.	Enter
a. Dependent Variable: Swelling Pressure (Sp), kpa			
b. All requested variables entered.			

Model Summary[b]										
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
γd	.936[a]	.876	.850	28.177	.876	33.881	5	24	.000	1.814
a. Predictors: (Constant), LS, NMC, Ac, γd, PI										
b. Dependent Variable: Swelling Pressure (Sp), kpa										

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	134492.564	5	26898.513	33.881	.000[b]
	Residual	19054.103	24	793.921		
	Total	153546.667	29			
a. Dependent Variable: Swelling Pressure (Sp), kpa						
b. Predictors: (Constant), LS, NMC, Ac, γd, PI						

Coefficients[a]										
Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
		B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
1	(Constant)	296.295	132.569		2.235	.035	22.687	569.904		
	γd	-78.138	41.430	-.450	-1.886	.071	-163.645	7.369	.091	11.012
	NMC	-2.415	1.283	-.267	-1.883	.072	-5.063	.233	.257	3.896
	Ac	-272.399	172.287	-.673	-1.581	.127	-627.982	83.184	.029	35.002
	PI	4.108	3.111	.721	1.320	.199	-2.313	10.529	.017	57.621
	LS	9.007	7.604	.182	1.184	.248	-6.687	24.701	.218	4.586
a. Dependent Variable: Swelling Pressure (Sp), kpa										

Coefficient Correlations[a]							
Model			LS	NMC	Ac	γd	PI
1	Correlations	LS	1.000	-.006	-.123	.355	-.007
		NMC	-.006	1.000	-.255	-.262	.304
		Ac	-.123	-.255	1.000	-.330	-.923
		γd	.355	-.262	-.330	1.000	.516
		PI	-.007	.304	-.923	.516	1.000
	Covariance's	LS	57.822	-.059	-160.708	111.874	-.168
		NMC	-.059	1.646	-56.319	-13.916	1.212
		Ac	-160.708	-56.319	29682.848	-2355.479	-494.949
		γd	111.874	-13.916	-2355.479	1716.421	66.541
		PI	-.168	1.212	-494.949	66.541	9.679
a. Dependent Variable: Swelling Pressure (Sp), kpa							

Collinearity Diagnostics[a]									
Model	Dimension	Eigen value	Condition Index	Variance Proportions					
				(Constant)	γd	NMC	Ac	PI	LS
1	1	5.736	1.000	.00	.00	.00	.00	.00	.00
	2	.246	4.825	.00	.02	.01	.00	.00	.00
	3	.009	24.831	.00	.33	.85	.00	.00	.00
	4	.006	31.410	.01	.02	.03	.05	.01	.51
	5	.002	58.173	.55	.29	.01	.10	.03	.45
	6	.001	107.036	.44	.34	.11	.85	.96	.04

a. Dependent Variable: Swelling Pressure (Sp), kpa

Residuals Statistics[a]	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	59.28	317.52	194.67	68.100	30
Std. Predicted Value	-1.988	1.804	.000	1.000	30
Standard Error of Predicted Value	6.906	18.160	12.364	2.475	30
Adjusted Predicted Value	57.06	323.98	195.39	68.312	30
Residual	-35.841	47.537	.000	25.633	30
Std. Residual	-1.272	1.687	.000	.910	30
Stud. Residual	-1.378	1.780	-.011	1.003	30
Deleted Residual	-50.769	54.368	-.719	31.348	30
Stud. Deleted Residual	-1.405	1.870	-.004	1.025	30
Mahal. Distance	.775	11.080	4.833	2.307	30
Cook's Distance	.000	.225	.037	.046	30
Centered Leverage Value	.027	.382	.167	.080	30

a. Dependent Variable: Swelling Pressure (Sp), kpa