Relationship between compression index and index properties of expansive soils of Akaki Kality sub city

Selamyihun Assefa Ajemie

A Thesis Submitted to the Department of Civil Engineering, School of Civil Engineering and Architecture

Office of Graduate Studies
Adama Science and Technology University

September, 2023
Adama, Ethiopia

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Advisor: Argaw Asha (PhD.)

A Thesis Submitted to the Department of Civil Engineering,
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Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Civil Engineering
(Specialization in Geotechnical Engineering)

Office of Graduate Studies
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DECLARATION

I hereby declare that this Master thesis entitled **"Relationship between compression index and index properties of expansive soils of Akaki Kality sub city"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Selamyihun Assefa	______________________	24/09/2023
Name of student	Signature	Date

RECOMMENDATION

I/we, the advisor(s) of this thesis, hereby certify that I/we have read the revised version of the thesis entitled "**Relationship between compression index and index properties of expansive soils of Akaki Kality sub city**" prepared under my/our guidance by Selamyihun Assefa submitted in partial fulfillment of the requirements for the degree of Masters of Science in Civil Engineering. Therefore, I/we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Argaw Asha (Ph.D.)	__________________	24/09/2023
Major Advisor/Supervisor	Signature	Date
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APPROVAL PAGE

I/we, the advisors of the thesis entitled **"Relationship between compression index and index properties of expansive soils of Akaki Kality sub city**" and developed by Selamyihun Assefa, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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Co-advisor	Signature	Date

APPROVAL OF BOARD OF REVIEWERS

We, the undersigned, members of the Board of Examiners of the thesis by Selamyihun Assefa have read and evaluated the thesis entitled **"Relationship between compression index and index properties of expansive soils of Akaki Kality sub city**" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Civil Engineering.

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ABBREVIATIONS

ASTU	Adama Science and Technology University
AASTU	Addis Ababa Science and Technology University
AASHTO	American Association of State, Highway & Transport Official
ASTM	American Society for Testing Material
BS	British Standard
CEC	Cation Exchange Capacity
FSI	Free Swell Index
FSR	Free Swell Ratio
GI	Group Index
LS	Linear Shrinkage
LL	Liquid Limit
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
RMSE	Root Mean Square Error
SI	Shrinkage Index
SL	Shrinkage Limit
TP	Test Pit
T-O-T	Tetrahedron-Octahedron-Tetrahedron Bond
USCS	Unified Soil Classification System
ZAV	Zero Air Void

ACRONYMS

ϕ	Angle of Internal Friction
C_V	Coefficient of Consolidation
C_C	Coefficient of Curvature
Cu	Coefficient of Uniformity
R^2	Correlation Coefficient
Cc	Compression Index
γ_d	Dry Density
e_0	Initial Void Ratio
N	Number of Soil Samples
C_r	Swelling index
Su	Undrained Shear Strength
E	Void Ratio
V_K	Volume of Soil in Kerosene
V_W	Volume of Soil in Water
γ_w	Wet Density

ABSTRACT

*Determining the engineering properties of soil like compressibility parameters plays a significant role in forecasting settlement of overlaying structures on the earth crust when they rests on expansive soil mass. One dimensional consolidation test is one of the major tests that was required a long time and extra cost to conduct & used to know consolidation parameters like compression index of soils. In this study, correlations are developed to predict compression index (Cc) from index parameters so that one can be able to model Akaki Kality sub city soils with compression index using simple laboratory tests. Therefore, developing such correlation models are used to get required parameters with in short period of time in addition to laboratory cost minimization. Disturbed soil samples from sixteen different locations in Akaki Kality sub city were collected. Laboratory tests like specific gravity, grain size analysis, free swell index test, linear shrinkage, Atterberg limit, and one-dimensional consolidation test for a total of sixteen test samples were conducted. From one dimensional consolidation tests, compressibility parameters like Cc were determined. From the results of limited tests, an indicative good correlation is observed between Cc and OMC, MDD, LL, PL, and PI. The obtained correlation equation of compression index are Cc= 0.06*OMC-1.74, Cc= -2.05*MDD+3, Cc= 0.1*PL-3.07, Cc= 0.04*LL-3.31, Cc= 0.07*PI-3.11, Cc= 0.036*OMC-0.763*MDD-0.01, and Cc= 0.08*LL-0.066*PI-3.207 with* R^2 *and RMSE (0.942 & 0.164), (0.924 & 0.018), (0.963 & 0.098), (0.937 & 0.017), (0.823 & 0.085), (0.95 & 0.017), and (0.971 & 0.037) respectively. Based on value of* R^2 *and RMSE better correlation equation was obtained from linear regression between Cc & LL. However, a Poor correlation is developed between Cc and OMC which have higher RMSE of 0.164 when compared to the other models. The developed correlations will be important inputs in modeling Akaki Kality clay soils with regression model analysis using simple index tests. In addition, the results of this study can serve as a basis for further study of such correlations on different clay soils in the country. In this study, regression analysis was used to explore the significance of individual independent (index) soil properties. Regression model and correlation of compression index for optimum moisture content, maximum dry density, liquid limit, plastic limit, and plasticity index were obtained from the linear regression analysis. This correlation will be helpful for geotechnical engineers in developing the coefficient of compression (Cc) value of expansive/clay soil from index properties. Finally, based on the general findings of the study, suitable recommendations and best correlation model have been forwarded.*

Keywords: Atterberg Limits, Compression Index, Correlation, Maximum Dry Density, Optimum Moisture Content, Regression Model.

CHAPTER ONE

INTRODUCTION

1.1. Background

Determining the engineering properties of soil like compressibility parameters plays a significant role in forecasting settlement of overlaying structures on the earth crust when they rest on expansive soil mass. One dimensional consolidation test is one of the major tests used to know consolidation parameters of soil. Parameter like compression index which is used in determination of settlement magnitude was obtained from consolidation tests. But consolidation test process needs longer time & more budget to conduct and therefore, it is constructive if the value of the compression index can be interrelated with index properties such as liquid limit, plastic limit, and plasticity index. The correlations between the engineering and index properties of soils will reduce the workload of a soil investigation program in case of urgency (Akbarimehr *et al.*, 2021 ; Kabeta *et al*., 2022).

Professionals need extra skill and the ability to interpret application results with local conditions. Due to these factors, several attempts were made in the previous years to predict the compression index based on the properties of the soil index, which is rather convenient to decide and requires much less time in the laboratory. Soil index properties, which include Atterberg Limit values and moisture content, are physical soil properties. Therefore, the characteristics of this index are used to determine the soil compression index (Cc).

The objective of the research was to determine the relationship between the compression index (Cc) and the index properties of the soil. The compression tendencies of expansive soils are quantified by the compressibility parameters. Determination of compressibility of expansive soils, namely, recompression index and compression index (Cc), is important for the design of foundation (Kabeta *et al*., 2022).

A major concern of the foundation engineer is to predict the behavior of changes in the volume of soil stress when exposed to changes in a stressful environment. Geotechnical engineers practicing in such areas are involved in a better understanding of relationships between the physical and chemical properties of active clay. The soil is mostly selected fine-grained and clayey/silt inherited with compressibility. Selected samples have been checked for index and engineering properties. Numerical modeling is an approach or method that is used to estimate, correlate, model, and analyze the relationships between dependent and independent variables. This study focuses on the correlation between compression index and Atterberg limit & compaction parameters by using numerical modeling linear regression analysis approaches. Regression analysis uses extremely complicated equations to evaluate large datasets and interprets them into coordinates on a lines or curves.

1.2. Statement of the Problem

In most areas of our country, expansive soil causes cracks and defects on structural and non-structural members of building, highway, railway, dams, and underground structures constructed over it, which causes extra expense of maintenance and even loss of life. This may be due to insufficient soil exploration which arises from time consuming characteristics of some soil tests like one dimensional consolidation test. And also, such tests require much more budgets and skills to conduct and analyses. Therefore, the immediate way to obtain the result of such test with simple procedure is required. Hence, this study aims to correlate compression index with different index properties of Akaki Kality soils.

1.3. Objectives of the Study

1.3.1. General objective

The main objective of this study is to determine relationship between compression index and index properties of expansive soils of Akaki Kality sub city.

1.3.2. Specific objectives

The specific objectives of this study is to:

- Determine relationship between compression index (Cc) and optimum moisture content (OMC) of expansive soils.
- Determine relationship between compression index (Cc) and maximum dry density (MDD) of expansive soils.
- Investigate relationship between compression index (Cc) and liquid limit (LL) of expansive soils.
- Assess relationship between compression index (Cc) and plasticity index (PI) of expansive soils.
- Validate and compare developed equations with the existing calculated values and correlation approaches of the study.

1.4. Research Question

- What is the relationship between optimum moisture contents (OMC) and compression index (Cc) value of expansive soils?
- What is the relationship between maximum dry densities (MDD) and compression index (Cc) value of expansive soils?
- What is the relationship between liquid limits (LL) and compression index (Cc) value of expansive soils?
- What is the relationship between plasticity index (PI) and compression index (Cc) value of expansive soils?
- Which index property have more significant relationship with compression index of study area soils?

1.5. Scope of the Study

This research was compiled through by reviewing different literatures related to the area and performing a series of laboratory experiments on materials used for the study. It was aimed to investigate the relationship between compression index and index properties of expansive soils collected from Akaki Kality sub city. The laboratory tests conducted were specific gravity test, grain size analysis, standard compaction tests, Atterberg limit tests, and one-dimensional consolidation test. The standard method used for laboratory test was most commonly under control of ASTM standard. Finally, the result obtained through study have been fairly analyzed to correlate with each other and validated with previously obtained correlation equations via different scholars.

1.6. Significance of the Study

One dimensional consolidation test is one of the most complicated and time-consuming test that require high amount of cost to perform. The result obtained from consolidation test are mainly used to determine degree/ amount of settlements of civil structures rests on the soil mass. The parameters obtained from the test includes compression index, coefficient of volume compressibility, coefficient of consolidation, and initial void ratio which are the basic input to design and analyses every foundation in settlement forecasting. But the parameters obtained from such tests are not as such easy to obtain in short period of time and therefore correlating them with index properties, which are found through quick simple tests is the optional way. Again, when there is limited cost of new or existing site exploration the result obtained from this study result are used to determine compressibility properties of areal soil. And also, this study is going to be used as secondary source of information for the future related studies.

1.7. Structure of the Thesis

The thesis is divided into five chapters. The first chapter starts with introduction, and describes background, purpose, scope, limitation and significance of the study. The second chapter provides a brief literature review on sources and origin of expansive soils, methods of identification and classifications of expansive soils, consolidation parameters of expansive soil, and previously obtained related works on correlation between properties of expansive soils. The third chapter addresses the methods and the materials used for the investigation, as well as the laboratory testing protocols performed. The fourth chapter includes scientific analysis and discussion of the research findings, as well as a comparison and validation of obtained models with actual study outcomes. The fifth chapter summarizes the overall findings and recommendations that may be drawn from the current study effort.

CHAPTER TWO

LITERATURE REVIEW

2.1. Origin of Expansive Soil

The destructive process in the formation of soil from rock may be either through physical or chemical weathering. Physical process of soil formation is simply changing of rock particle size which is most commonly undergoes due to action of wind, water or glacier erosion and also cyclic action of freezing and thawing which creates cracks in rock mass. The resulting soil particles have the same mineralogical composition as that of the parent rock, but their particle size is too finer. But chemical processes result in changes in the mineral form of the parent rock due to the action of water, especially if it contains traces or drops of acid or alkali, oxygen and carbon dioxide. Chemical weathering results in the formation of groups of crystalline particles of colloidal size less than 0.002 mm, known as clay minerals. For example, the overall feldspar weathering process can be simplified as the alteration of sodium feldspar to common clay minerals, such as kaolinite *(*Yuan *et al.*, 2019).

$$2NaAlSi_3O_8 + 2H^+ + 9H_2O \rightarrow Al_2Si_2O_5(OH)_4(\text{kaolinite}) + 4H_2SiO_{4(aq)} + 2Na^+ \quad (1)$$

And also, potassium feldspar altered to kaolinite due to action of acidic rain as shown on chemical equation below.

$$2KAlSi_3O_8 + 2CO_2 + 11H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 4H_4SiO_{4(aq)} + 2K^+ + 2HCO_3{}^- \quad (2)$$

2.2. Properties of Expansive Soil

Expansive soil is clay such as montmorillonite or bentonite that is prone to expansion or shrinkage, directly related to seasonal variation in water content. Expansive soils swell when they exposed to large amounts of water and shrink when the water evaporates or when they get dry. This continuous cycle of wetting and drying of soil keeps the soil in perpetual motion, causing structures built on such soil to sink or rise unevenly, often requiring extra foundation repair. Expansive soils are composed primarily of minerals in incredibly fine particles with little or no organic material and are thus incredibly viscous, proving difficult to drain. Many soils that exhibit swelling and shrinking behavior contain expansive clay minerals, such as smectite, that absorb water, the more of this clay soil contains the higher its swell potential and the more water it can absorb. As a result, these materials swell, and thus increase in volume, when they get wet and shrink when they dry. The more water they absorb, the more their volume increases (Jones *et al*., 2012).

2.3. Clay Mineral Basic Unit

The properties that define the composition of clay minerals are derived from chemical compound present in clay minerals, symmetrical arrangement of atoms and ions and the forces that bind them together. The clay minerals are mainly known as the complex silicates of various cations such as aluminum, magnesium and iron. On the basis of the arrangement of these ions, basic crystalline units of the clay minerals are of two types (Neeraj & Mohan, 2021). These are:

2.3.1. Silicon-oxygen tetrahedron

It consists of a single central silicon atom surrounded by four oxygen atoms, with which the central atom bonds. The geometric figure drawn for this arrangement has four sides, with each side being an equilateral triangle. To visualize this, imagine a three-dimensional ball and stick model in which three oxygen atoms are holding up their central silicon atom, much like the three legs of a stool, with the fourth oxygen atom sticking straight up above the central atom. Then tetrahedron units were joined together in different configuration to form the tetrahedral silica sheet.

2.3.2. Aluminum or magnesium octahedron

Consists of a single aluminum or magnesium atom surrounded by six hydroxyl ions and combined to form gibbsite or brucite octahedron sheet, respectively. That means, if aluminum is the dominating atom in each connected unit, it becomes gibbsite sheet unless it becomes brucite sheet if magnesium is the dominating atom.

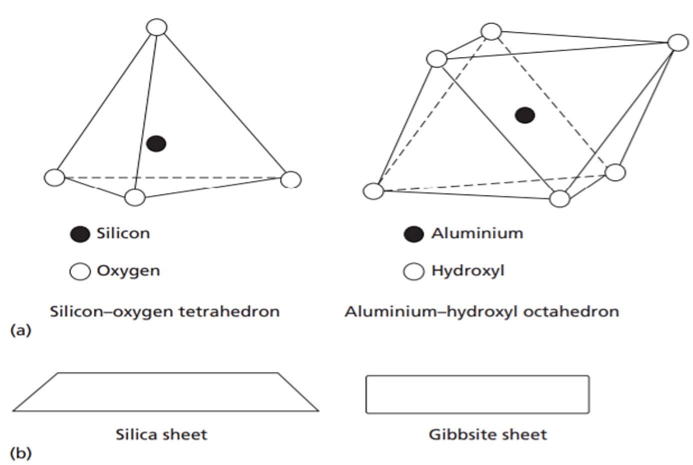

Figure 2-1: Clay minerals basic unit (Craig & Knappett, 2012)

2.4. Common Structures of Clay Mineral Groups

2.4.1. Kaolinite group

This group of clay minerals consist of single silica tetrahedral sheet & alumina octahedral sheet and its structure is often referred to as the 1:1 lattice type with typical basal spacing of about 7.2Å (Mitchell & Soga, 2005). They are derived from the weathering of either sodium or potassium feldspar under acidic water action and contain no exchangeable cations (Yuan *et al*., 2019).

The hydrogen bonding between the tetrahedral and octahedral layers is significant. This bonding holds the 1:1 layer tightly together leaving little or no interlayer space for absorption of water or cations, thus shrink & swell phenomenon is virtually non-existence (Dixon, 1989). There is high degree of regularity in the stacking of well crystallized kaolinite units, with crystal diameter ranging from 0.5-4μm and with specific surface area of 10-20 m²/g (Chen, 1975). The theoretical formula of kaolinite is given as $Al_4Si_4O_{10}(OH)_8$. It is the least active clay mineral with the lowest plasticity and lowest capacity for adsorbing cations among three clay mineral groups.

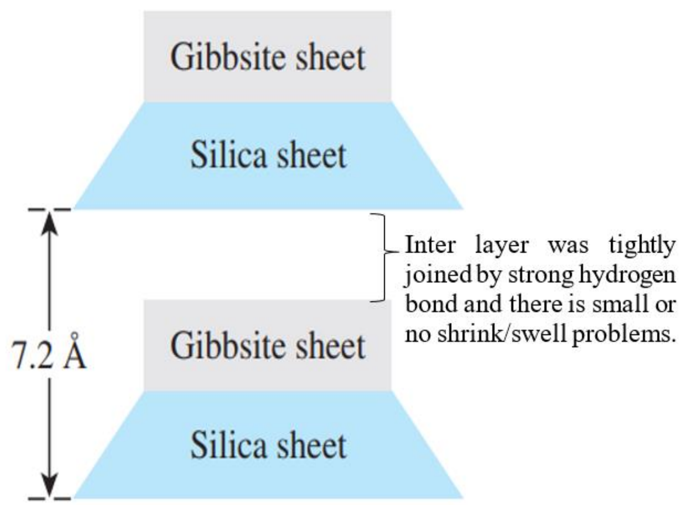

Figure 2-2: General structural arrangements of kaolinite clay mineral (Das & Sobhan, 2014)

2.4.2. Illite group

The structure of illite was formed of two silica tetrahedral sheets with a central sandwich of aluminum or magnesium octahedral sheet. The illite group was also arranged with a 2:1 lattice type, which is similar to the montmorillonite group in structural arrangements. They are derived from weathering of silicates including mica and alkali feldspar under alkaline conditions (Mitchell & Soga, 2005).

When they compared to montmorillonite minerals, illite minerals have low plasticity and swell potential due to their larger particle diameter of 0.5-10μm and lower specific surface area of 65-180 m^2/g (Chen, 1975). Poorly hydrated potassium cations occupy the area between T-O-T sequences of layers, which is accountable for the lack of swelling. Illite is structurally similar to Muscovite, but contains somewhat more silicon, magnesium, iron & water and significantly less tetrahedral aluminum and interlayer potassium. They have a common formula of $[(K, H_3O)(Al, Mg, Fe)_2(Si, Al)_4O_{10}[(OH)_2, (nH_2O)]]$ and contain an inner layer potassium ion (K^+) that is non-exchangeable. The shrink & swell potential of illite minerals is slightly higher than that of kaolinite, but much lower than that of smectite group minerals.

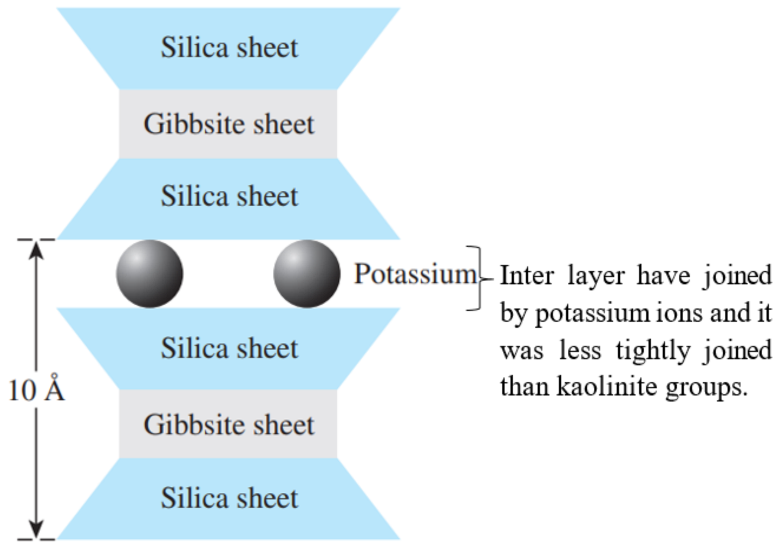

Figure 2-3: General structural arrangements of illite clay minerals (Das & Sobhan, 2014)

2.4.3. Montmorillonite or smectite group

The general term for all expanding 2:1 phyllosilicate mineral are called smectite group, which consists of two silica tetrahedral sheets connected by aluminum or magnesium octahedral sheets at the center. Individual clay particles are plate-shaped with an average diameter of roughly 1μm and a thickness of 9.6Å detected under magnification of about 25,000 times using a scanning electron microscope with a typical basal spacing of 9.6-17.1Å or more (Mitchell & Soga, 2005). Montmorillonite minerals show extensive inner layer expansion on hydration. The particle diameter ranges from 0.05-10 μm with large active specific surface area of about 50-840 m^2/g exposed, allowing enormous range of guest molecules like water to introduce because inter sheet bonding is mainly due to weak van der Waal's forces (Chen, 1975). Chemically, it was a hydrated sodium calcium aluminum magnesium silicate hydroxide, with a chemical formula $(Na, Ca)_3(Al, Mg)_2(Si_4O_{10})(OH)_2.nH_2O$.

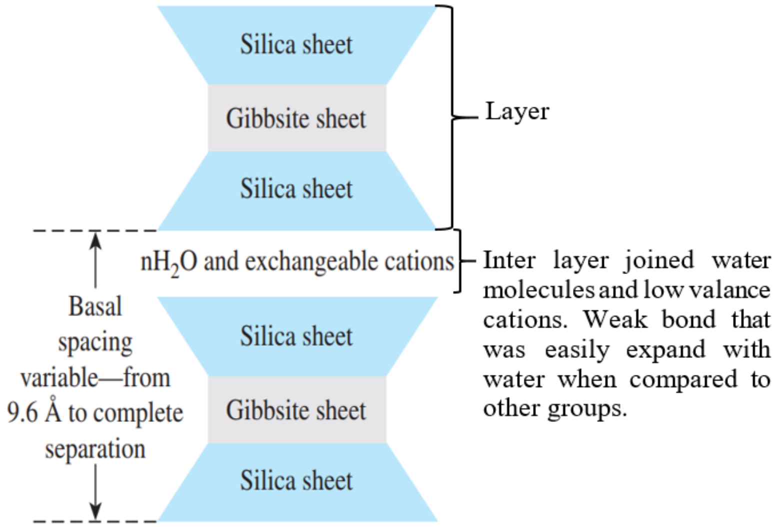

Figure 2-4: General structural arrangements of smectite clay mineral (Das & Sobhan, 2014)

2.5. Methods of Identifying Expansive Soils

Investigation of expansive soils on earth crust was generally done through two important methods. The first method is through visual identification and recognize the material as expansive soil and the second method is through sampling, characterizing, testing and measuring of material properties to be used as the basis for design.

2.5.1. Field identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages (Nelson & Miller, 1975). Important identities to be observed while investigation was done includes:

- ✓ High dry strength and low wet strength.
- ✓ Sticking property and low traffic ability when it gets wet.
- ✓ Usually have a black or gray color.
- ✓ Wide or deep shrinkage cracks appears on the surface.
- ✓ Cut surfaces have a shiny appearance.
- ✓ Appearance of cracks on nearby structures.

These types of soil are most commonly found in arid and semi-arid areas of the globe because there is a large variation in temperature and rainfall.

2.5.2. Laboratory identification

This method of identification can be done through mineralogical identification and inferential methods.

A) Mineralogical identification: Clay mineralogy is a fundamental governing factor that control property of expansive soil (Nelson & Miller, 1975). Clay minerals can be identified using a variety of techniques, the more common of which are:

- ✓ X-ray diffraction (XRD)
- ✓ Differential thermal analysis (DTA)
- ✓ Dye adsorption
- ✓ Chemical analysis
- ✓ Electron microscope resolution (EMR)

Chen, (1975) argued that these techniques should be used in combination with each other to get better and consistent outcomes. However, these procedures are only used in research laboratories due to the need for complex and specialized apparatus, which is expensive, as well as professional analysis skill was required for the generated result data.

B) Inferential Testing Methods: These methods were tried to link some of the index properties of fine-grained soils with the soil clay mineralogical composition to estimate their swell potential. They can be classified as indirect methods and direct methods.

1) Indirect methods: These method make use of soil index properties such as liquid limit, shrinkage limit, percent clay size composition of soils and also some of the indices such as plasticity index, shrinkage index and the like to estimate the swell potential of soils (Asuri & Keshavamurthy, 2016).

a) Liquid limit: This upper bound of plasticity limit is determined in the laboratory by the conventional Casagrande method or by the fall cone method. Liquid limit of a soil is regarded as the water holding capacity of the soil, which in turn has been taken as a measure of soil swell potential. Many classification schemes are available in different geotechnical engineering literatures to recognize the degree of soil swell potential based on the liquid limit of fine-grained soils, as shown in table 2-1.

Table 2-1: Expansive soil classification based on LL (Asuri & Keshavamurthy, 2016)

Swell potential	Liquid limit (%)		
	Chen (1975)	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

b) Plasticity Index: It is the difference between the liquid limit and plastic limit of fine-grained soils. Higher the plasticity index, more plastic the soil is and have higher soil swell potential. Different schemes available to recognize the soil expansiveness based on the plasticity index of the soils are given in table 2-2.

Table 2-2: Expansive soil classification based on PI (Asuri & Keshavamurthy, 2016)

Swell potential	Plasticity Index (%)		
	Holtz and Gibbs (1956)	Chen (1975)	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

c) Shrinkage limit: It represents the lower bound water content for any volume reduction of a soil mass and regarded as a measure of volume stability of the in situ soils (Asuri & Keshavamurthy, 2016). The table given below present the schemes available to recognize swelling potential of fine-grained soils based on shrinkage limit.

Table 2-3: Expansive soil classification based on SL (Emmanuel *et al*., 2021)

Swell Potential Holtz and Gibbs (1956)	Shrinkage Limit (%)	Volume change Altmeyer (1956)	Shrinkage Limit (%)
Low	>15	Non-critical	>12
Medium	10-16	Marginal	10-12
High	7-12	Critical	<10
Very high	<11		

d) Shrinkage Index: is the numerical difference between shrinkage limit and plastic limit for remolded soils (IS 2809, 1972). The classification of the swell potential of fine-grained soils based on their shrinkage index is given in the table below.

Table 2-4: Expansive soil classification based on SI (IS:1498, 2007)

Swell Potential	Shrinkage Index (%)
Low	<15
Medium	15-30
High	30-60
Very high	>60

e) Free swell index: Free swell index is also one of the most commonly used simple test method to estimate the swelling potential of expansive clay (Rao, 2006). In this method, two oven-dried samples weighing 10g each and passing through 0.425 mm sieve were taken. One sample is put in a 100ml graduated glass cylinder containing kerosene which is nonpolar liquid and the other sample is put in a similar cylinder containing distilled water. Both the samples are gently stirred and left undisturbed for 24 hours, and then their volumes are noted. Then free swell index is expressed as:

$$\text{Free swell index}(\%) = \left(\frac{V_W - V_k}{V_k}\right) * 100 \qquad (3)$$

Where: V_w and V_k are final soil volume soaked in water and kerosene, respectively.

Table 2-5: Relationship between FSI and degree of expansiveness (Rao, 2006)

Degree of expansiveness	Free swell index (%)
Low	<20
Moderate	20-35
High	35-50
Very High	>50

f) Free swell ratio: To determine the swell property Prakash & Sridharan, (2004), proposed the free swell ratio method of characterizing the soil swelling. Free swell ratio is defined as the ratio of sediments volume of 10 cm^3 oven dried soil passing through 0.425 mm sieve in distilled water to that of kerosene.

$$\text{Free swell ratio} = \frac{V_w}{V_k} \qquad (4)$$

Where: V_w and V_k are final soil volume soaked in water and kerosene, respectively.

Table 2-6: Classification of soil based on FSR (Prakash & Sridharan, 2004)

FSR	Soil expansiveness	Clay type	Dominant mineral type
<1.0	Negligible	Non-swelling	Kaolinite
1.0-1.5	Low	Mixture of swelling & non-swelling	Kaolinite and montmorillonite
1.5-2.0	Moderate	Swelling	Montmorillonite
2.0-4.0	High	Swelling	Montmorillonite
>4.0	Very High	Swelling	Montmorillonite

g) Cation exchange capacity (CEC): is the quantity of exchangeable cations required to balance the negative charge on the surface of the clay particles and expressed in milli equivalents per 100 grams of dry clay, and it is related to clay mineralogy. Clays having high CEC values have a high surface activity and have a greater water holding capacity. In general, swell potential increases as the CEC increases (Nelson & Miller, 1975).

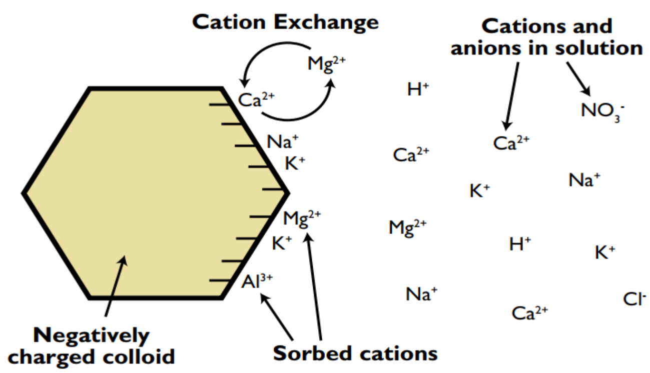

Figure 2-5: Simplified representation of cation exchange capacity (McCauley *et al.*, 2005)

Table 2-7: Typical CEC values of basic clay minerals (Nelson & Miller, 1975)

Clay mineral	CEC (meq/100gm)
Kaolinite	3-15
Illite	10-40
Montmorillonite	80-150

h) Activity of clays: As per Venkatramaiah, (2006) revealed, indirect method of obtaining information on the type and effect of clay mineral in a soil is to relate plasticity index to the amount of clay size particles. It is known that for a given amount of clay mineral, the plasticity resulting in a soil will vary for the different types of clays. Activity can be determined from the results of the standard laboratory tests such as the hydrometer test, liquid limit and plastic limit test. Activity (A) is defined as the ratio of plasticity index to the percentage of clay sizes, as shown in equation below.

$$\text{Activity(A)} = \frac{\text{Plasticity index}}{\text{\% Clay fraction}} \tag{5}$$

Clays containing kaolinite will have relatively low activity and those containing montmorillonite will have high activity. Based on this classification:

- ✓ Montmorillonite clay (expansive clay) is defined as active.
- ✓ Illite clay as normal and,
- ✓ Kaolinite clay as inactive.

Table 2-8: Degree of colloidal activity (Venkatramaiah, 2006)

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

2) Direct methods: The most satisfactory and convenient method of determining the swelling potential and swelling pressure of an expansive clay is by direct measurement. Direct measurement of expansive soils can be achieved by the use of the conventional one dimensional consolidation (Chen, 1975). These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment.

2.6. Soil Classification System

Soils differ according to their origins, compositions, locations, geological histories, and a variety of other characteristics. Even if two soils were recovered from close boring holes on the same building site, they may be substantially different in their geotechnical properties. However, it is more convenient and comfortable for engineers when soils are classified into groups with comparable engineering properties. Without doing laboratory or field-testing, engineers may comprehend the approximate engineering properties of such categorized soils. Soil classification is a procedure that assists engineers during the early design stage of geotechnical engineering problems.

There are many soil classification systems that are currently used in many countries. Those methods mostly use consistency limits and soil gradation information for the classification of soils. Commonly, there are two classification systems that are widely used in geotechnical engineering aspect. These are:

A. Unified soil classification system (USCS) and,
B. American association of state highway and transportation officials (AASHTO) classification system.

2.6.1. Unified Soil Classification System

This system was firstly developed by Arthur Casagrande for wartime airfield construction in 1940 and the system was modified and adopted for regular use by army corps of engineers and then by the bureau of reclamation in 1952 as the unified soil classification system which currently incorporated on ASTM standard manual. According to this method, soils are divided into two sub major categories.

1) Coarse grained soil that are gravelly and sandy in nature with less than 50% of soil sample passing through the sieve size of 0.075 mm, i.e. F_{200}<50%. Naming of categorization starts with prefix G for gravelly soils and S for sandy soils.

2) Fine-grained soils when 50% or more of soil sample passing through the sieve size 0.075 mm, i.e. F_{200} > 50%. Naming of group symbol starts with M for inorganic silts, C for inorganic clays, O for organic silt and clays, and Pt for peats and muck for highly organic soils.

Again, coarse grained materials subdivided into gravel and sand based on amount of soil retained on sieve having opening size of 4.75 mm. When more than 50% soil retained on sieve No.4 the soil is gravel and when more than 50% of soil pass sieve No.4 material falls under sandy soil. Similarly, fine-grained soils also subdivided into silt and clay based on their location on the plasticity chart shown on figure 2-6.

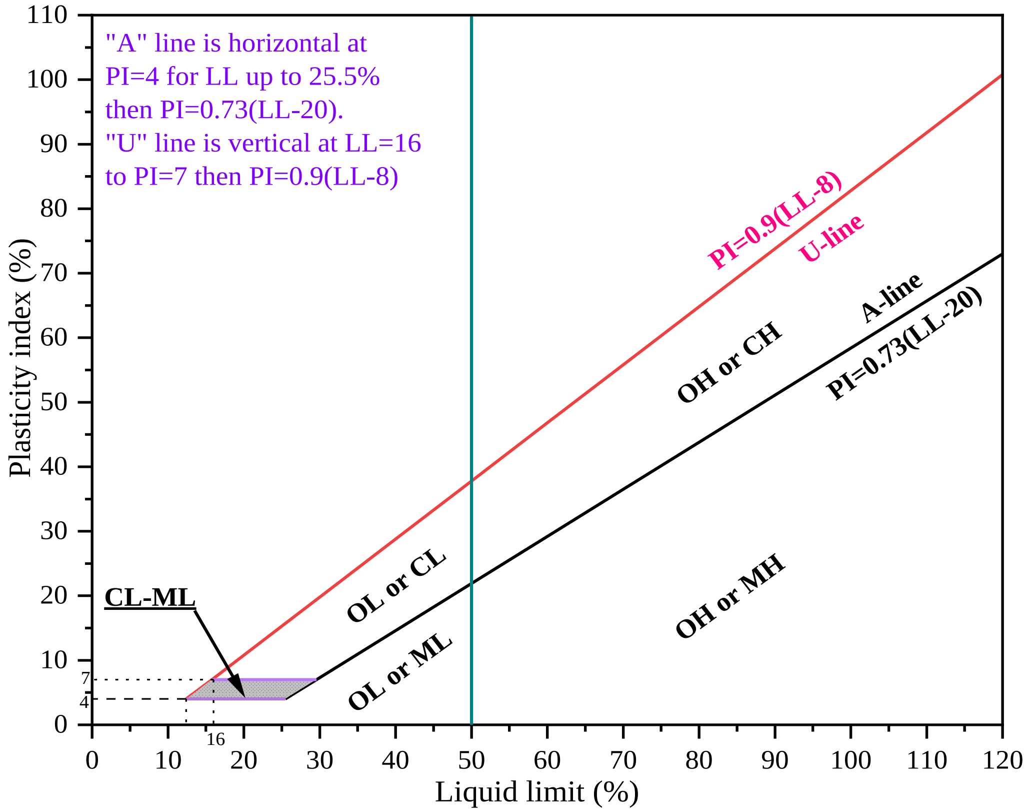

Figure 2-6: Plasticity chart for fine-grained soils classification by USCS (ASTM D 2487, 2000)

Table 2-9: Soil classification based on particle size range by USCS

Soil type		Particle Size (mm)
Clay		≤0.002
Silt		0.002-0.075
Sand	Fine	0.075-0.425

	Medium	0.425-2.0
	Coarse	2.0-4.75
Gravel		4.75-75

There are also some additional qualitative suffixes added on group symbol based on amount of Coefficient of uniformity (C_u) and coefficient of curvature (C_C) obtained from gradation curve for coarse grained soils and suffixes added on group symbol of fine-grained soil based on amount of plastic index and liquid limit amount as summarized in table 2-10.

Table 2-10: Unified soil classification system chart (ASTM D 2487, 2000)

Criteria for Assigning Group Symbols and Group Names Using Laboratory Tests [A]				**Soil Classification**	
				Group Symbol	**Group Name** [B]
COARSE GRAINED SOILS More than 50% retained on No. 200 sieve	Gravels More than 50% of coarse fraction retained on No. 4 sieve	Clean Gravels Less than 5% fines [E]	$C_U \geq 4$ and $1 \leq C_C \leq 3$ [C]	GW	Well-graded gravel [D]
			$C_U < 4$ and/or $1 > C_C > 3$ [C]	GP	Poorly graded gravel [D]
		Gravel with Fines More than 12% fines [E]	Fines classify as ML or MH	GM	Silty gravel [D,F,G]
			Fines classify as CL or CH	Urule; 1>GC	Clayey gravel [D,F,G]
	Sands 50% or more of coarse Fraction passes No. 4 sieve	Clean sands Less than 5% fines [I]	$CU > 6$ and $1 \leq CC \leq 3$ [C]	SW	Well-graded sand [H]
			$C_U < 6$ and/or $1 > C_C > 3$ [C]	SP	Poorly graded sand [H]
		Sands with Fines More than 12% fines [I]	Fines classify as CL or CH	SM	Silty sand [F,G,H]
			Fines classify as CL or CH	SC	Clayey sand [F,G,H]
FINE-GRAINE SOILS 50% or more passes the No. 200 sieve	Silts and Clays Liquid limit less than 50	Inorganic	PI > 7 and plots on or above "A" line [J]	CL	Lean clay [K,L,M]
			PI < 4 or plots below "A" line [J]	ML	Silt [K,L,M]
		Organic	$\frac{LL(\text{oven dried})}{LL(\text{dried})} < 0.75$	OL	Organic clay [K,L,M,N]
				OL	Organic silt [K,L,M,O]
	Silt and Clays Liquid limit 50 or more	Inorganic	PI plots on or above "A" line	CH	Fat clay [K,L,M]
			PI plots below "A" line	MH	Elastic silt [K,L,M]
		Organic	$\frac{LL(\text{oven dried})}{LL(\text{dried})} < 0.75$	OH	Organic clay [K,L,M,P]
					Organic silt [K,L,M,Q]
HIGHLY ORGANIC SOILS	Primarily organic matter , dark in color , and organic odor			PT	Peat

[A] Based on the material passing the 3-in. (75 mm) sieve. [B] If field sample contained cobbles or boulders, or both, add "with cobbles or boulders, or both" to group name. [C] $C_U = D_{60}/D_{10}$ & $CC = (D_{30})^2 / D_{10} \times D_{60}$. [D] If soil contains $\geq$ 15% sand, add "with sand" to group name. [E] Gravels with 5 to 12% fines require dual symbols: GW-GM: well-graded gravel with silt, GW-GC: well graded gravel with clay, GP-GM: poorly graded gravel with silt, GP-GC: poorly graded gravel with clay. [F] If fines classify as CL-ML, use dual symbol GC-GM, or SC-SM. [G] If fines are organic, add "with organic fines" to group name. [H] If soil contains $\geq$ 15% gravel, add "with gravel" to group name. [I] Sand with 5 to 12% fines require dual symbols: SW-SM: well-graded sand with silt, SW-SC: well graded sand with clay, SP-SM: poorly graded sand with silt, SP-

SC: poorly graded sand with clay. [J] If Atterberg limits plot in hatched area, soil is a CL-ML, silty clay. [K] If soil contains 15 to 29% plus No.200, add "with sand" or "with gravel," whichever is predominant. [L] If soil contains $\geq$ 30% plus No.200, predominantly sand, add "sand" to group name. [M] If soil contains $\geq$ 30% plus No.200, predominantly gravel, and add "gravelly" to group name. [N] PI $\geq$ 4 and plots on or above "A" line. [O] PI < 4 and plots below "A" line. [P] PI plots on or above "A" line. [Q] PI plots below "A" line.

2.6.2. AASHTO classification system

This soil classification system is used to determine the suitability of soils for earthworks, embankments, and road bed materials in highway construction. According to this classification system, granular soils are soils in which 35% or less are finer than the No. 200 sieve. Silty clay soils are soils in which more than 35% are finer than the No. 200 sieve (Muni Budhu, 2010). The classification method uses liquid limit, plastic limit and information obtained from grain size distribution curve to classify soils into seven major groups, A-1 through A-7. The first three groups, A-1 through A-3, are granular (coarse grained) soils, while the last four groups, A-4 through A-7, are silty clay (fine-grained) soils. Figure 2-7 and table 2-11 were used for soil classification system. The procedure of classification uses an elimination process of column, from the upper left corner toward downward and right. If the condition on the row is not satisfied, the entire column is eliminated, and it is never referred back. After the last row check for PI, one or possibly more than one column may survive this elimination process. If more than one column survived, the first column from the left is selected as a group or subgroup.

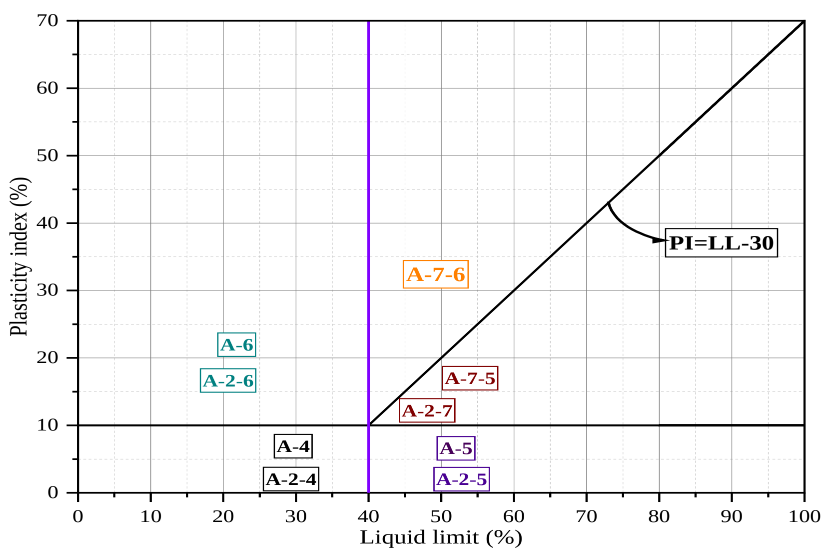

Figure 2-7: Liquid limit and plasticity index ranges for fine-grained materials (AASHTO:M 145-91, 2008)

Table 2-11: Classification of soils and soil-aggregate mixtures (AASHTO:M 145-91, 2008)

General Classification	Granular Materials (35 Percent or Less Passing 75μm)							Silt-Clay Materials (More Than 35 Percent Passing 75μm)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve analysis, percent passing											
2.00mm(No.10)	50 max	-	-	-	-	-	-	-	-	-	-
0.425mm(No.40)	30 max	50 max	51 min	-	-	-	-	-	-	-	-
75μm(No.200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425mm (No.40)											
Liquid limit		-	-	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plastic index		6 max	NP	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[a]
Usual type of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to Good							Fair to Poor			

[a] Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30 and, Plasticity index of A-7-6 subgroup is greater than LL minus 30.

Placing of A-3 before A-2 is necessary in the “left to right elimination process” and does not indicate superiority of A–3 over A–2.

Group index (GI) value is appended additionally in parentheses to the main group to provide a measure of quality of a soil as highway subgrade material and calculated through the following formula.

$$\mathrm{GI} = (\mathrm{F} - 35)[0.2 + 0.005(\mathrm{LL} - 40)] + 0.01(\mathrm{F} - 15)(\mathrm{PI} - 10) \quad (6)$$

Where: F is percentage passing 75 μm (No. 200) sieve, expressed as a whole number, LL is liquid limit, and PI is plasticity index.

When the calculated group index is negative, the group index shall be reported as zero and should be reported to the nearest whole number. And also when calculated GI is more than 20, it is assumed to be taken as 20. Soil having less GI has good strength and quality, but soil having higher group index has less quality and not appropriate to use as construction material.

2.7. Theoretical Concept on Consolidation of Fine-Grained Soils

Structures are built on soil mass and transfer loads to the subsoil through their foundations. The effect of the loads is felt by the soil, normally up to a depth of about four times the width of the foundation. The soil within this depth gets compressed due to the imposed stresses. The compression of the soil mass leads to the decrease in the volume of the mass, which results in the settlement of the structure. If the settlement is not kept to a tolerable limit, the desire use of the structure may be impaired and the design life of the structure may be reduced. It is therefore important to have a mean of predicting the amount of soil compression or consolidation.

Soil consolidation refers to the process by which the volume of a partially or fully saturated soil decreases due to an applied stress. When a load is applied to a low permeability soil, it is initially carried by the water that exists in the porous saturated soil and result in a rapid increase of pore water pressure. This excess pore water pressure is dissipated as water drains away from the void space and the pressure is transferred to the soil skeleton, which is gradually compressed, resulting in settlements. The consolidation procedure lasts until the excess pore water pressure is dissipated, most of the time up to 24 hours. The total compression of soil under load is composed of three components which includes elastic settlement, primary consolidation settlement, and secondary compression. Elastic settlement occurs due to elastic deformation of soil mass without changing in the moisture content, and primary consolidation is happened because of expulsion of the water that occupies the void spaces. But secondary consolidation occurred due to the plastic adjustment of soil fabrics under a constant effective stress (Muni Budhu, 2010).

The rate of consolidation of soil mass depends on the permeability of the soil and length of drainage path, H_{dr} in the soil. A soil with a lower hydraulic conductivity will take longer time to drain the initial excess pore water, and settlement will proceed at a slower rate. And also, consolidation process with single drainage will take four times longer to reach a particular settlement than for soil consolidated in double drainage path (Muni Budhu, 2010).

Clayey soils undergo consolidation settlement not only under the action of external loads or surcharge loads but also occurred under its own weight or weight of soils that exist above the clay which is geostatic loads. Clayey soils should also undergo settlement when the earth was dewatered (e.g., groundwater pumping) because the effective stress on the clay increases.

2.7.1. Compressibility characteristics

The standard one-dimensional consolidation test is conducted on a saturated specimen using an Odometer. The soil specimen is placed inside a metal ring with two porous stones, one at the top of the specimen and another at the bottom. The load is applied to the specimen through a lever arm, and deformation is measured through an attached dial gauge on the consolidation machine. The specimen is kept soaked in water bath during the test. Each load is usually kept for 24 hours. After that, the load is usually doubled and the compression measurement recording is continued. At the end of the test, the dry mass of the test specimen is determined, which is required to determination of volume of solid soils (Fikadu, 2015). Then compressibility characteristics of a soil such as compression index (Cc), recompression index (Cr), coefficient of consolidation (C_v) and coefficient of volume compressibility (m_v) are determined from the one-dimensional consolidation test result.

Plots of void ratio (e) after consolidation against effective stress (σ′) for a saturated soil were drawn to show an initial compression of loading followed by unloading and recompression. The e-log σ′ relationship for a normally consolidated soil is nearly linear, and is called the one-dimensional compression line. During compression along this line, permanent or irreversible changes in soil structure continuously take place, and the soil does not revert to the original structure during expansion. If a soil is over consolidated, its state will be represented by a point on the expansion or recompression parts of the e-log σ′ plot. The changes in soil structure along this line are almost fully recoverable, as shown on figure 2-8.

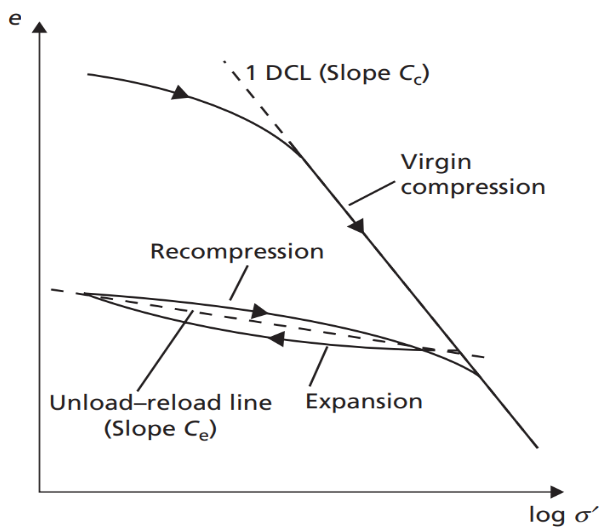

Figure 2-8: Void ratio-stress relationship on logarithmic scale (Craig & Knappett, 2012)

The compressibility of the soil can be quantified by one of the following coefficients. These coefficients are compression index (C_C) and coefficient of volume compressibility (m_v).

A) Compression index (C_C): is the slope of the linear portion of void ratio (e) versus logarithm of effective pressure (log σ′) relationship, is extensively used for settlement determination (Sridharan & Gurtug, 2005). It is also negative slope of consolidation curve and dimensionless parameter of consolidation.

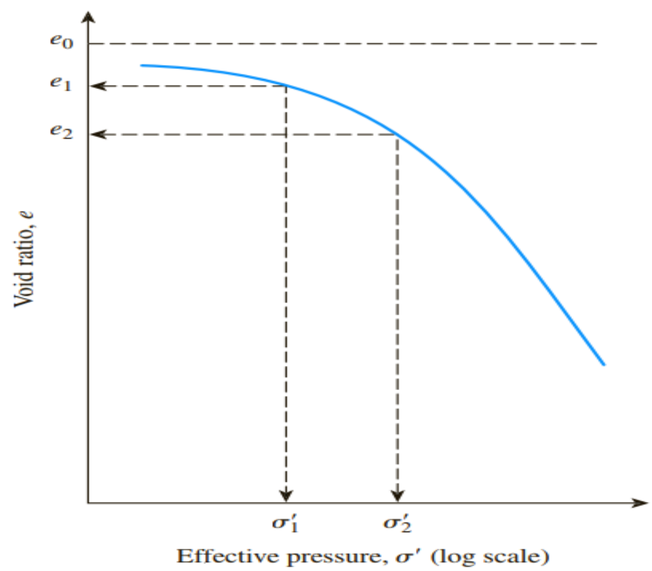

Figure 2-9: Typical plot of e versus log δ' (Das & Sobhan, 2014)

For any two points on the linear portion of the plot shown on figure 2-9, compressibility index becomes calculated by the following equation.

$$Cc = \frac{e_1 - e_2}{\log\left(\frac{\sigma_{2'}}{\sigma_{1'}}\right)} \quad (7)$$

Where Cc stands for coefficient of compressibility, e_1 and e_2 are void ratios of soil specimen before and after loading respectively and σ_2' and σ_1' are axial stress that the specimen withstand that are after and before load is doubled respectively.

B) Coefficient of volume compressibility (m_v): defined as the volume change per unit volume per unit increase in effective stress that means ratio of volumetric strain to applied stress (Craig & Knappett, 2012). The units of m_V are the inverse of stiffness (MPa^{-1}). This parameter was calculated from e-σ curve and used to assess degree of compressibility and hydraulic conductivity of soil specimen. The volume change may be expressed in terms of either void ratio or specimen thickness. If, for an increase in effective stress from σ_1' to σ_2', the void ratio decreases from e_1 to e_2, then m_V is calculated as:

$$M_v = \frac{(e_1 - e_2)}{(1 + e_0)(\sigma_2' - \sigma_1')} \quad (8)$$

Where m_V is coefficient of volume compressibility of soil specimen at two different effective axial stresses $\sigma_1{}'$ and $\sigma_2{}'$ with respective void ratios e_1 and e_2, and e_0 is initial void ratio.

2.7.2. Pre-consolidation pressure determination

Pre consolidation pressure is the maximum effective vertical overburden stress that a particular soil sample has sustained in the past. It is important in geotechnical engineering, particularly for finding the expected settlement of foundations and embankments. The parameter is determined from e-log σ' curve of loading condition shown on figure 2-10 after conducting consolidation test in the laboratory through some procedures include:

- Draw the tangent to the curve at D through line DH and bisect the angle between the tangent DH and the horizontal line DF through line DG;
- Produce back the straight-line part BC, which is the tangent to the end of consolidation curve;
- The abscissa of the point of intersection of the bisector line DG and BC produced gives the approximate value of the pre consolidation pressure.

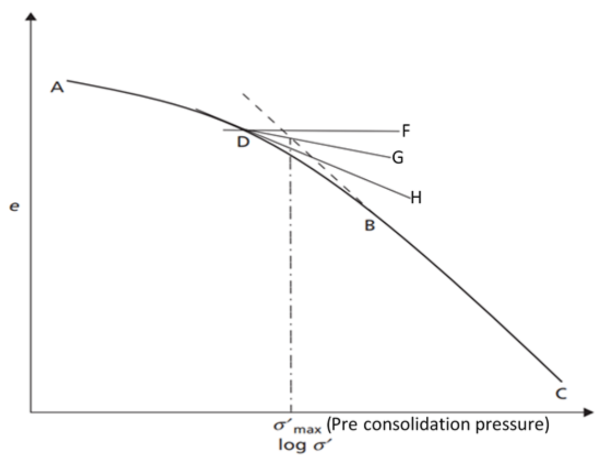

Figure 2-10: Determination of pre consolidation pressure (Craig & Knappett, 2012)

2.7.3. Coefficient of consolidation determination methods

The coefficient of consolidation relates to how long it will take for an amount of consolidation to take place, which is mainly depending up on length of drainage path and permeability of soil mass. It is used to calculate hydraulic conductivity of material. From the test result, it is possible to get deformation at required time interval under action of every axial stresses. And then a plot of deformation versus log time or square root of time was drawn to determine coefficient of consolidation as per Casagrande or Taylor method respectively.

A) Logarithm of time (Casagrande) method: The experimental curve is obtained by plotting the dial gauge readings in the odometer test against the time in minutes, plotted on a logarithmic axis. In the experimental curve, the point corresponding to starting of primary consolidation (U_V=0) can be determined by using the fact that the initial part of the curve represents an approximately parabolic relationship between compression and time (Craig & Knappett, 2012). The final part of the experimental curve is linear but not horizontal, and the point of primary consolidation ending (a_{100}) corresponding to U_V =100% is taken as the intersection of the two linear parts of the curve. Then two points on the curve are selected, which are A and B for which the values of time at point B are four times that of A and the vertical distance between them, ζ, is measured. An equal distance of ζ above point A fixes the dial gauge reading (a_s) corresponding to starting of primary consolidation.

After that, average of deformation gap between a_s and a_{100} will give a dial reading at 50% consolidation (a_{50}) with respective time (t_{50}) to determine coefficient of consolidation by the following equation.

$$C_v = \frac{(T_v * {H_{dr}}^2)}{t_{50}} \tag{9}$$

Where T_V is time factor taken as 0.197 for 50% consolidation, is taken as half of average thickness of specimen if drainage is two-way and full average thickness of specimen for one way drainage.

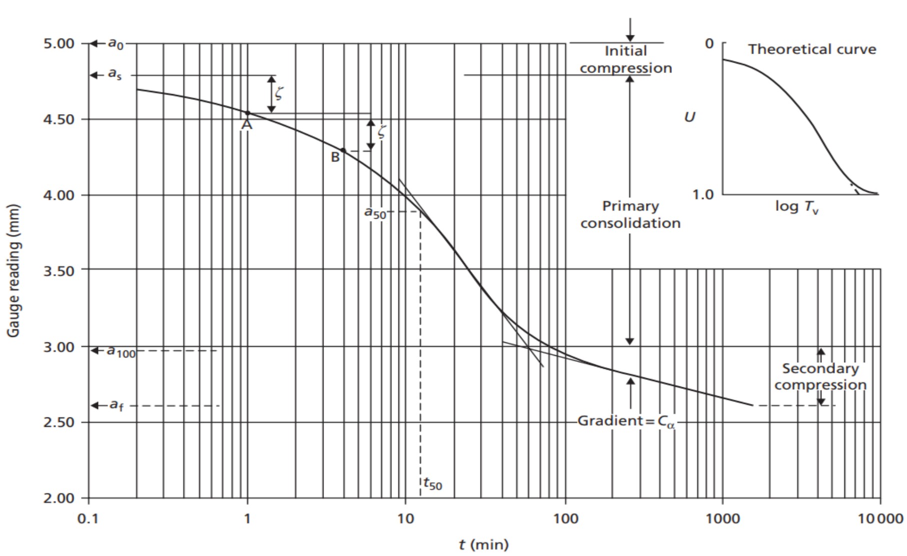

Figure 2-11: Deformation versus time curve on logarithmic horizontal scale (Craig & Knappett, 2012)

B) The square root of time (Taylor's) method: From the result recorded, the dial gauge readings being plotted against the square root of time in minutes as shown on figure 2-12. Then draw a line AB through the early portion of the curve. Finally, draw a line AC based on distance of OC is equal to 1.15 times OB and then abscissa of point D where line AC cross the consolidation curve is equal to square root of t_{90}.

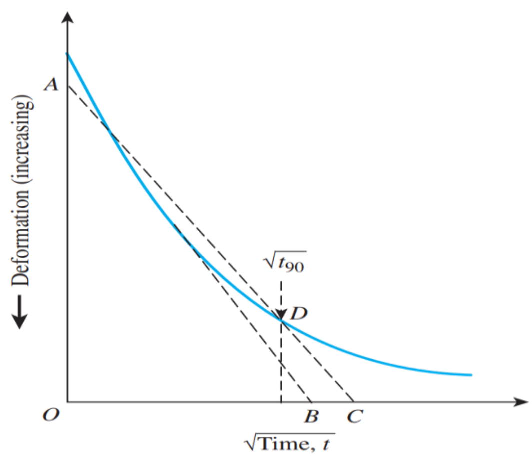

Figure 2-12: Deformation versus square root of time curve (Craig & Knappett, 2012)

For 90% consolidation time factor, T_V is equal to 0.848 and C_v is calculated by the following formula:

$$C_v = \frac{(0.848 * {H_{dr}}^2)}{t_{90}} \tag{10}$$

Where: H_{dr} is determined in the same way as in logarithm of time method.

2.8. Previous Studies Related to Correlation between Soil Properties

Correlations are very important method to estimate engineering properties of soils, especially for preliminary investigation of projects where there is financial limitation, lack of test equipment and limited time. Several studies were attempted to develop correlation equations for prediction of compression index in terms of different index properties. Some of these researches are listed below.

Skempton, (1944) conducted consolidation test on a number of clays collected from different locations and gave the following equation for the compression index for a remolded sample: Skempton model $Cc = 0.007(LL - 10\%)$.
Terzaghi and Peck model $Cc = 0.009(LL - 10\%)$

Nishida, (1956) derives theoretically linear correlation for all kind of undisturbed clays as showed in equation below: $Cc = 0.54(eo - 0.35)$

Similarly, Azzouz, (1976) presented correlation as: $Cc = 0.4(eo - 0.25)$

Some Correlations between Liquid Limit (LL) and Plasticity index (PI) with Compression index (Cc),

$Cc = 0.007(LL - 7.0\%)$ Skempton, (1944)

$Cc = 0.006(LL - 9.0\%)$ Azzouz *et al*., (1976

$Cc = 0.007(LL - 7.0\%)$ Moh a kol. (1989)

$Cc = 0.009(LL - 8.0\%)$ Tsuchida, (1991)

$Cc = 0.0092(LL + 1.315)$ Tripathi, 2009

$Cc = 0.0141(LL - 10.149)$ Shushil Giri, (2019)

$Cc = 1.325PI$ Koppula, (1981) and Wroth *et al*., (1978)

$Cc = 0.014(PI + 3.6)$ Sridharan and Nagaraj, (2000)

Cc = 0.0196 (PI + 6.05) Tripathi, 2009

Cc = 0.0259 (PI + 1.88) Shushil Giri, (2019)

Cc = 128.7/ (SI) 3.54 + 0.0002 Prof. Guruprasad Jadhav, (2016)

These equations were obtained by research conducted on soil from the country of origin of the researchers, in most of the cases and when used in other countries, these equations either over estimate or underestimate the Cc.

Akbarimehr *et al*., (2021) found the following empirical equations for the relationship between density and initial void ratio with compression index for both disturbed & undisturbed soil samples.

For undisturbed samples;

$$C_c = -0.33\gamma_w + 0.795,\ R^2 = 0.91 \quad (11)$$

$$C_c = 0.272e_0 + 0.005,\ R^2 = 0.82 \quad (12)$$

$$C_c = -0.41\gamma_d + 0.85,\ R^2 = 0.82 \quad (13)$$

For disturbed samples and

$$C_c = -0.21\gamma_w + 0.57,\ R^2 = 0.72 \quad (14)$$

$$C_c = 0.23e_0 + 0.14,\ R^2 = 0.83 \quad (15)$$

$$C_c = -0.23\gamma_d + 0.51,\ R^2 = 0.73 \quad (16)$$

Kabeta *et al*., (2022) also investigated the following empirical equations for the relationship between Atterberg limit and compression index of soil samples from Jimma town.

$$C_c = 0.0021LL + 0.1196,\ R^2 = 0.82 \quad (17)$$

$$C_c = 0.0034PL + 0.1573,\ R^2 = 0.6135 \quad (18)$$

$$C_c = 0.0036PI + 0.1342,\ R^2 = 0.6059 \quad (19)$$

Dehghanian & İpek, (2022) also investigated the following empirical equations for the relationship between LL, PI and compression index of soil samples.

$$C_c = 0.0076LL - 0.1368,\ R^2 = 0.9249 \tag{20}$$

$$C_c = 0.0078PI + 0.1384,\ R^2 = 0.8804 \tag{21}$$

Salih, (2020) worked on soil samples from various Iraq regions. While obtaining this correlation result, undisturbed soil samples were used. Soils LL, PI and e_0 values ranged from (30% to 70%), (10% to 32%), and (0.4493 to 0.983) respectively. As a result of this study, it was observed that there were different correlation equations to determine Cc.

$$C_c = -0.0037LL + 0.352,\ R^2 = 0.46, RMSE = 0.0318, N = 76 \tag{22}$$

$$C_c = -0.0049PI + 0.2882,\ R^2 = 0.44, RMSE = 0.0648, N = 76 \tag{23}$$

$$C_c = 0.2494e_0 + 0.0045,\ R^2 = 0.65, RMSE = 0.0335, N = 81 \tag{24}$$

Güllü *et al.*, (2016) conducted a study suggesting a correlation between Cc and natural water content (w_n), LL, and initial void ratio. The correlation established on 69 fine-grained soil samples obtained from Baghdad city is suitable for use in the Baghdad region.

$$C_c = 0.00553w_n + 0.05321,\ R^2 = 0.53, RMSE = 0.028 \tag{25}$$

$$C_c = 0.00454LL - 0.01246,\ R^2 = 0.87, RMSE = 0.017 \tag{26}$$

$$C_c = 0.08358e_0 + 0.12739,\ R^2 = 0.21, RMSE = 0.033 \tag{27}$$

$$C_c = 0.004483LL + 0.028871e_0 - 0.03029,\ R^2 = 0.87, RMSE = 0.016 \tag{28}$$

CHAPTER THREE

MATERIALS AND METHOD

3.1. Description of Study Area

The study was conducted in Addis Ababa specifically in Akaki Kality sub city, which is one found on the south eastern margin of the city. It shares boundary with Bole sub-city in the North, Kirkos and Nifas Silk Lafto sub cities in the North West and Oromia regional state in the South. The lowest point 2,050 meters in the Southern periphery and the maximum elevation is 2,331 meters above sea level. The Sub city has 11 Woredas and covers total plot area of 156 km^2 (Eshetu, 2017). The geographical location of the area is found approximately on 8°53'45''N latitude and 38°47'21''E longitude. The area has annual average temperature ranges from 9.9℃ to 22.7℃ with total average annual rainfall of 1117.10 mm (Tesfaye, 2009). The geological history of the studied area is an integral part of the evolution and development of the Ethiopian Plateau and the Rift system, because of its location at the western margin of the Main Ethiopian Rift (MER). The area is covered by different volcanic rocks with both acidic and basic compositions and overlain by fluvial and residual soils varying in thickness from a few centimeters to several meters below natural ground level. Black cotton soil is the predominant soil type (Muche, 2019).

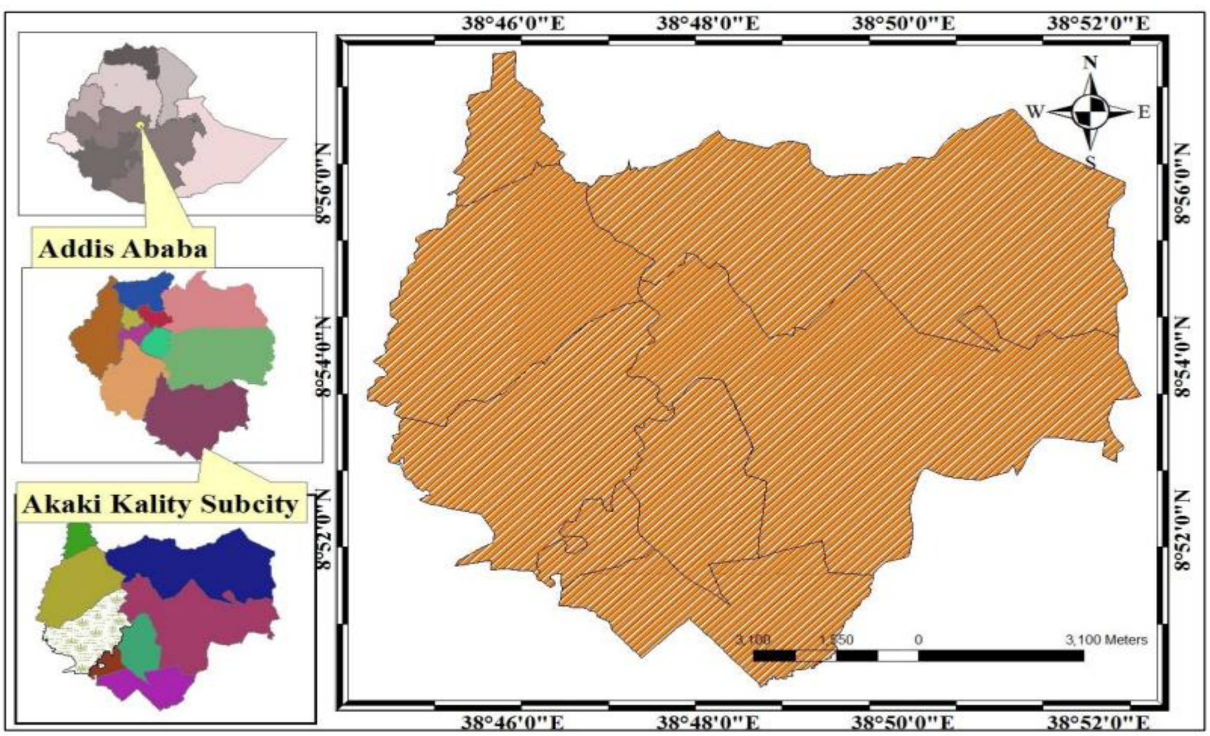

Figure 3-1: Map of study area

3.2. Weather and climate of study area

According to Berhanu *et al.*, (2014), climate in Ethiopia is geographically quite diverse which most commonly follows varied topography and categorized in to five different sub zones based on altitude, rainfall and temperature variation. It ranges from the high cold area named as “wurch” to the highly hot climatic condition area known as “Berha” having different physical measurement characteristics such as altitude, mean annual precipitation and temperature as shown in table 3-1.

Table 3-1: Climate zones of Ethiopia and their physical characteristics (Berhanu *et al.*, 2014)

Zones	Altitude (m)	Mean annual rainfall (mm)	Mean annual temperature (°C)
Wurich (cold to moist)	>3200	900-2200	Below 11.5
Dega (cool to humid)	2300-3200	900-1200	11.5-17.5
Weynadega (cool sub-humid)	1500-2300	800-1200	17.5-20
Kola (warm semi arid)	500-1500	200-800	20-27.5
Berha (hot arid)	< 500	Below 200	Above 27.5

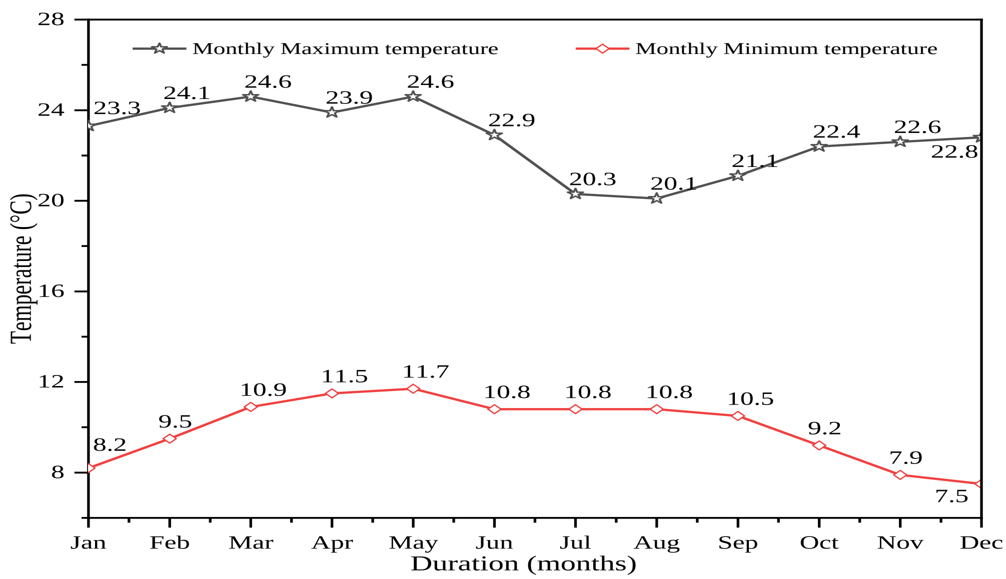

Figure 3-2: Monthly mean minimum and maximum temperature of study area (Tesfaye, 2009)

For the case, the study area is located on altitude of around 2331m which is between 2300 m & 3200 m and categorized under Dega (cool to humid) climate zone. Based on data from Tesfaye, (2009), mean monthly temperature of the study area is around 16.30°C, which is within range (11.5 mm-17.5 mm) of specified climate zone. Mean annual rainfall of the study area is 1117.10 mm, which is in the range of 900 mm-1200 mm.

3.3. Collection and Preparation of Soil Samples

Disturbed expansive soil samples from 16 test pits were collected from Akaki Kality sub city through digging of test pits to depth of 2 m from the natural ground surface. Then soil samples were packed in to plastic bags having specified identity of borehole number and transported to geotechnical laboratory for further investigation. As per (Kemal, 2015) studied properties of soils in this area, almost all soil was characterized and classified as fat clay (CH) having black color. Depending up on this borehole was selected to take samples from 16 sampling sites having geographical locations shown on table 3-2. Laboratory tests such as specific gravity, Atterberg limits, linear shrinkage, differential free swell test, particle size distribution analysis, standard compaction, and consolidation tests were performed on dry disturbed soil samples to determine the relationship between compression index and index properties of soil in the study area.

The soil sample collected was air dried and sieved with sieve size of 4.75 mm as required for laboratory test. Then if undisturbed sample will be needed in the case, disturbed soil having known weight was remolded at minimum of 95% of maximum dry density with optimum moisture content by using appropriate molds under control of certain standard.

Figure 3-3: Geographical location of the test pits

Table 3-2: Geographical locations of sampling sites

Sampling site	Latitude (Northing)	Longitude (Easting)
TP-1	8°51'48.42''	38°48'27.24''
TP-2	8°52'22.24''	38°48'7.34''
TP-3	8°52'16.01''	38°49'4.93''
TP-4	8°53'19.47''	38°48'42.80''
TP-5	8°53'44.48''	38°48'3.43''
TP-6	8°54'31.99''	38°48'22.22''
TP-7	8°51'55.60''	38°47'10.41''
TP-8	8°51'14.96''	38°47'35.70''
TP-9	8°53'34.34''	38°46'28.76''
TP-10	8°56'4.23''	38°46'1.25''
TP-11	8°55'25.41''	38°46'18.21''
TP-12	8°54'41.69''	38°45'41.18''
TP-13	8°54'22.99''	38°44'39.09''
TP-14	8°53'48.80''	38°47'4.07''
TP-15	8°54'13.67''	38°46'36.50''
TP-16	8°52'36.64''	38°47'29.52''

3.4. General Flow Chart of the Study

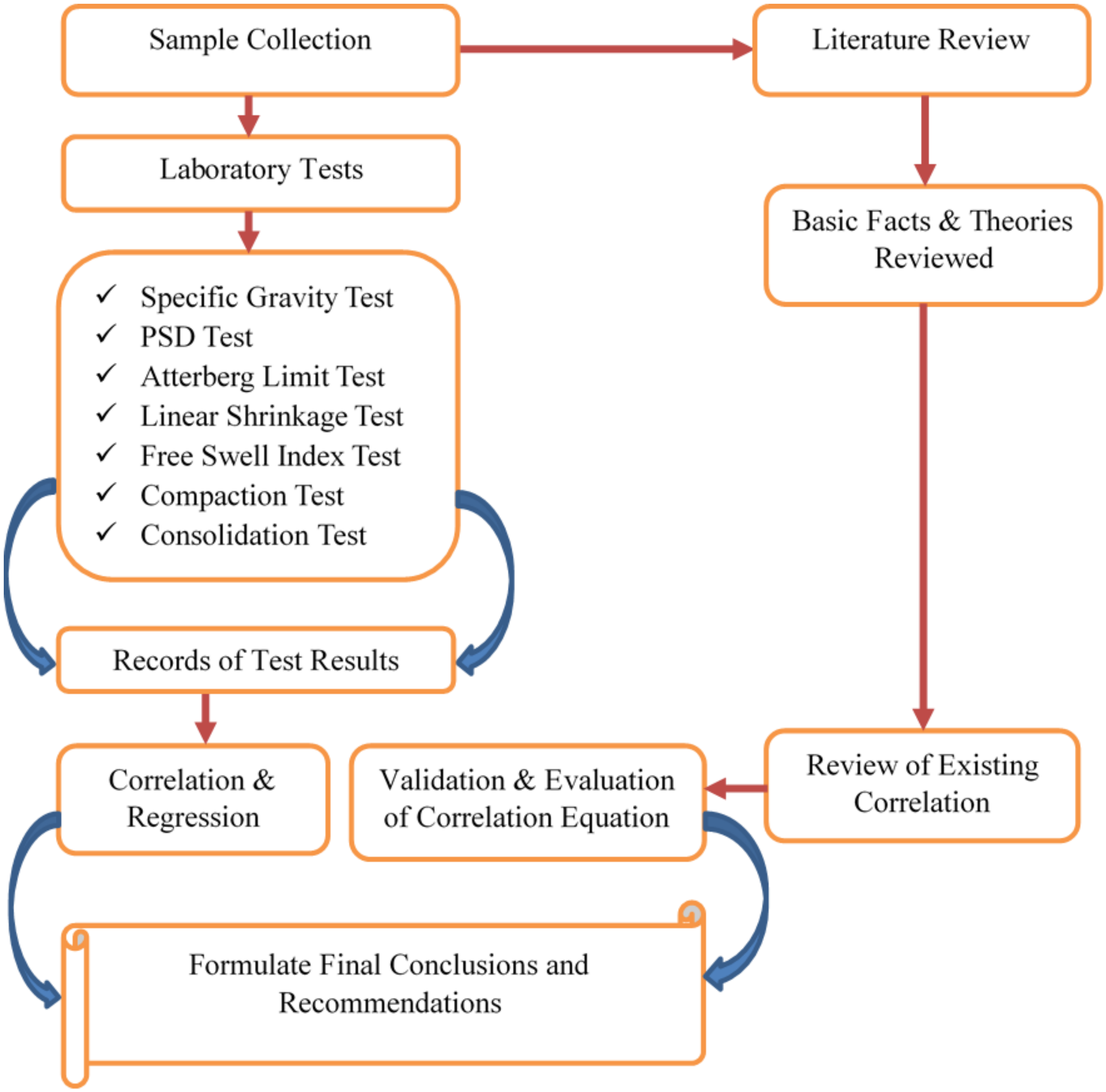

Figure 3-4: Summarized methodology chart of the study

3.5. Laboratory Tests

After all materials required for the study were prepared, different laboratory experiments performed to create correlation between every properties as per required for the study. Laboratory tests conducted for this study were listed with their standard test method of operation in table 3-3.

Table 3-3: Laboratory tests conducted on materials

Test conducted	Standard code used
Specific gravity test	ASTM D 854
Grain size analysis test	ASTM D 6913

Free swell index test	IS 2720-40
Atterberg limit test	ASTM D 4318
Linear shrinkage test	BS 1377-2
Standard compaction test	ASTM D 698
Consolidation test	ASTM D 2435

3.5.1. Specific gravity test

The specific gravity of a material is the ratio of the mass of a unit volume of soil solids at a specific temperature to the mass of an equal volume of gas free distilled water at the same temperature. This test method is applied to the soil fraction that passes through sieve size of 4.75 mm and in case it was used to determine phase relationship of solids such as the degree of saturation, void ratio and other soil properties. However, the test is used to determine the specific gravity of soil by using the density of water and usually reported at 20°C temperature i.e. if testing temperature is different from room temperature (20°C), result obtained is going to be corrected for temperature effect. To determine specific gravity of a single material, at least two trial tests were needed to take the average of the two result and report it as specific gravity. For the case of this study, about 10gm of dry soil sample finer than sieve No.4 was used to determine specific gravity of each material and calculated by the following formulas.

$$G_T = \frac{M_s}{M_s + (M_a - M_b)} * \rho_{w(T)} \tag{29}$$

Where G_T is specific gravity of soil at testing temperature T(°C), M_s is mass of dry soil in gram, M_b is mass of pycnometer containing soil and water, M_a is mass of pycnometer filled with water at temperature T(°C) which is calculated from:

$$M_a = \frac{\rho_{w(T)}}{\rho_{w(T')}} * \left(M_a' - M_p\right) + M_p \tag{30}$$

Where $\rho_{w(T)}$ is density of water at temperature T(°C), $\rho_{w(T')}$ is density of water at temperature T'(°C), M_a' is weight of pycnometer filled with water in grams, M_p is weight of empty pycnometer in grams.

Finally, specific gravity calculated at temperature T(°C) was corrected and reported for temperature effect by multiplying it with some factor k as shown in equation 15.

$$G_{20} = k * G_T \tag{31}$$

3.5.2. Grain size analysis test

Grain size analysis is a typical laboratory test conducted in the soil mechanics field, which used to determine the particle size distribution of soils. The analysis is conducted via two techniques which are through sieve analysis which is capable of determining the particle size ranging from 0.075 mm to 100 mm, whereas distribution of particles smaller than 0.075 mm can be determined using the hydrometer analysis method.

i) Sieve analysis: is a method that is used to determining the grain size distribution of soils that are greater than 0.075 mm in diameter. It is usually performed for sand and gravel, but cannot be used as the method for determining the grain size distribution of finer soil. The sieves used in this method are made of woven wires with square openings. Data obtained from sieve analysis may also be useful in developing relationships concerning the porosity and packing in the soil mass. Information obtained from the particle size analysis, uniformity coefficient (Cu), coefficient of curvature (Cc), and effective size (D_{10}), are also used to classify the soil and determine whether the soil is suitable for construction purpose. And also this test result gives clue about soil water movement if permeability test is not available. The standard test method used for this test was ASTM D 6913.

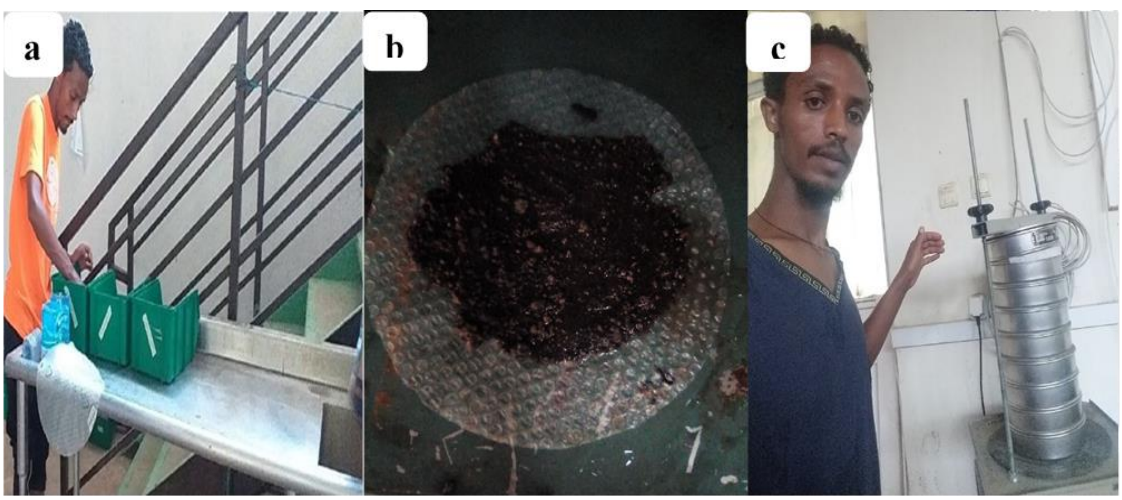

Figure 3-5: Gradation test (a) soaking dry mass sample in water (b) wet sample retained on sieve No.200 after washing (c) sieve stack prepared for shaking on sieve shaker

ii) Hydrometer analysis: The hydrometer analysis of soil is based on Stokes law to calculate the size of soil particles from the speed at which they settle out of suspension in the water. For this study around 50g of dry soil passing 75 µm sieve was taken and mixed with distilled water and dispersing agent like sodium hexa-metaphosphate, (NaPO3)6 to form a gently mixed slurry. Then the prepared slurry was backfilled to a cylinder having 1000ml mark capacity and 152H hydrometer was immersed into the cylinder to record a reading as per ASTM D 7928 standard method. Then from recorded data percent finer and respective particle diameter was determined which shows the grain size distribution for soils finer than No.200 sieve. However, when this result was combined with a sieve analysis, it can offer a complete gradation profile called particle size distribution curve of soils and addresses some interesting information such as C_u and C_C which are obtained by the following equations.

$$C_u = \frac{D_{60}}{D_{10}} \quad \text{and} \quad C_C = \frac{(D_{30})^2}{D_{10} * D_{60}} \tag{32}$$

Where: D_{10}, D_{30}, and D_{60} are the particle size that corresponds to the percent finer of 10%, 30%, and 60%, respectively.

3.5.3. Atterberg limit

Atterberg limit tests are an investigation conducted on fine-grained soils to determine the amount of water required to attain different behavioral states. This test is done to determine the liquid limit, plastic limit, and the plasticity index of the soil samples which have significant role in soil classification system. The mass of dry sample passing through sieve No.40 (425 µm) was used to perform the tests. The tests were done by following ASTM D 4318 standard method.

Liquid limit (LL): is arbitrarily defined as the water content, in percent, at which a paste of soil in a standard cup and cut by a groove of standard dimensions will flow together at the base of the groove for a distance of 13 mm when subjected to 25 shocks from the cup being dropped 10 mm in a standard liquid limit apparatus operated at a rate of two shocks per second. To conduct the test first, the soil samples was exactly mixed with water by repeatedly stirring, kneading, and chopping with the spatula and placed it in the Casagrande cup. The cup containing the sample was lifted and dropped at a rate of 2 drops/sec until the two sides of the sample come in contact at the bottom of the groove, along with a distance of about 13 mm. The number of blows required to close the grove to this distance was recorded, and its moisture content was determined. The relationship between the water content and the number blow is plotted on xy plane and the water content correspond to 25 blows is called liquid limit of the materials.

Plastic limit (PL): is the water content at which soil change its state from a plastic to a semi-solid state. This test involves repeatedly rolling a soil pastes sample on a smooth glass plate into a 3 mm thread until it reaches a point where it crumbles. Then, water content of rolled thread was determined and recorded as a plastic limit.

Plasticity index (PI): is the difference between the liquid limit and the plastic limit of soil and described as the range of moisture at which a material behaves in a plastic state, which used in classifying fine-grained soils.

3.5.4. Linear shrinkage test

Linear shrinkage is the percentage decrease in length of a wet soil sample filled in to the standard mold when it gets fully dried, starting with a moisture content of the sample from liquid limit. The test was conducted based on BS 1377-2 standard method. To perform the test, an oven dried sample of about 150g passing through a sieve size of 425 µm is needed. Then a sample having known mass was mixed with water to attain its liquid limit. Finally, mud prepared was filled and compacted into standard mold which have greased its inner faces and put it inside an oven dry machine to remove available moisture in the soil sample and determine the compressed length of dry sample. Then linear shrinkage was calculated by the following equation, shown for every sample separately.

$$\text{Linear shrinkage(LS)} = \frac{(\mathrm{L_O} - \mathrm{L_D})}{\mathrm{L_O}} * 100\% \qquad (33)$$

Where: $\mathrm{L_O}$ is original length of wet sample and, $\mathrm{L_D}$ is oven dried length of dry sample.

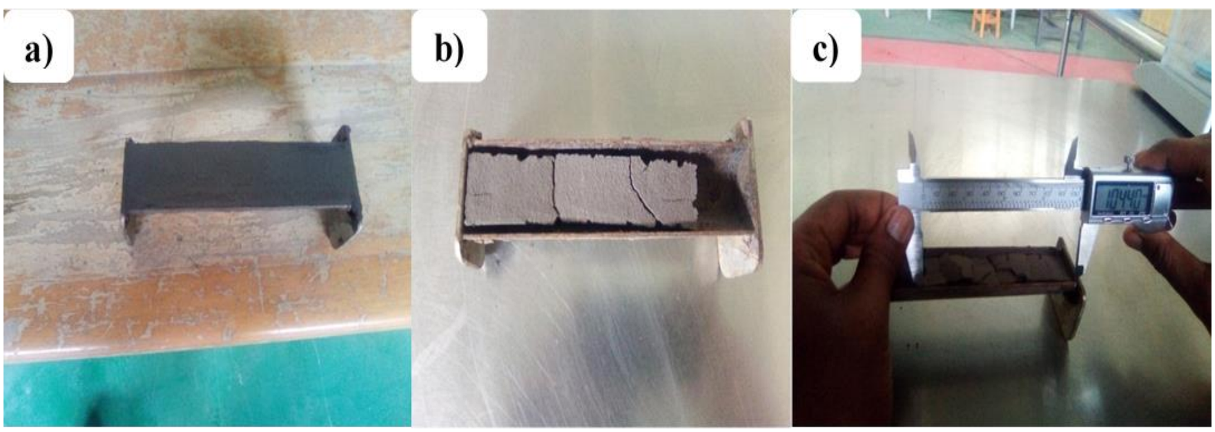

Figure 3-6: Linear shrinkage determination (a) wet sample prepared for drying (b) oven dried sample (c) measuring length of dry sample

3.5.5. Free swell index test

This is the simplest test conducted in the study to determine the swelling properties of the soil samples. The method was suggested by Holtz and Gibbs (1956) to measure the swelling potential of cohesive soils. Free swell index test was conducted following IS 2720-40, (1977) testing procedure. First two oven-dried soil samples passing through 425 µm sieve were taken and 10gm of each sample were placed separately in two 100ml graduated cylinder. The first cylinder is filled with kerosene and the other is filled with distilled water to the mark of 100ml and gently shaking or stirring the mixtures with a steel rod to remove entrapped air voids. Then allow the suspension to settle and attain the state of its equilibrium for a duration of not less than 24 hours. After that, final volumes of materials soaked were recorded and then FSI and FSR was calculated by using the following equations.

$$\mathrm{FSI} = \frac{(\mathrm{Vw} - \mathrm{Vk})}{\mathrm{Vk}} * 100\% \quad \& \quad \mathrm{FSR} = \frac{\mathrm{Vw}}{\mathrm{Vk}} \tag{34}$$

Where: V_w and V_k are volumes of soil specimen read from the graduated cylinder containing distilled water and kerosene, respectively.

3.5.6. Standard compaction test

Laboratory standard compaction tests were carried out on natural soil samples collected from study area to determine optimum moisture content and maximum dry density of material samples. In this research, standard proctor compaction test was implemented by 600KN-m/m^3 standard effort in the mold having 4 inches (101.6 mm) diameter & internal effective height of 4.6 inches (117 mm) under which the material was compacted into three layers by applying 25 blows in each layer (ASTM D 698, 2003). Moisture was started from 8% (200ml) for the initial sample, and the wet density was measured in each step until it becomes maximum and then decreasing after increasing water content. After measuring wet mass for each soil samples for different water content, a portion of each sample from top, middle and bottom was taken to an oven dry machine to determine average moisture content that was available in the soil. Then the dry density of each sample at different moisture content was determined using the following equation.

$$\rho_{dry}(\mathrm{g/cm^3}) = \frac{\rho_{wet},\ \mathrm{g/cm^3}}{1+ w} \tag{35}$$

Where: ρ_{dry} is dry density of sample, ρ_{wet} is wet (bulk) density of sample and w is average moisture content in decimal number.

Dry density obtained was limited to be under the linear portion called ZAV line which shows soil mass was below saturated condition and all void volume between particles was occupied by water, and it was determined by the following equation.

$$\gamma_{dry}(ZAV) = \frac{G_s \gamma_w}{1 + wG_s} \tag{36}$$

Where: $\gamma_{dry}(ZAV)$ is dry unit weight of saturated soil, γ_w is unit weight of water and w & G_s are respective average water content and specific gravity of samples.

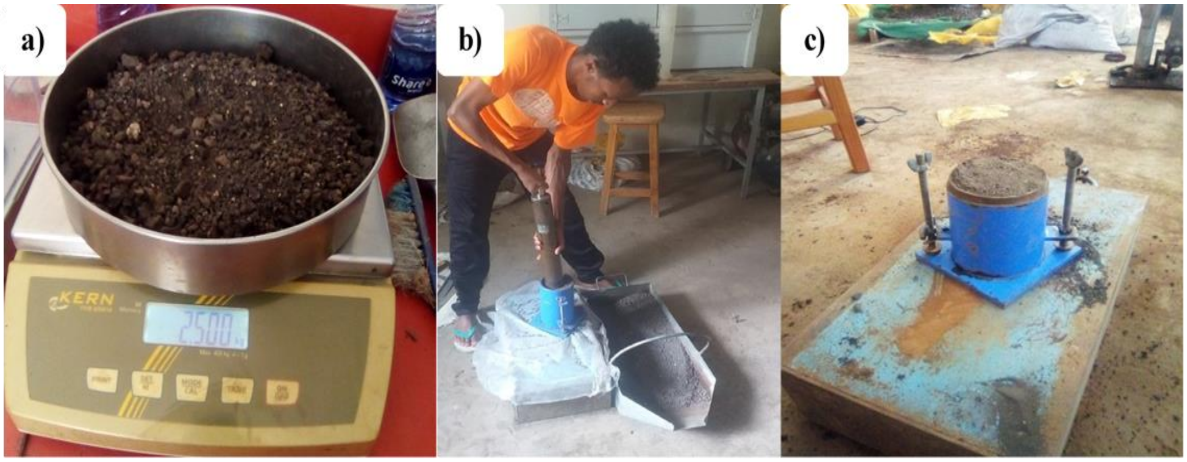

Figure 3-7: Standard compaction test (a) prepared soil sample (b) compaction operation (c) compacted sample

3.5.7. Consolidation test

The consolidation test was conducted according to the procedure given by ASTM D 2435 standard method. The samples for the consolidation test were prepared by mixing the soil with the respective optimum moisture content that was obtained from standard compaction test and then compacted to attain MDD in standard odometer specimen ring having 60 mm diameter and 20 mm height. The samples were fixed in the consolidation cell with height of 20 mm and immersed in water to make it under fully saturation. Then consolidation test was conducted by applying incremental loads starting with 50 KPa and ending with 1600 KPa. At each loading stage, the deformation at 0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30, 60, 120, 240, 480, and 1440 minutes was recorded on an observation sheet for further analysis using Casagrande's logarithm of time fitting method. When the loading of 1600KPa reached, unloading stages were start conducting by reducing constant load. This test was conducted for all natural soil samples to determine parameters such as compression index, coefficient of consolidation, coefficient of the volume of compressibility, and initial void ratio of samples.

Figure 3-8: Photographic view of consolidation machine ready for data recording

3.6. Analysis Methods Used

Generally in this analysis procedures the value of compression index (Cc) was considered as the dependent variable whereas the liquid limit (LL), plastic limit (PL), plasticity index (PI), optimum moisture content (OMC), and maximum dry density (MDD) values were the independent variables. In conducting out the statistical analysis, statistical software program called SPSS-27 was used to determine the scatter plot, correlation and regression. The Microsoft excel spread sheet was also used as another option which is found as the most powerful and easily manageable tool for scatter plot analysis and determination of correlation between two variables.

However, when determination of the relationships among 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. A Computer Program used for statistical analysis and data management called SPSS-27 was used to develop the empirical equations which correlate compression index with index properties such as OMC, MDD, PL, LL, and PI. It can take data from almost any type of file and use them to generate tabulated reports, charts, and plots of distributions and trends, descriptive statistics, and conduct complex statistical analyses.

The linear regression equations take the form:

$$y = mx + b \tag{37}$$

The "m" is regression coefficient, representing the amount the dependent variable changes when the independent changes in single unit. The "b" is the constant, where the regression line intercepts the y-axis; representing the amount the dependent variable "y" will be when all the independent variables become zero.

To determine the strength and select best fit from each correlation the R^2 value for the trend line was calculated. R^2 is the relative predictive power of a model and is a descriptive measure between 0 and 1. The closer it is to one the greater the ability for the equation to predict an outcome or the great relationship between variables. And also, root mean square error (RMSE) is other factor to select best model from the proposed ones. The lowest RMSE value of models, the more accurate result of compression index was predicted with that empirical formula.

$$R^2 = \frac{\sum(\mathrm{Var}_{\mathrm{mean}}) - \sum(\mathrm{Var}_{\mathrm{line}})}{\sum(\mathrm{Var}_{\mathrm{mean}})} \tag{38}$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N}\sum_{1}^{N}(C_c, \mathrm{pred} - C_c, \mathrm{act})^2} \tag{39}$$

Where, $\mathrm{Var}_{\mathrm{mean}}$= variation of scatter point from mean line, $\mathrm{Var}_{\mathrm{line}}$= variation of scatter point from fitted line, N= number of data point, C_c, pred = predicted compression index value of each model, and C_c, act = actual compression index value determined from laboratory test.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Overview

Laboratory experiments including specific gravity, particle size distribution, free swell index, Atterberg limit, standard compaction, and one-dimensional consolidation tests were done on different 16 soil samples collected from all respective test pits to classify and determine the relationship between compression index to other index properties like optimum moisture content, maximum dry density and consistency limits. Therefore, based on obtained test results data was entered to SPSS-27 software and analyzed for linear regression to obtain the relationship between properties as per formulated objectives. Finally, the developed correlation equations was validated with either previously formulated equation or observed results during this study.

4.1.1. Particle size distribution analysis of soil samples

Table 4-1: Summary of particle size analysis soil samples

Sample	Source	Combination of particles size (%)			
		≥ 4.75 mm (Gravel)	0.075 mm-4.75mm (Sand)	0.075 mm-0.002 mm (Silt)	≤ 0.002 mm (Clay)
TP-1	2 m	1.3	4.9	40.07	53.73
TP-2	2 m	2.2	4	40.01	53.79
TP-3	2 m	1.7	6.7	35.48	56.12
TP-4	2 m	2	9.8	34.88	53.32
TP-5	2 m	2.2	10	33.68	54.12
TP-6	2 m	2.3	9.9	35.1	52.7
TP-7	2 m	2	10	36.58	51.42
TP-8	2 m	2.5	11.3	33.86	52.34
TP-9	2 m	2.2	10.4	36.09	51.31
TP-10	2 m	1.5	9.6	37.3	51.6
TP-11	2 m	2	8.77	38.98	50.25
TP-12	2 m	2.3	9.1	33.54	55.06
TP-13	2 m	2.4	8.8	38.45	50.35
TP-14	2 m	2.2	9.3	36.71	51.79
TP-15	2 m	2.6	10.4	36.5	50.5
TP-16	2 m	2.3	9.6	35.29	52.81

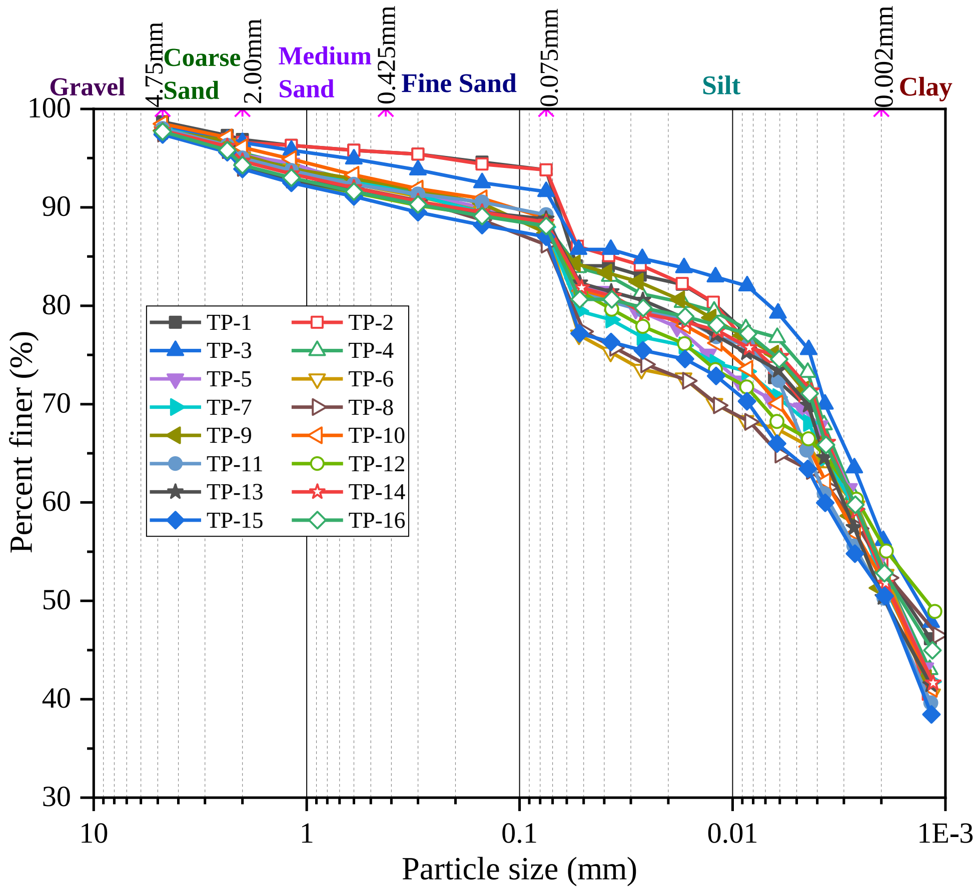

Figure 4-1: Particle size distribution curves of soil samples used for the study

Particle size analysis is the quantitative determination of the distribution of particle size in soils which is performed under the control of ASTM D 6913, (2004) for coarse-grained soils and ASTM D 7928, (2021) fine-grained soils. From table 4-1, for all soil samples collected study area majority of material sample was finer through sieve size of 75 microns which means all samples were categorized under fine grained soil. Referring plasticity chart under USCS, all soil samples have liquid limit greater than 50% and falls above A-line which categorized as CH, inorganic fat clay having high plasticity group. Again, from plasticity chart under AASHTO classification system, all soil samples fall under A-7-5 group having group index of 20.

4.1.2. Atterberg limit of natural soil

Atterberg limit test results include liquid limit, plastic limit, plastic index and linear shrinkage result under which all are followed by (ASTM D 4318, 2000) except BS 1377-2, (1990) was used to determine linear shrinkage property of soil.

From test result summary shown in table 4-5; liquid limit, plastic limit, plasticity index and linear shrinkage of soil samples from TP-1 to TP-16 ranges between (81% & 85.66%), (33.05%

& 35.07%), (47.80% & 50.59%), and (18.27% & 25.12%) respectively. The result shows that the soils in the study area are highly plastic with high plasticity index values. Plastic limit and plasticity index result obtained are mainly used in soil classification system and shows soil grouped as CH and A-7-5 (20) as per USCS and AASHTO system respectively. The size of linear shrinkage is used to characterize soil and interpret cracking size & characteristics occurred due to seasonal moisture variation.

4.1.3. Free swell index of soil samples

Free swell is the increase in volume of a soil, without any external constraints, due to submergence in water and used to identify the potential of a soil to swell which might need further detailed investigation regarding swelling and swelling pressures under different field conditions. The test was performed under control of IS 2720 part 40, (2002) standard method.

Table 4-2: FSI and FSR result of soil samples

Designation	FSI (%)	FSR	Degree of expansiveness based on FSI, LL, and PI
TP-1	99.00	1.99	Very high
TP-2	96.47	1.96	Very high
TP-3	96.00	1.96	Very high
TP-4	99.00	1.99	Very high
TP-5	94.00	1.94	Very high
TP-6	91.00	1.91	Very high
TP-7	95.00	1.95	Very high
TP-8	89.00	1.89	Very high
TP-9	93.40	1.93	Very high
TP-10	90.10	1.90	Very high
TP-11	89.00	1.89	Very high
TP-12	93.60	1.94	Very high
TP-13	94.80	1.95	Very high
TP-14	93.00	1.93	Very high
TP-15	89.60	1.90	Very high
TP-16	90.50	1.91	Very high

The soil samples from study area have FSI and FSR ranges between (89% & 99%) and (1.89 &1.99) respectively from which material from first and fourth test pit have more swelling potential when compared with others.

4.1.4. Standard compaction test result of natural soil

Compaction of soils is a procedure in which soil sustains under mechanical stress is densified by reducing the volume of void in the mass. Soil mass consists of solid particles and voids filled with water or/and air. When soil is subjected to stress, soil particles are redistributed within the soil mass and the void volume decreases, resulting in densification. The test follows ASTM D 698, (2000) standard procedures and used to increase strength, decrease compressibility and permeability of soils.

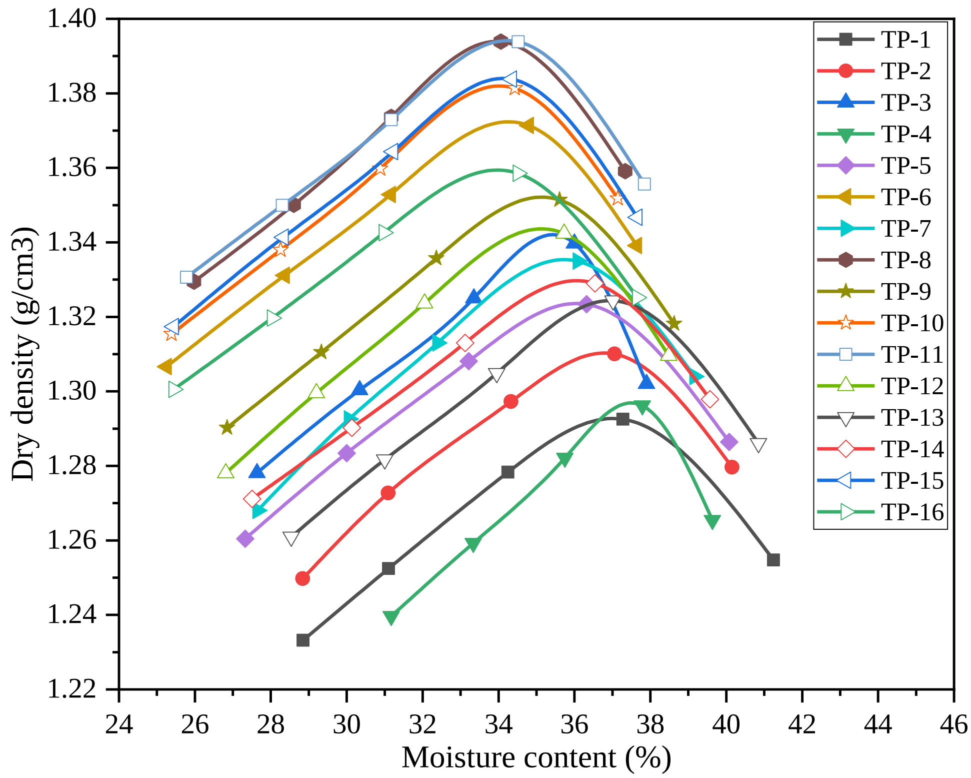

Figure 4-2: Compaction curves of soil samples

Results obtained reveals that OMC result soil samples was ranges between 34.06% & 37.79%, again MDD ranges between 1.29g/cm^3 to 1.39g/cm^3 as shown on figure 4-2.

4.1.5. Compressibility characteristics of soil samples

Table 4-3: Summary of consolidation test result of specimens for TP-1 to TP-8

Cases	P (kPa)	Sample type							
		TP-1	TP-2	TP-3	TP-4	TP-5	TP-6	TP-7	TP-8
e (loading)	50	1.096	0.901	0.951	1.059	0.947	0.921	0.990	0.793
	100	0.991	0.829	0.875	0.945	0.887	0.889	0.968	0.763
	200	0.906	0.732	0.759	0.829	0.823	0.835	0.907	0.720
	400	0.807	0.668	0.662	0.690	0.742	0.769	0.840	0.677
	800	0.705	0.625	0.582	0.573	0.656	0.688	0.771	0.646
	1600	0.577	0.559	0.478	0.462	0.552	0.605	0.699	0.605
e (unloading)	50	0.644	0.586	0.534	0.544	0.643	0.651	0.714	0.639
	100	0.632	0.585	0.523	0.531	0.634	0.644	0.711	0.632
	200	0.622	0.582	0.507	0.515	0.616	0.632	0.707	0.624

	400	0.612	0.571	0.488	0.494	0.598	0.619	0.704	0.618
	800	0.599	0.565	0.475	0.484	0.578	0.612	0.701	0.611
	1600	0.577	0.559	0.478	0.462	0.552	0.605	0.699	0.605
C_C		0.339	0.323	0.267	0.370	0.269	0.180	0.259	0.145
e_0		0.969	0.981	0.975	0.987	0.935	0.950	0.998	0.960
C_V (cm^2/min)		0.011	0.020	0.024	0.023	0.028	0.049	0.038	0.047
Average m_v (Mpa^{-1})		0.392	0.296	0.354	0.459	0.268	0.186	0.165	0.140

Table 4-4: Summary of consolidation test result of specimens for TP-9 to TP-16

Cases	P (kPa)	Sample type							
		TP-9	TP-10	TP-11	TP-12	TP-13	TP-14	TP-15	TP-16
e (loading)	50	0.929	0.956	0.958	0.934	0.870	0.868	0.967	0.878
	100	0.884	0.924	0.933	0.912	0.806	0.809	0.931	0.841
	200	0.814	0.868	0.884	0.877	0.720	0.730	0.885	0.781
	400	0.752	0.801	0.844	0.821	0.659	0.680	0.834	0.729
	800	0.673	0.719	0.787	0.753	0.609	0.631	0.782	0.665
	1600	0.595	0.644	0.714	0.633	0.566	0.590	0.728	0.600
e (unloading)	50	0.643	0.685	0.763	0.702	0.610	0.620	0.794	0.647
	100	0.637	0.676	0.747	0.685	0.600	0.610	0.768	0.640
	200	0.627	0.668	0.734	0.668	0.590	0.603	0.752	0.630
	400	0.615	0.659	0.727	0.654	0.580	0.599	0.743	0.622
	800	0.604	0.651	0.721	0.644	0.571	0.593	0.734	0.611
	1600	0.595	0.644	0.714	0.633	0.566	0.590	0.728	0.600
C_C		0.262	0.185	0.160	0.224	0.288	0.262	0.153	0.198
e_0		0.976	0.986	0.988	0.950	0.941	0.932	0.953	0.918
C_V (cm^2/min)		0.039	0.048	0.055	0.047	0.024	0.025	0.051	0.046
Ave. m_v (Mpa^{-1})		0.223	0.184	0.144	0.142	0.271	0.247	0.168	0.193

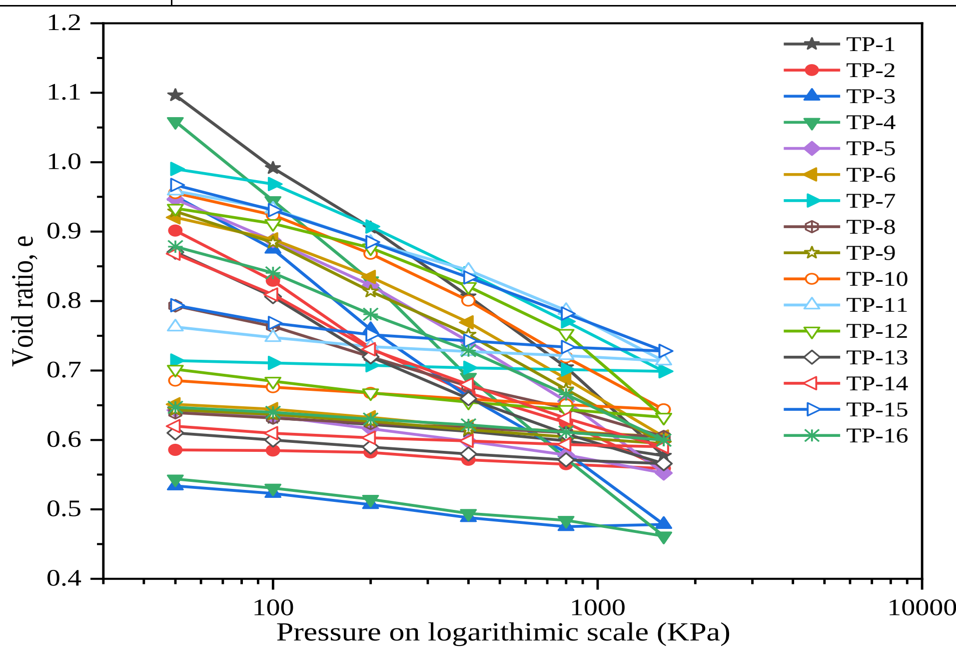

Figure 4-3: Variation of e versus log P of soil samples

From figure 4-3 and table 4-3 to 4-4, one dimensional consolidation results of soil samples reveals that initial void ratio, compression index, coefficient of consolidation and coefficient of volume compressibility ranges between (0.92 to 1), (0.15 to 0.37), (0.01 cm^2/min to 0.05 cm^2/min), and (0.14MPa^{-1} to 0.46MPa^{-1}) respectively.

Table 4-5: Test result summary of basic soil properties

Sample	G_S	OMC (%)	MDD (g/cm^3)	PL (%)	LL (%)	LS (%)	C_C	USCS	AASHTO
TP-1	2.606	37.28	1.29	34.97	84.70	23.97	0.339	CH	A-7-5
TP-2	2.602	37.06	1.31	35.03	85.50	23.34	0.323	CH	A-7-5
TP-3	2.610	36	1.34	34.51	84.38	21.96	0.267	CH	A-7-5
TP-4	2.618	37.79	1.3	35.07	85.66	25.12	0.370	CH	A-7-5
TP-5	2.500	36.32	1.32	34.46	83.63	23.04	0.269	CH	A-7-5
TP-6	2.700	34.79	1.37	33.37	81.64	19.13	0.180	CH	A-7-5
TP-7	2.670	36.09	1.33	34.20	83.91	22.26	0.259	CH	A-7-5
TP-8	2.801	34.06	1.39	33.10	81.06	18.27	0.145	CH	A-7-5
TP-9	2.463	35.61	1.35	34.41	82.95	22.90	0.262	CH	A-7-5
TP-10	2.700	34.43	1.38	33.48	82.00	20.90	0.185	CH	A-7-5
TP-11	2.680	34.52	1.39	33.31	81.45	19.79	0.160	CH	A-7-5
TP-12	2.690	35.73	1.34	33.80	82.83	20.66	0.224	CH	A-7-5
TP-13	2.650	37.02	1.32	34.70	84.20	23.47	0.288	CH	A-7-5
TP-14	2.710	36.54	1.33	34.27	83.80	22.51	0.262	CH	A-7-5
TP-15	2.700	34.35	1.38	33.05	81.00	20.04	0.153	CH	A-7-5
TP-16	2.650	34.51	1.36	33.80	81.60	21.19	0.198	CH	A-7-5

4.2. Correlation of Compression Index with Different Index Properties

4.2.1. Relationship between C_C and OMC

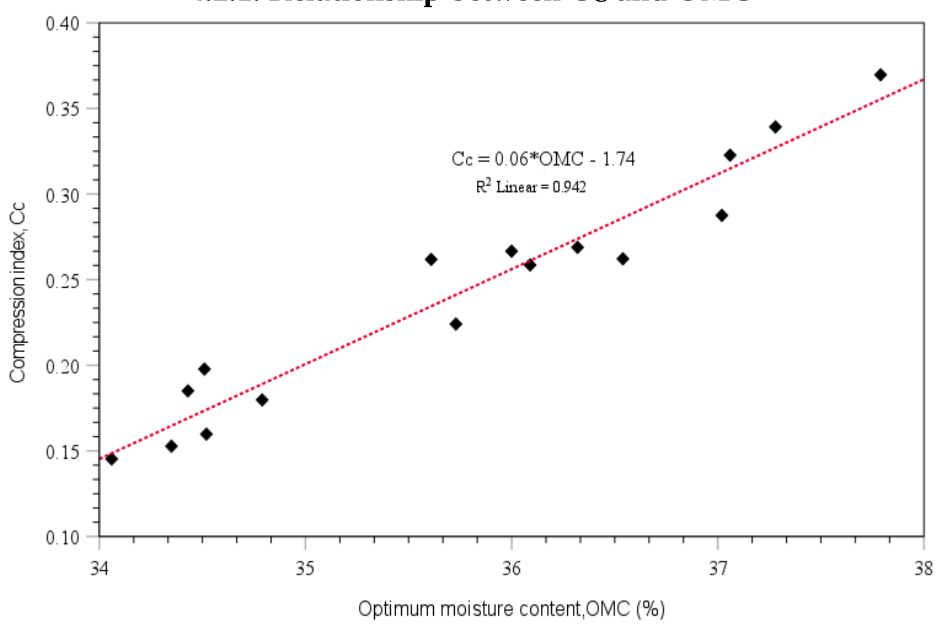

Figure 4-4: Observed Cc and OMC with linear regression analysis

Figure 4-4 reveals the relationship between compression index and optimum moisture content of Akaki Kality soil which follows increasing fashion with correlation coefficient of 0.942. similar result was obtained by (Sen & Pal, 2017).

4.2.2. Relationship between C_C and MDD

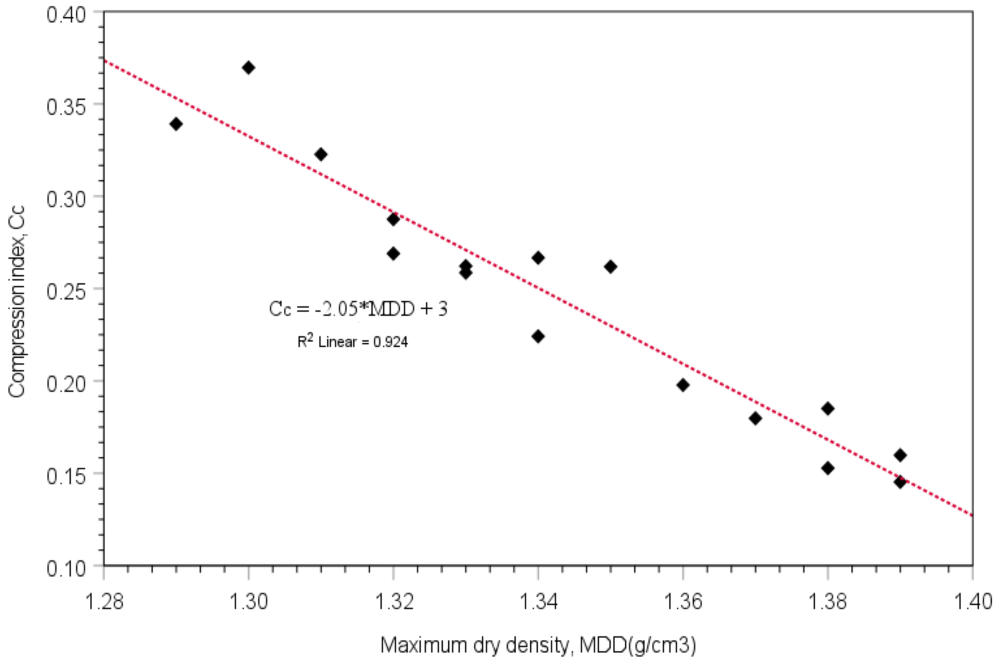

Figure 4-5: Observed Cc and MDD with linear regression analysis

Figure 4-5 reveals the relationship between compression index and maximum dry density of soil from the study area which follows decreasing fashion with correlation coefficient of 0.924 and similar result was obtained by (Akbarimehr *et al*., 2021; Apu *et al*., 2021).

4.2.3. Relationship between Cc and PL

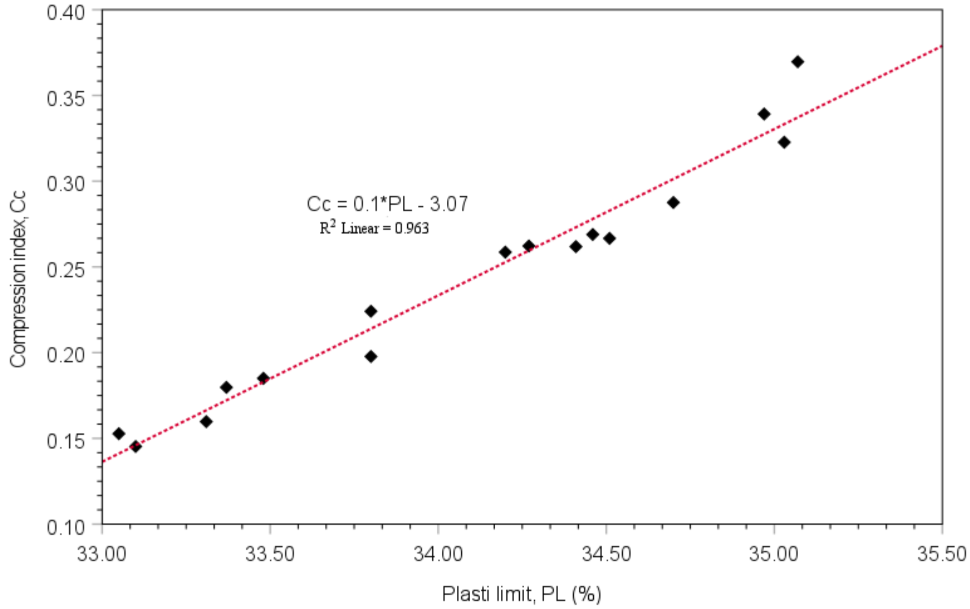

Figure 4-6: Observed Cc and PL with linear regression analysis

Figure 4-6 shows the relationship between compression index and plastic limit of soil from the study area which follows decreasing fashion with correlation coefficient of 0.963 and similar result was obtained by (Kabeta *et al*., 2022).

4.2.4. Relationship between Cc and LL

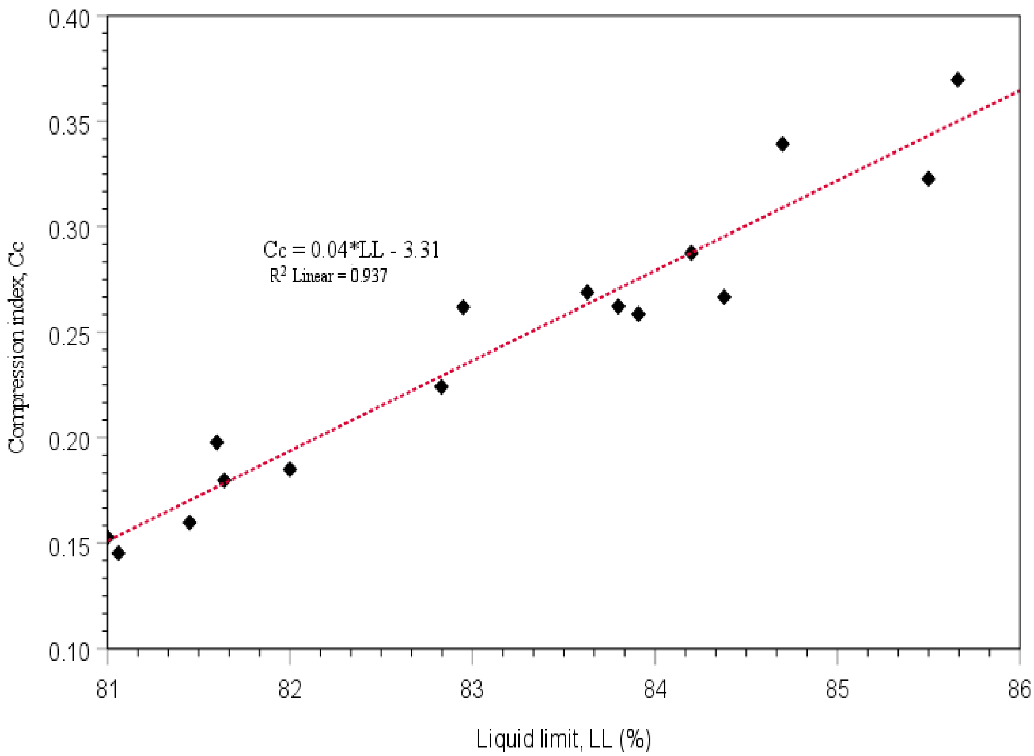

Figure 4-7: Observed Cc and LL with linear regression analysis

Figure 4-7 shows the relationship between compression index and liquid limit of soil from the study area which follows decreasing fashion with correlation coefficient of 0.937 and similar result was obtained by (Kabeta *et al*., 2022).

4.2.5. Relationship between Cc and PI

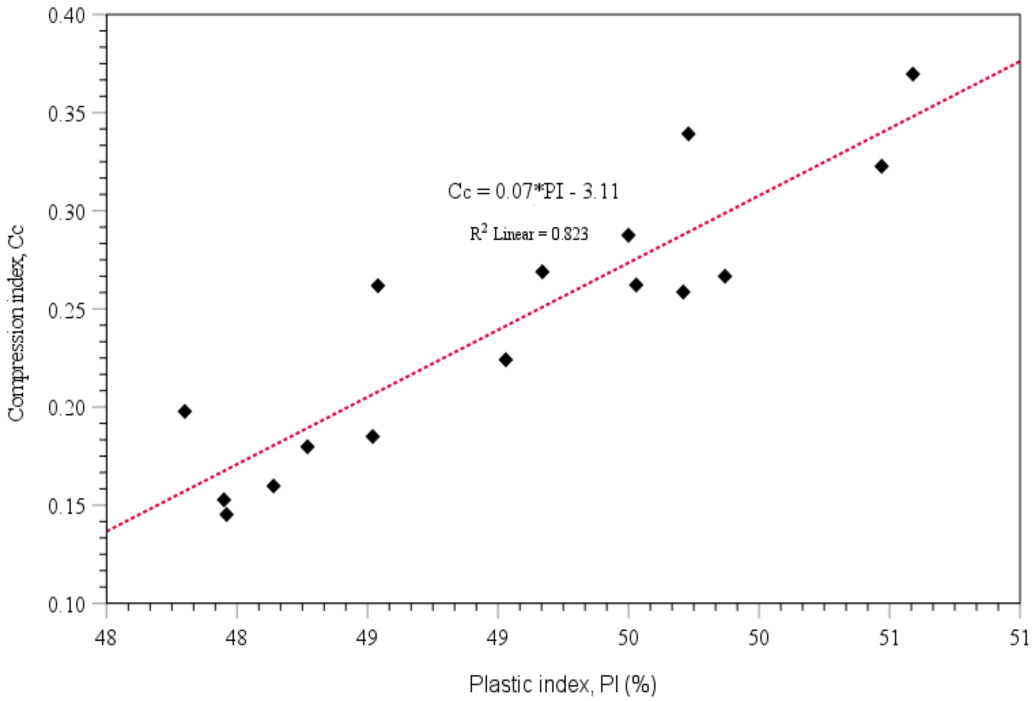

Figure 4-8: Observed Cc and PI with linear regression analysis

Figure 4-8 shows the relationship between compression index and plasticity index of soil from the study area which follows decreasing fashion with correlation coefficient of 0.823 and similar result was obtained by (Kabeta *et al*., 2022).

4.3. Validation and Selection of Best Fit Model

Table 4-6: Estimated and determined Cc values of soil samples

Test Pits	Actual Cc values	Predicted Cc values						
		Cc from OMC	Cc from MDD	Cc from PL	Cc from LL	Cc from PI	Cc from OMC & MDD	Cc from LL & PI
TP-1	0.339	0.497	0.356	0.427	0.311	0.371	0.348	0.287
TP-2	0.323	0.484	0.315	0.433	0.345	0.423	0.325	0.302
TP-3	0.267	0.420	0.253	0.381	0.297	0.381	0.264	0.252
TP-4	0.370	0.527	0.335	0.437	0.352	0.431	0.359	0.307
TP-5	0.269	0.439	0.294	0.376	0.265	0.332	0.290	0.238
TP-6	0.180	0.347	0.192	0.267	0.180	0.269	0.197	0.139
TP-7	0.259	0.425	0.274	0.350	0.277	0.370	0.274	0.225
TP-8	0.145	0.304	0.151	0.240	0.155	0.247	0.156	0.113
TP-9	0.262	0.397	0.233	0.371	0.236	0.288	0.242	0.225

TP-10	0.185	0.326	0.171	0.278	0.196	0.286	0.177	0.151
TP-11	0.160	0.331	0.151	0.261	0.172	0.260	0.172	0.132
TP-12	0.224	0.404	0.253	0.310	0.231	0.322	0.254	0.183
TP-13	0.288	0.481	0.294	0.400	0.289	0.355	0.316	0.262
TP-14	0.262	0.452	0.274	0.357	0.272	0.357	0.291	0.228
TP-15	0.153	0.321	0.171	0.235	0.153	0.247	0.174	0.108
TP-16	0.198	0.331	0.212	0.310	0.178	0.236	0.195	0.166

Table 4-7: Summary of proposed empirical equations with their RMSE and R^2

Model	Equations	R^2	RMSE	N
1	$C_c = 0.06 * OMC - 1.74$	0.942	0.164	16
2	$C_c = -2.05 * MDD + 3$	0.924	0.018	16
3	$C_c = 0.1 * PL - 3.07$	0.963	0.098	16
4	$C_c = 0.04 * LL - 3.31$	0.937	0.017	16
5	$C_c = 0.07 * PI - 3.11$	0.823	0.085	16
6	$C_c = 0.036 * OMC - 0.763 * MDD - 0.01$	0.950	0.017*	16
7	$C_c = 0.08 * LL - 0.066 * PI - 3.207$	0.971	0.037	16

* Shows that the model obtained have high R^2 and less RMSE value which selected as better fit.

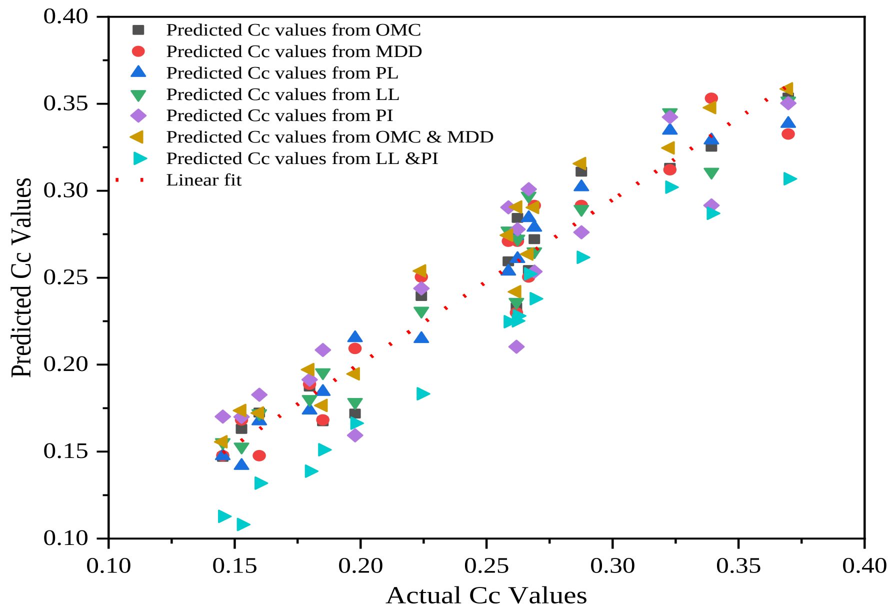

Figure 4-9: Graph of actual Cc plotted against predicted Cc

For validation of the all seven prediction models, 16 control tests which cover 100% of the total data were used. Table 4-6 shows the actual Cc values, and predicted Cc values from actual OMC, MDD, PL, LL, and PI values through using model 1 to 7.

There is no existing equation developed to predict Cc values from index parameters for Akaki Kality soil, except the current model. Therefore the result of currently developed models is compared with the actual values of Cc used in this study. Figure 4-9 shows the graph plotted using actual experimental Cc and the Cc predicted by the developed correlation equations. The point at which the predicted Cc equals the experimental Cc is represented by a straight line. Most of the points are found to be very close to the straight line. This shows that the prediction equation can be used for preliminary characterization of the compression index of the soil in the study area.

But when the models were compared to each other, empirical equation of Cc related with liquid limit (Cc= 0.036*OMC-0.763*MDD-0.01) was selected as the best fit because of it have less RMSE and almost the same correlation coefficient with other models. And also on figure 4-9 light brown backward arrow symbol representing the predicted result of the model is more close to straight dot line than others which is additional confirmation as it was the best fit model.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This paper was aimed to investigate the relationship between compression index and index properties like OMC, MDD, PL, LL and PI of expansive soils of Akaki Kality area through linear regression using SPSS-27. Finally, the following results were obtained and concluded as follows.

- All soil samples collected from the area fine grained materials having liquid limit greater than 50% and falls above A-line which categorized them as CH, inorganic fat clay having high plasticity group using USCS and A-7-5 group having GI of 20 as per AASHTO classification system.
- There are seven different models formulated with different correlation equations having respective R^2 and RMSE values. The correlation is done to relate compression index with OMC, MDD, PL, LL, and PI values and come up with (Cc= 0.06*OMC-1.74, R2=0.942, RMSE=0.164), (Cc= -2.05*MDD+3, R2=0.924, RMSE=0.018), (Cc=0.1*PL-3.07, R2=0.963, RMSE=0.098), (Cc= 0.04*LL-3.31, R^2=0.937, RMSE=0.017), (Cc= 0.07*PI-3.11, R^2=0.823, RMSE=0.085), (Cc= 0.036*OMC-0.763*MDD-0.01, R^2=0.950, RMSE=0.017), and (Cc= 0.08*LL-0.066*PI-3.207, R^2=0.971, RMSE=0.037) results respectively.
- Linear correlation model formulated from OMC and MDD was proposed as the most accurate and best empirical formula to determine compression index of soil for this study.

5.2. Recommendation and Limitation of the Study

- ✓ For this study only sixteen test pits was taken and assumed as overall representatives of soil samples from the study area due to limitation of budget and resources. Therefore it should be recommended for further studies by incorporating more number of test pits.
- ✓ The study was tried to investigate only relationship between Cc with limited index properties, but it should also be mentioned to consider for the correlations of compression index with other more index properties.

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APPENDICES

Appendix-A: Specific Gravity of Materials Used for the Study

Table A-1: Specific gravity of soil sample collected from TP-1

S. No.	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	50.8	49.76
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.95	146.5
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.6	153.12
6	Temperature of M_b measured, T (°C)	20.6	21.6
7	Density of water at T (°C), $P_{w\ (T)}$	0.99808	0.99786
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.89	146.42
9	Weight of dry material,M_s (gm)	10.88	10.86
10	Specific gravity of material at T °C, G_T	2.606	2.606
11	Correction Factor	0.99987	0.99966
12	Specific gravity of material at 20 °C, G_{20}	2.606	2.606
13	Average G_s	2.606	

Table A-2: Specific gravity of soil sample collected from TP-2

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	43.86	43.73
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.68	146.49
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.22	152.74
6	Temperature of M_b measured, T (°C)	22.5	21.5
7	Density of water at T (°C), $P_{w\ (T)}$	0.99766	0.99789
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.57	146.41
9	Weight of dry material,M_s (gm)	10.79	10.265
10	Specific gravity of material at T °C, G_T	2.601	2.606
11	Correction Factor	0.99945	0.99968
12	Specific gravity of material at 20 °C, G_{20}	2.599	2.605
13	Average G_s	2.602	

Table A-3: Specific gravity of soil sample collected from TP-3

S. No	Specific gravity determination parameters	Pycnometer Id.

		A	B
1	Weight of Pycnometer, M_p(gm)	43.96	43.93
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.65	146.46
3	Temperature of water at Ma' measured, T' (°C)	17.1	17.3
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99876	0.99872
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.2	152.72
6	Temperature of M_b measured, T (°C)	22.5	21.5
7	Density of water at T (°C), $P_{w\ (T)}$	0.99766	0.99789
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.54	146.37
9	Weight of dry material,M_s (gm)	10.79	10.265
10	Specific gravity of material at T °C, G_T	2.608	2.613
11	Correction Factor	0.99945	0.99968
12	Specific gravity of material at 20 °C, G_{20}	2.607	2.612
13	Average G_s	2.610	

Table A-4: Specific gravity of soil sample collected from TP-4

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer,M_p(gm)	43.94	43.96
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.84	146.67
3	Temperature of water at Ma' measured, T' (°C)	17.8	17.8
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99863	0.99863
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.37	152.87
6	Temperature of M_b measured, T (°C)	22	22
7	Density of water at T (°C), $P_{w\ (T)}$	0.99777	0.99777
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.75	146.58
9	Weight of dry material,M_s(gm)	10.7	10.15
10	Specific gravity of material at T °C, G_T	2.616	2.623
11	Correction Factor	0.99957	0.99957
12	Specific gravity of material at 20 °C, G_{20}	2.615	2.621
13	Average G_s	2.618	

Table A-5: Specific gravity of soil sample collected from TP-5

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	33.49	34.14
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	133.26	134.16
3	Temperature of water at Ma' measured, T' (°C)	17.4	17.4

4	Density of water at T' (°C), $P_{w\ (T')}$	0.99872	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	139.29	140.3
6	Temperature of M_b measured, T (°C)	22.4	21.8
7	Density of water at T (°C), $P_{w\ (T)}$	0.99768	0.99782
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	133.16	134.07
9	Weight of dry material,M_s(gm)	10.21	10.355
10	Specific gravity of material at T °C, G_T	2.499	2.504
11	Correction Factor	0.99947	0.99961
12	Specific gravity of material at 20 °C, G_{20}	2.498	2.503
13	Average G_s	2.501	

Table A-1: Specific gravity of soil sample collected from TP-6

S. No.	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	43.8	43.76
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.81	146.36
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.6	153.12
6	Temperature of M_b measured, T (°C)	20.6	21.6
7	Density of water at T (°C), $P_{w\ (T)}$	0.99808	0.99786
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.74	146.27
9	Weight of dry material,M_s (gm)	10.88	10.86
10	Specific gravity of material at T °C, G_T	2.700	2.701
11	Correction Factor	0.99987	0.99966
12	Specific gravity of material at 20 °C, G_{20}	2.700	2.700
13	Average G_s	2.700	

Table A-2: Specific gravity of soil sample collected from TP-7

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	43.86	43.73
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.57	146.39
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.22	152.74
6	Temperature of M_b measured, T (°C)	22.5	21.5
7	Density of water at T (°C), $P_{w\ (T)}$	0.99766	0.99789

8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.46	146.31
9	Weight of dry material, M_s (gm)	10.79	10.265
10	Specific gravity of material at T °C, G_T	2.672	2.671
11	Correction Factor	0.99945	0.99968
12	Specific gravity of material at 20 °C, G_{20}	2.670	2.670
13	Average G_s	2.67	

Table A-3: Specific gravity of soil sample collected from TP-8

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p(gm)	43.66	43.53
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.37	146.20
3	Temperature of water at Ma' measured, T' (°C)	17.9	17.5
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99876	0.99872
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.2	152.72
6	Temperature of M_b measured, T (°C)	22.5	21.5
7	Density of water at T (°C), $P_{w\ (T)}$	0.99766	0.99789
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.25	146.11
9	Weight of dry material, M_s (gm)	10.79	10.265
10	Specific gravity of material at T °C, G_T	2.802	2.803
11	Correction Factor	0.99945	0.99968
12	Specific gravity of material at 20 °C, G_{20}	2.800	2.802
13	Average G_s	2.801	

Table A-4: Specific gravity of soil sample collected from TP-9

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p(gm)	43.9	43.79
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	147.09	146.92
3	Temperature of water at Ma' measured, T' (°C)	18	17.8
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99863	0.99863
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.37	152.87
6	Temperature of M_b measured, T (°C)	22	22
7	Density of water at T (°C), $P_{w\ (T)}$	0.99777	0.99777
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	147.00	146.83
9	Weight of dry material, M_s(gm)	10.7	10.15
10	Specific gravity of material at T °C, G_T	2.465	2.463
11	Correction Factor	0.99957	0.99957

12	Specific gravity of material at 20 °C, G_{20}	2.464	2.462
13	Average G_s	2.463	

Table A-5: Specific gravity of soil sample collected from TP-10

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	33.29	34.11
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	132.95	133.86
3	Temperature of water at Ma' measured, T' (°C)	17.3	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99872	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	139.29	140.3
6	Temperature of M_b measured, T (°C)	22.4	21.8
7	Density of water at T (°C), $P_{w\ (T)}$	0.99768	0.99782
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	132.85	133.77
9	Weight of dry material,M_s(gm)	10.21	10.355
10	Specific gravity of material at T °C, G_T	2.702	2.701
11	Correction Factor	0.99947	0.99961
12	Specific gravity of material at 20 °C, G_{20}	2.700	2.699
13	Average G_s	2.7	

Table A-1: Specific gravity of soil sample collected from TP-11

S. No.	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	43.8	43.76
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.84	146.39
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.6	153.12
6	Temperature of M_b measured, T (°C)	20.6	21.6
7	Density of water at T (°C), $P_{w\ (T)}$	0.99808	0.99786
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.77	146.30
9	Weight of dry material,M_s (gm)	10.88	10.86
10	Specific gravity of material at T °C, G_T	2.680	2.681
11	Correction Factor	0.99987	0.99966
12	Specific gravity of material at 20 °C, G_{20}	2.680	2.680
13	Average G_s	2.68	

Table A-2: Specific gravity of soil sample collected from TP-12

S. No	Specific gravity determination parameters	Pycnometer Id.

		A	B
1	Weight of Pycnometer, M_p (gm)	43.86	43.73
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.54	146.37
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.22	152.74
6	Temperature of M_b measured, T (°C)	22.5	21.5
7	Density of water at T (°C), $P_{w\ (T)}$	0.99766	0.99789
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.43	146.28
9	Weight of dry material,M_s (gm)	10.79	10.265
10	Specific gravity of material at T °C, G_T	2.692	2.690
11	Correction Factor	0.99945	0.99968
12	Specific gravity of material at 20 °C, G_{20}	2.690	2.689
13	Average G_s	2.69	

Table A-3: Specific gravity of soil sample collected from TP-13

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p(gm)	43.9	43.83
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.58	146.41
3	Temperature of water at Ma' measured, T' (°C)	17.1	17.3
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99876	0.99872
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.2	152.72
6	Temperature of M_b measured, T (°C)	22.5	21.5
7	Density of water at T (°C), $P_{w\ (T)}$	0.99766	0.99789
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.47	146.32
9	Weight of dry material,M_s (gm)	10.79	10.265
10	Specific gravity of material at T °C, G_T	2.653	2.650
11	Correction Factor	0.99945	0.99968
12	Specific gravity of material at 20 °C, G_{20}	2.652	2.649
13	Average G_s	2.65	

Table A-4: Specific gravity of soil sample collected from TP-14

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer,M_p(gm)	43.6	43.59
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.69	146.55
3	Temperature of water at Ma' measured, T' (°C)	17.8	17.8

4	Density of water at T' (°C), $P_{w\ (T')}$	0.99863	0.99863
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.37	152.87
6	Temperature of M_b measured, T (°C)	22	22
7	Density of water at T (°C), $P_{w\ (T)}$	0.99777	0.99777
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.60	146.46
9	Weight of dry material,M_s(gm)	10.7	10.15
10	Specific gravity of material at T °C, G_T	2.716	2.707
11	Correction Factor	0.99957	0.99957
12	Specific gravity of material at 20 °C, G_{20}	2.715	2.706
13	Average G_s	2.71	

Table A-5: Specific gravity of soil sample collected from TP-15

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	33.59	34.61
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	132.96	133.85
3	Temperature of water at Ma' measured, T' (°C)	17.3	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99872	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	139.29	140.3
6	Temperature of M_b measured, T (°C)	22.4	21.8
7	Density of water at T (°C), $P_{w\ (T)}$	0.99768	0.99782
8	Weight of (Pycnometer + water) at T °C, M_a (gm)	132.86	133.77
9	Weight of dry material,M_s(gm)	10.21	10.355
10	Specific gravity of material at T °C, G_T	2.697	2.704
11	Correction Factor	0.99947	0.99961
12	Specific gravity of material at 20 °C, G_{20}	2.696	2.703
13	Average G_s	2.7	

Table A-5: Specific gravity of soil sample collected from TP-16

S. No	Specific gravity determination parameters	Pycnometer Id.	
		A	B
1	Weight of Pycnometer, M_p (gm)	43.78	43.76
2	Weight of (Pycnometer + water), $M_{a'}$ (gm)	146.88	146.44
3	Temperature of water at Ma' measured, T' (°C)	17.2	17.4
4	Density of water at T' (°C), $P_{w\ (T')}$	0.99874	0.99871
5	Weight of (Pycnometer + material + Water, M_b (gm)	153.6	153.12
6	Temperature of M_b measured, T (°C)	20.6	21.6
7	Density of water at T (°C), $P_{w\ (T)}$	0.99808	0.99786

8	Weight of (Pycnometer + water) at T °C, M_a (gm)	146.81	146.35
9	Weight of dry material, M_s(gm)	10.88	10.86
10	Specific gravity of material at T °C, G_T	2.654	2.648
11	Correction Factor	0.99987	0.99966
12	Specific gravity of material at 20 °C, G_{20}	2.653	2.647
13	Average G_s	2.65	

Appendix-B: Swelling Properties of Materials

Table B-1: Free swell index of soil samples

Sample	V_K (ml)	V_W (ml)	FSI (%)	Degree of swell
TP-1	10	19.9	99.0	Very high
TP-2	10.2	20.04	96.5	Very high
TP-3	10	19.6	96.0	Very high
TP-4	10	19.9	99.0	Very high
TP-5	10	19.4	94.0	Very high
TP-6	10	19.1	91.0	Very high
TP-7	10	19.5	95.0	Very high
TP-8	10	18.9	89.0	Very high
TP-9	10	19.34	93.4	Very high
TP-10	10	19.01	90.1	Very high
TP-11	10	18.9	89.0	Very high
TP-12	10	19.36	93.6	Very high
TP-13	10	19.48	94.8	Very high
TP-14	10	19.3	93.0	Very high
TP-15	10	18.96	89.6	Very high
TP-16	10	19.05	90.5	Very high

Appendix-C: Particle Size Distribution Result

Parameters used for test

Time (min) = t (min)	Adjusted percent finer (%) = P_a (%)
Actual hydrometer reading = R_a	Effective depth (Cm) = L (Cm)
Corrected hydrometer reading = R_c	Coefficient of temperature adjustment = K
Percent finer (%) = P (%)	Diameter of particle (mm) = D (mm)
Sieve number = SN	Percent retained (%) = P_R (%)

Sieve size(mm) = S_S(mm) Cumulative percent retained (%) = CP_R (%)

Mass of soil retained (gm) = M_R(gm) Percent passed (%) = P_P (%)

Weight of dry soil and CSP sample prepared to be washed = 1000gm and 500gm for ESA

Table C-1: Grain size analysis result of soil sample collected from TP-1

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	13	1.30	1.30	98.70
8	2.36	14	1.40	2.70	97.30
10	2	4	0.40	3.10	96.90
16	1.18	6	0.60	3.70	96.30
30	0.6	5	0.50	4.20	95.80
50	0.3	4	0.40	4.60	95.40
100	0.15	8	0.80	5.40	94.60
200	0.075	8	0.80	6.20	93.80
	Pan	937.42	93.74	100.00	0.00

Table C-2: Hydrometer analysis result of soil sample collected from TP-1

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	46	44.35	89.62	84.06	8.8	4.20	0.0128872	0.054
1	46	44.35	89.62	84.06	8.8	2.97	0.0128872	0.038
2	45.5	43.85	88.61	83.11	8.85	2.10	0.0128872	0.027
5	45	43.35	87.60	82.17	8.9	1.33	0.0128872	0.017
10	44	42.35	85.58	80.27	9.1	0.95	0.0128872	0.012
20	42.5	40.85	82.54	77.43	9.3	0.68	0.0128872	0.009
40	40	38.35	77.49	72.69	9.7	0.49	0.0128872	0.006
80	38.5	36.85	74.46	69.85	10	0.35	0.0128872	0.005
120	36.5	34.85	70.42	66.05	10.3	0.29	0.0128872	0.004
240	33.5	31.85	64.36	60.37	10.8	0.21	0.0128872	0.003
480	30	28.35	57.29	53.73	11.4	0.15	0.0128872	0.002
1440	26	24.35	49.20	46.15	12	0.09	0.0128872	0.001

Table C-3: Grain size analysis of soil sample collected from TP-2

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	22	2.20	2.20	97.80
8	2.36	9	0.90	3.10	96.90
10	2	3	0.30	3.40	96.60
16	1.18	3	0.30	3.70	96.30
30	0.6	5	0.50	4.20	95.80
50	0.3	4	0.40	4.60	95.40
100	0.15	10	1.00	5.60	94.40
200	0.075	6	0.60	6.20	93.80

	Pan	937.98	93.80	100.00	0.00

Table C-4: Hydrometer analysis result of soil sample collected from TP-2

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	47	45.35	91.73	86.04	8.6	4.15	0.0129024	0.054
1	46.5	44.85	90.71	85.09	8.7	2.95	0.0129024	0.038
2	46	44.35	89.70	84.14	8.8	2.10	0.0129024	0.027
5	45	43.35	87.68	82.24	8.9	1.33	0.0129024	0.017
10	44	42.35	85.66	80.35	9.1	0.95	0.0129024	0.012
20	42	40.35	81.61	76.55	9.4	0.69	0.0129024	0.009
40	40.5	38.85	78.58	73.71	9.65	0.49	0.0129024	0.006
80	38.5	36.85	74.53	69.91	10	0.35	0.0129024	0.005
120	36.5	34.85	70.49	66.12	10.3	0.29	0.0129024	0.004
240	33.5	31.85	64.42	60.43	10.8	0.21	0.0129024	0.003
480	30	28.35	57.34	53.79	11.4	0.15	0.0129024	0.002
1440	23	21.35	43.18	40.51	12.5	0.09	0.0129024	0.001

Table C-5: Grain size analysis of soil sample collected from TP-3

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	17	1.70	1.70	98.30
8	2.36	14	1.40	3.10	96.90
10	2	3	0.30	3.40	96.60
16	1.18	8	0.80	4.20	95.80
30	0.6	9	0.90	5.10	94.90
50	0.3	11	1.10	6.20	93.80
100	0.15	13	1.30	7.50	92.50
200	0.075	9	0.90	8.40	91.60
	Pan	915.45	91.55	100.00	0.00

Table C-6: Hydrometer analysis result of soil sample collected from TP-3

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46.35	93.57	85.71	8.4	4.10	0.012872	0.053
1	48	46.35	93.57	85.71	8.4	2.90	0.012872	0.037
2	47.5	45.85	92.56	84.78	8.5	2.06	0.012872	0.027
5	47	45.35	91.55	83.86	8.6	1.31	0.012872	0.017
10	46.5	44.85	90.54	82.94	8.7	0.93	0.012872	0.012
20	46	44.35	89.53	82.01	8.8	0.66	0.012872	0.009
40	44.5	42.85	86.50	79.24	9	0.47	0.012872	0.006
80	42.5	40.85	82.47	75.54	9.3	0.34	0.012872	0.004
120	39.5	37.85	76.41	69.99	9.8	0.29	0.012872	0.004
240	36	34.35	69.34	63.52	10.4	0.21	0.012872	0.003

480	32	30.35	61.27	56.12	11.1	0.15	0.012872	0.002
1440	27.5	25.85	52.18	47.80	11.8	0.09	0.012872	0.001

Table C-7: Grain size analysis of soil sample collected from TP-4

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	20	2.00	2.00	98.00
8	2.36	16	1.60	3.60	96.40
10	2	9	0.90	4.50	95.50
16	1.18	12	1.20	5.70	94.30
30	0.6	16	1.60	7.30	92.70
50	0.3	11	1.10	8.40	91.60
100	0.15	19	1.90	10.30	89.70
200	0.075	15	1.50	11.80	88.20
	Pan	881.9	88.19	100.00	0.00

Table C-8: Hydrometer analysis result of soil sample collected from TP-4

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48.5	47.2	95.10	83.88	8.35	4.09	0.012988	0.053
1	48	46.7	94.10	82.99	8.4	2.90	0.012988	0.038
2	47	45.7	92.08	81.22	8.6	2.07	0.012988	0.027
5	46.5	45.2	91.07	80.33	8.7	1.32	0.012988	0.017
10	46	44.7	90.07	79.44	8.8	0.94	0.012988	0.012
20	45	43.7	88.05	77.66	8.9	0.67	0.012988	0.009
40	44.5	43.2	87.04	76.77	9	0.47	0.012988	0.006
80	42.5	41.2	83.01	73.22	9.3	0.34	0.012988	0.004
120	39.5	38.2	76.97	67.89	9.8	0.29	0.012988	0.004
240	35.5	34.2	68.91	60.78	10.5	0.21	0.012988	0.003
480	31.3	30	60.45	53.31	11.15	0.15	0.012988	0.002
1440	25.5	24.2	48.76	43.01	12	0.09	0.012988	0.001

Table C-9: Grain size analysis of soil sample collected from TP-5

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	22	2.20	2.20	97.80
8	2.36	14	1.40	3.60	96.40
10	2	11	1.10	4.70	95.30
16	1.18	8	0.80	5.50	94.50
30	0.6	21	2.10	7.60	92.40
50	0.3	11	1.10	8.70	91.30
100	0.15	13	1.30	10.00	90.00
200	0.075	22	2.20	12.20	87.80
	Pan	878	87.80	100.00	0.00

Table C-10: Hydrometer analysis result of soil sample collected from TP-5

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	46.5	45.2	93.81	82.37	8.7	4.17	0.01349	0.056
1	46	44.7	92.77	81.46	8.8	2.97	0.01349	0.040
2	45	43.7	90.70	79.63	8.9	2.11	0.01349	0.028
5	44	42.7	88.62	77.81	9.1	1.35	0.01349	0.018
10	42.5	41.2	85.51	75.08	9.3	0.96	0.01349	0.013
20	41	39.7	82.40	72.34	9.6	0.69	0.01349	0.009
40	40	38.7	80.32	70.52	9.7	0.49	0.01349	0.007
80	39.5	38.2	79.28	69.61	9.8	0.35	0.01349	0.005
120	38.5	37.2	77.21	67.79	10	0.29	0.01349	0.004
240	35	33.7	69.94	61.41	10.6	0.21	0.01349	0.003
480	31	29.7	61.64	54.12	11.2	0.15	0.01349	0.002
1440	25	23.7	49.19	43.19	12.2	0.09	0.01349	0.001

Table C-11: Grain size analysis result of soil sample collected from TP-6

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	23	2.30	2.30	97.70
8	2.36	12	1.20	3.50	96.50
10	2	14	1.40	4.90	95.10
16	1.18	12	1.20	6.10	93.90
30	0.6	15	1.50	7.60	92.40
50	0.3	13	1.30	8.90	91.10
100	0.15	15	1.50	10.40	89.60
200	0.075	18	1.80	12.20	87.80
	Pan	877	87.70	100.00	0.00

Table C-12: Hydrometer analysis result of soil sample collected from TP-6

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	46	44.35	87.72	77.01	8.8	4.20	0.01253	0.053
1	45	43.35	85.74	75.28	8.9	2.98	0.01253	0.037
2	44	42.35	83.76	73.54	9.1	2.13	0.01253	0.027
5	43.5	41.85	82.77	72.67	9.15	1.35	0.01253	0.017
10	42	40.35	79.80	70.07	9.4	0.97	0.01253	0.012
20	41	39.35	77.83	68.33	9.6	0.69	0.01253	0.009
40	40.5	38.85	76.84	67.46	9.65	0.49	0.01253	0.006
80	39.5	37.85	74.86	65.73	9.8	0.35	0.01253	0.004
120	38	36.35	71.89	63.12	10.1	0.29	0.01253	0.004
240	36	34.35	67.94	59.65	10.4	0.21	0.01253	0.003
480	32	30.35	60.03	52.70	11.1	0.15	0.01253	0.002

1440	25	23.35	46.18	40.55	12.2	0.09	0.01253	0.001

Table C-13: Grain size analysis of soil sample collected from TP-7

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	20	2.00	2.00	98.00
8	2.36	14	1.40	3.40	96.60
10	2	16	1.60	5.00	95.00
16	1.18	12	1.20	6.20	93.80
30	0.6	10	1.00	7.20	92.80
50	0.3	16	1.60	8.80	91.20
100	0.15	17	1.70	10.50	89.50
200	0.075	15	1.50	12.00	88.00
	Pan	879.25	87.93	100.00	0.00

Table C-14: Hydrometer analysis result of soil sample collected from TP-7

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	47	45.35	90.29	79.46	8.6	4.15	0.012644	0.052
1	46.5	44.85	89.29	78.58	8.7	2.95	0.012644	0.037
2	45.5	43.85	87.30	76.83	8.85	2.10	0.012644	0.027
5	45	43.35	86.31	75.95	8.9	1.33	0.012644	0.017
10	44	42.35	84.32	74.20	9.1	0.95	0.012644	0.012
20	43.5	41.85	83.32	73.32	9.15	0.68	0.012644	0.009
40	42	40.35	80.34	70.70	9.4	0.48	0.012644	0.006
80	40.5	38.85	77.35	68.07	9.65	0.35	0.012644	0.004
120	38.5	36.85	73.37	64.56	10	0.29	0.012644	0.004
240	35.5	33.85	67.39	59.31	10.5	0.21	0.012644	0.003
480	31	29.35	58.43	51.42	11.2	0.15	0.012644	0.002
1440	25.5	23.85	47.48	41.79	12.1	0.09	0.012644	0.001

Table C-15: Grain size analysis of soil sample collected from TP-8

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	25	2.50	2.50	97.50
8	2.36	17	1.70	4.20	95.80
10	2	18	1.80	6.00	94.00
16	1.18	12	1.20	7.20	92.80
30	0.6	8	0.80	8.00	92.00
50	0.3	13	1.30	9.30	90.70
100	0.15	20	2.00	11.30	88.70
200	0.075	25	2.50	13.80	86.20
	Pan	861.84	86.18	100.00	0.00

Table C-16: Hydrometer analysis result of soil sample collected from TP-8

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46.35	89.77	77.38	8.4	4.10	0.0121766	0.050
1	47	45.35	87.83	75.71	8.6	2.93	0.0121766	0.036
2	46	44.35	85.89	74.04	8.8	2.10	0.0121766	0.026
5	45	43.35	83.96	72.37	8.9	1.33	0.0121766	0.016
10	43.5	41.85	81.05	69.87	9.15	0.96	0.0121766	0.012
20	42.5	40.85	79.12	68.20	9.3	0.68	0.0121766	0.008
40	40.5	38.85	75.24	64.86	9.65	0.49	0.0121766	0.006
80	39.5	37.85	73.30	63.19	9.8	0.35	0.0121766	0.004
120	38.5	36.85	71.37	61.52	10.15	0.29	0.0121766	0.004
240	36	34.35	66.53	57.35	10.4	0.21	0.0121766	0.003
480	33	31.35	60.72	52.34	10.9	0.15	0.0121766	0.002
1440	29.5	27.85	53.94	46.49	11.45	0.09	0.0121766	0.001

Table C-17: Grain size analysis of soil sample collected from TP-9

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	22	2.20	2.20	97.80
8	2.36	10	1.00	3.20	96.80
10	2	15	1.50	4.70	95.30
16	1.18	14	1.40	6.10	93.90
30	0.6	10	1.00	7.10	92.90
50	0.3	11	1.10	8.20	91.80
100	0.15	14	1.40	9.60	90.40
200	0.075	30	3.00	12.60	87.40
	Pan	874	87.40	100.00	0.00

Table C-18: Hydrometer analysis result of soil sample collected from TP-9

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46	96.44	84.29	8.4	4.10	0.0133602	0.055
1	47.5	45.5	95.39	83.37	8.5	2.92	0.0133602	0.039
2	47	45	94.34	82.45	8.6	2.07	0.0133602	0.028
5	46	44	92.24	80.62	8.8	1.33	0.0133602	0.018
10	45	43	90.15	78.79	8.9	0.94	0.0133602	0.013
20	44	42	88.05	76.96	9.1	0.67	0.0133602	0.009
40	43	41	85.96	75.12	9.2	0.48	0.0133602	0.006
80	41	39	81.76	71.46	9.6	0.35	0.0133602	0.005
120	38	36	75.47	65.96	10.1	0.29	0.0133602	0.004
240	34	32	67.09	58.63	10.7	0.21	0.0133602	0.003
480	30	28	58.70	51.30	11.4	0.15	0.0133602	0.002
1440	25	23	48.22	42.14	12.2	0.09	0.0133602	0.001

Table C-19: Grain size analysis of soil sample collected from TP-10

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	15	1.50	1.50	98.50
8	2.36	14	1.40	2.90	97.10
10	2	10	1.00	3.90	96.10
16	1.18	12	1.20	5.10	94.90
30	0.6	16	1.60	6.70	93.30
50	0.3	14	1.40	8.10	91.90
100	0.15	10	1.00	9.10	90.90
200	0.075	20	2.00	11.10	88.90
	Pan	889	88.90	100.00	0.00

Table C-20: Hydrometer analysis result of soil sample collected from TP-10

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46.35	91.67	81.50	8.4	4.10	0.01253	0.051
1	47.5	45.85	90.68	80.62	8.5	2.92	0.01253	0.037
2	47	45.35	89.69	79.74	8.6	2.07	0.01253	0.026
5	46	44.35	87.72	77.98	8.8	1.33	0.01253	0.017
10	45	43.35	85.74	76.22	8.9	0.94	0.01253	0.012
20	43.5	41.85	82.77	73.58	9.15	0.68	0.01253	0.008
40	41.5	39.85	78.82	70.07	9.5	0.49	0.01253	0.006
80	39	37.35	73.87	65.67	9.9	0.35	0.01253	0.004
120	37	35.35	69.92	62.15	10.2	0.29	0.01253	0.004
240	34	32.35	63.98	56.88	10.7	0.21	0.01253	0.003
480	31	29.35	58.05	51.61	11.2	0.15	0.01253	0.002
1440	25	23.35	46.18	41.06	12.2	0.09	0.01253	0.001

Table C-21: Grain size analysis result of soil sample collected from TP-11

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	20	2.00	2.00	98.00
8	2.36	17	1.70	3.70	96.30
10	2	13	1.30	5.00	95.00
16	1.18	12.65	1.27	6.27	93.74
30	0.6	14	1.40	7.67	92.34
50	0.3	10	1.00	8.67	91.34
100	0.15	8	0.80	9.47	90.54
200	0.075	13	1.30	10.77	89.24
	Pan	892.2	89.22	100.00	0.00

Table C-22: Hydrometer analysis result of soil sample collected from TP-11

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)

0.5	47.5	45.85	91.08	81.28	8.5	4.12	0.012606	0.052
1	47	45.35	90.09	80.39	8.6	2.93	0.012606	0.037
2	46.5	44.85	89.10	79.50	8.7	2.09	0.012606	0.026
5	46	44.35	88.10	78.62	8.8	1.33	0.012606	0.017
10	45	43.35	86.12	76.85	8.9	0.94	0.012606	0.012
20	44.5	42.85	85.12	75.96	9	0.67	0.012606	0.008
40	42.5	40.85	81.15	72.41	9.3	0.48	0.012606	0.006
80	38.5	36.85	73.20	65.32	10.1	0.36	0.012606	0.004
120	36	34.35	68.24	60.89	10.4	0.29	0.012606	0.004
240	33	31.35	62.28	55.57	10.9	0.21	0.012606	0.003
480	30	28.35	56.32	50.26	11.4	0.15	0.012606	0.002
1440	24	22.35	44.40	39.62	12.4	0.09	0.012606	0.001

Table C-23: Grain size analysis of soil sample collected from TP-12

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	23	2.30	2.30	97.70
8	2.36	17	1.70	4.00	96.00
10	2	18	1.80	5.80	94.20
16	1.18	15	1.50	7.30	92.70
30	0.6	12	1.20	8.50	91.50
50	0.3	13	1.30	9.80	90.20
100	0.15	10	1.00	10.80	89.20
200	0.075	6	0.60	11.40	88.60
	Pan	886	88.60	100.00	0.00

Table C-24: Hydrometer analysis result of soil sample collected from TP-12

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46.35	91.87	81.40	8.4	4.10	0.012568	0.052
1	47	45.35	89.89	79.64	8.6	2.93	0.012568	0.037
2	46	44.35	87.91	77.89	8.8	2.10	0.012568	0.026
5	45	43.35	85.93	76.13	8.9	1.33	0.012568	0.017
10	43.5	41.85	82.95	73.50	9.15	0.96	0.012568	0.012
20	42.5	40.85	80.97	71.74	9.3	0.68	0.012568	0.009
40	40.5	38.85	77.01	68.23	9.65	0.49	0.012568	0.006
80	39.5	37.85	75.02	66.47	9.8	0.35	0.012568	0.004
120	38.5	36.85	73.04	64.71	10.15	0.29	0.012568	0.004
240	36	34.35	68.09	60.32	10.4	0.21	0.012568	0.003
480	33	31.35	62.14	55.06	10.9	0.15	0.012568	0.002
1440	29.5	27.85	55.20	48.91	11.45	0.09	0.012568	0.001

Table C-25: Grain size analysis of soil sample collected from TP-13

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	24	2.40	2.40	97.60
8	2.36	16	1.60	4.00	96.00
10	2	18	1.80	5.80	94.20
16	1.18	14	1.40	7.20	92.80
30	0.6	12	1.20	8.40	91.60
50	0.3	12	1.20	9.60	90.40
100	0.15	9	0.90	10.50	89.50
200	0.075	7	0.70	11.20	88.80
	Pan	888	88.80	100.00	0.00

Table C-26: Hydrometer analysis result of soil sample collected from TP-13

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46.35	92.70	82.32	8.4	4.10	0.01272	0.052
1	47.5	45.85	91.70	81.43	8.5	2.92	0.01272	0.037
2	47	45.35	90.70	80.54	8.6	2.07	0.01272	0.026
5	46	44.35	88.70	78.77	8.8	1.33	0.01272	0.017
10	45	43.35	86.70	76.99	8.9	0.94	0.01272	0.012
20	44	42.35	84.70	75.21	9.1	0.67	0.01272	0.009
40	43	41.35	82.70	73.44	9.2	0.48	0.01272	0.006
80	41	39.35	78.70	69.89	9.6	0.35	0.01272	0.004
120	38	36.35	72.70	64.56	10.1	0.29	0.01272	0.004
240	34	32.35	64.70	57.45	10.7	0.21	0.01272	0.003
480	30	28.35	56.70	50.35	11.4	0.15	0.01272	0.002
1440	25	23.35	46.70	41.47	12.2	0.09	0.01272	0.001

Table C-27: Grain size analysis of soil sample collected from TP-14

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	22	2.20	2.20	97.80
8	2.36	16	1.60	3.80	96.20
10	2	15	1.50	5.30	94.70
16	1.18	13	1.30	6.60	93.40
30	0.6	14	1.40	8.00	92.00
50	0.3	14	1.40	9.40	90.60
100	0.15	11	1.10	10.50	89.50
200	0.075	10	1.00	11.50	88.50
	Pan	885	88.50	100.00	0.00

Table C-28: Hydrometer analysis result of soil sample collected from TP-14

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48.5	46.85	92.46	81.83	8.35	4.09	0.012494	0.051

1	48	46.35	91.47	80.95	8.4	2.90	0.012494	0.036
2	47	45.35	89.50	79.21	8.6	2.07	0.012494	0.026
5	46.5	44.85	88.51	78.33	8.7	1.32	0.012494	0.016
10	46	44.35	87.53	77.46	8.8	0.94	0.012494	0.012
20	45	43.35	85.55	75.71	8.9	0.67	0.012494	0.008
40	44.5	42.85	84.57	74.84	9	0.47	0.012494	0.006
80	42.5	40.85	80.62	71.35	9.3	0.34	0.012494	0.004
120	39.5	37.85	74.70	66.11	9.8	0.29	0.012494	0.004
240	35.5	33.85	66.80	59.12	10.5	0.21	0.012494	0.003
480	31.3	29.65	58.51	51.79	11.15	0.15	0.012494	0.002
1440	25.5	23.85	47.07	41.66	12	0.09	0.012494	0.001

Table C-29: Grain size analysis of soil sample collected from TP-15

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)
4	4.75	26	2.60	2.60	97.40
8	2.36	18	1.80	4.40	95.60
10	2	17	1.70	6.10	93.90
16	1.18	14	1.40	7.50	92.50
30	0.6	14	1.40	8.90	91.10
50	0.3	16	1.60	10.50	89.50
100	0.15	13	1.30	11.80	88.20
200	0.075	12	1.20	13.00	87.00
	Pan	870	87.00	100.00	0.00

Table C-30: Hydrometer analysis result of soil sample collected from TP-15

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	46.5	44.85	88.70	77.17	8.7	4.17	0.01253	0.052
1	46	44.35	87.72	76.31	8.8	2.97	0.01253	0.037
2	45.5	43.85	86.73	75.45	8.85	2.10	0.01253	0.026
5	45	43.35	85.74	74.59	8.9	1.33	0.01253	0.017
10	44	42.35	83.76	72.87	9.1	0.95	0.01253	0.012
20	42.5	40.85	80.79	70.29	9.3	0.68	0.01253	0.009
40	40	38.35	75.85	65.99	9.7	0.49	0.01253	0.006
80	38.5	36.85	72.88	63.41	10	0.35	0.01253	0.004
120	36.5	34.85	68.93	59.97	10.3	0.29	0.01253	0.004
240	33.5	31.85	62.99	54.80	10.8	0.21	0.01253	0.003
480	31	29.35	58.05	50.50	11.4	0.15	0.01253	0.002
1440	24	22.35	44.20	38.46	12.4	0.09	0.01253	0.001

Table C-31: Grain size analysis of soil sample collected from TP-16

SN.	S_S (mm)	M_R (gm)	P_R (%)	CP_R (%)	P_P (%)

4	4.75	23	2.30	2.30	97.70
8	2.36	19	1.90	4.20	95.80
10	2	15	1.50	5.70	94.30
16	1.18	13	1.30	7.00	93.00
30	0.6	14	1.40	8.40	91.60
50	0.3	13	1.30	9.70	90.30
100	0.15	12	1.20	10.90	89.10
200	0.075	10	1.00	11.90	88.10
	Pan	881	88.10	100.00	0.00

Table C-32: Hydrometer analysis result of soil sample collected from TP-16

t(min)	R_a	R_c	P	P_a	L (Cm)	$\sqrt{L/T}$	K	D (mm)
0.5	48	46.35	92.70	81.67	8.4	4.10	0.01272	0.052
1	48	46.35	92.70	81.67	8.4	2.90	0.01272	0.037
2	47.5	45.85	91.70	80.79	8.5	2.06	0.01272	0.026
5	47	45.35	90.70	79.91	8.6	1.31	0.01272	0.017
10	46.5	44.85	89.70	79.03	8.7	0.93	0.01272	0.012
20	46	44.35	88.70	78.14	8.8	0.66	0.01272	0.008
40	44.5	42.85	85.70	75.50	9	0.47	0.01272	0.006
80	42.5	40.85	81.70	71.98	9.3	0.34	0.01272	0.004
120	39.5	37.85	75.70	66.69	9.8	0.29	0.01272	0.004
240	36	34.35	68.70	60.52	10.4	0.21	0.01272	0.003
480	32	30.35	60.70	53.48	11.1	0.15	0.01272	0.002
1440	27.5	25.85	51.70	45.55	11.8	0.09	0.01272	0.001

Appendix-D: Atterberg Limit Test Results

Parameters and formulas used for LL and PL calculation

Mass of water = (Mass of can +Wet soil) - mass of can

Mass of dry soil = (Mass of can +Wet soil) - mass of can

Moisture content (%) = Mass of water *100/ Mass of dry soil

Liquid limit = Water content at number of blows are equal to 25.

Plastic limit =Average water content of plastic limit test trials

Table D-1: Liquid limit and plastic limit of natural soil from TP-1

	Liquid limit			Plastic Limit		
Can ID	1	2	3	4	5	6
Mass (wet soil + can)(gm)	28.47	30.86	26.74	24.98	27.015	24.4
Mass (dry soil + can)(gm)	25.2	25.6	23.05	23.4	25.09	22.94
Mass of can (gm)	19.47	19.39	19.48	18.89	19.58	18.76

Mass of dry soil (gm)	5.73	6.21	3.57	4.51	5.51	4.18
Mass of water (gm)	3.27	5.26	3.69	1.58	1.925	1.46
Water content (%)	57.07	84.70	103.36	35.03	34.94	34.93
Number of blows (counts)	35.00	25.00	19.00	34.97		
Liquid limit (%)	84.70					

Table D-2: Liquid limit and plastic limit of natural soil from TP-2

Can ID	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	29.15	31.13	30.73	25.25	25.03	24.20
Mass(dry soil + can)(gm)	24.7	25.79	25.58	23.71	23.54	22.96
Mass of can(gm)	19.31	19.49	19.66	19.31	19.29	19.41
Mass of dry soil(gm)	5.39	6.3	5.92	4.4	4.25	3.55
Mass of water(gm)	4.45	5.34	5.15	1.54	1.49	1.244
Water content (%)	82.56	84.76	86.99	35.00	35.06	35.04
Number of blows (counts)	35.00	28.00	19.00	35.03		
Liquid limit (%)	85.50					

Table D-3: Liquid limit and plastic limit of natural soil from TP-3

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	31.31	33.67	30.35	24.85	23.02	24.09
Mass(dry soil + can)(gm)	25.28	27.2	26.58	23.52	21.92	22.92
Mass of can(gm)	19.28	19.28	19.63	19.67	18.73	19.53
Mass of dry soil(gm)	6	7.92	6.95	3.85	3.19	3.39
Mass of water(gm)	6.03	6.47	3.77	1.33	1.1	1.17
Water content (%)	100.50	81.69	54.24	34.55	34.48	34.51
Number of blows (counts)	19.00	26.00	35.00	34.51		
Liquid limit (%)	84.38					

Table D-4: Liquid limit and plastic limit of natural soil from TP-4

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	45.32	40.19	40.65	22.98	23.05	23.22
Mass(dry soil + can)(gm)	36.99	35.71	36.52	22.05	22.11	22.29
Mass of can(gm)	29.27	30.05	30.03	19.39	19.43	19.64
Mass of dry soil(gm)	7.72	5.66	6.49	2.66	2.68	2.65
Mass of water(gm)	8.33	4.48	4.13	0.932	0.94	0.93
Water content (%)	107.90	79.15	63.64	35.04	35.07	35.09
Number of blows (counts)	18.00	27.00	32.00	35.07		
Liquid limit (%)	85.66					

Table D-5: Liquid limit and plastic limit of natural soil from TP-5

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	30.19	31.79	27.7	34.50	34.67	34.96
Mass(dry soil + can)(gm)	24.72	26.12	24.21	33.35	33.4	33.7
Mass of can(gm)	19.33	19.34	18.72	30.03	29.7	30.04
Mass of dry soil(gm)	5.39	6.78	5.49	3.32	3.7	3.66
Mass of water(gm)	5.47	5.67	3.49	1.149	1.271	1.26
Water content (%)	101.48	83.63	63.57	34.61	34.35	34.43
Number of blows (counts)	19.00	25.00	33.00	34.46		
Liquid limit (%)	83.63					

Table D-6: Liquid limit and plastic limit of natural soil from TP-6

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	44.28	40.05	37.5	34.34	33.35	33.9
Mass(dry soil + can)(gm)	37.62	35.62	34.42	33.38	32.57	32.91
Mass of can(gm)	30.19	29.82	30.11	30.5	30.23	29.95
Mass of dry soil(gm)	7.43	5.8	4.31	2.88	2.34	2.96
Mass of water(gm)	6.66	4.43	3.08	0.9603	0.78	0.99
Water content (%)	89.64	76.38	71.46	33.34	33.33	33.45
Number of blows (counts)	19.00	29.00	34.00	33.37		
Liquid limit (%)	81.64					

Table D-7: Liquid limit and plastic limit of natural soil from TP-7

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	42.06	44.09	39.36	34.74	34.47	34.72
Mass(dry soil + can)(gm)	36.2	37.85	35.46	33.56	33.39	33.61
Mass of can(gm)	30.06	30.41	30.09	30.12	30.22	30.37
Mass of dry soil(gm)	6.14	7.44	5.37	3.44	3.17	3.24
Mass of water(gm)	5.86	6.243	3.9	1.176	1.084	1.109
Water content (%)	95.44	83.91	72.63	34.19	34.20	34.23
Number of blows (counts)	18.00	25.00	33.00	34.20		
Liquid limit (%)	83.91					

Table D-8: Liquid limit and plastic limit of natural soil from TP-8

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	31.63	26.83	29.95	23.48	23.74	23.96
Mass(dry soil + can)(gm)	25.82	23.68	25.65	22.49	22.67	22.87

Mass of can(gm)	19.43	19.8	19.43	19.49	19.44	19.57
Mass of dry soil(gm)	6.39	3.88	6.22	3	3.23	3.3
Mass of water(gm)	5.81	3.145	4.3	0.994	1.07	1.09
Water content (%)	90.92	81.06	69.13	33.13	33.13	33.03
Number of blows (counts)	18.00	25.00	35.00	33.10		
Liquid limit (%)	81.06					

Table D-9: Liquid limit and plastic limit of natural soil from TP-9

	Liquid limit			Plastic Limit		
Can Id	1	2	3	4	5	6
Mass(wet soil + can)(gm)	29.67	30.07	30.08	23.62	23.01	23.46
Mass(dry soil + can)(gm)	24.7	25.46	25.7	22.38	22.08	22.45
Mass of can(gm)	19.38	19.52	19.44	18.77	19.4	19.51
Mass of dry soil(gm)	5.32	5.94	6.26	3.61	2.68	2.94
Mass of water(gm)	4.97	4.61	4.38	1.24	0.93	1.005
Water content (%)	93.42	77.61	69.97	34.35	34.70	34.18
Number of blows (counts)	17.00	29.00	35.00	34.41		
Liquid limit (%)	82.95					

Table D-10: Liquid limit and plastic limit of natural soil from TP-10

	Liquid limit			Plastic Limit		
Can ID	1	2	3	4	5	6
Mass (wet soil + can)(gm)	32.96	29.71	28.43	24.86	23.95	24.57
Mass (dry soil + can)(gm)	26.72	24.92	24.61	23.47	22.82	23.26
Mass of can (gm)	19.46	18.88	19.45	19.31	19.44	19.35
Mass of dry soil (gm)	7.26	6.04	5.16	4.16	3.38	3.91
Mass of water (gm)	6.24	4.79	3.82	1.39	1.133	1.31
Water content (%)	85.95	79.30	74.03	33.41	33.52	33.50
Number of blows (counts)	19.00	29.00	35.00	33.48		
Liquid limit (%)	82.00					

Table D-11: Liquid limit and plastic limit of natural soil from TP-11

	Liquid limit			Plastic Limit		
Can ID	1	2	3	4	5	6
Mass(wet soil + can)(gm)	33.3	32.64	30.95	23.88	34.77	35.14
Mass(dry soil + can)(gm)	26.7	26.6	26.14	22.8	33.59	33.8
Mass of can(gm)	19.56	19.66	19.37	19.55	30.06	29.76
Mass of dry soil(gm)	7.14	6.94	6.77	3.25	3.53	4.04
Mass of water(gm)	6.6	6.04	4.81	1.08	1.18	1.344
Water content (%)	92.44	87.03	71.05	33.23	33.43	33.27
Number of blows (counts)	18.00	21.00	32.00	33.31		

Liquid limit (%)	81.45		

Table D-12: Liquid limit and plastic limit of natural soil from TP-12

	Liquid limit			Plastic Limit		
Can Id	1	2	3	4	5	6
Mass(wet soil + can)(gm)	33.34	32.55	30.95	23.96	34.78	35.19
Mass(dry soil + can)(gm)	26.7	26.6	26.14	22.82	33.61	33.82
Mass of can(gm)	19.56	19.66	19.37	19.45	30.16	29.75
Mass of dry soil(gm)	7.14	6.94	6.77	3.37	3.45	4.07
Mass of water(gm)	6.64	5.95	4.81	1.14	1.17	1.37
Water content (%)	93.00	85.73	71.05	33.83	33.91	33.66
Number of blows (counts)	17.00	23.00	34.00	33.80		
Liquid limit (%)	82.83					

Table D-13: Liquid limit and plastic limit of natural soil from TP-13

	Liquid limit			Plastic Limit		
Can Id	1	2	3	4	5	6
Mass(wet soil + can)(gm)	33.74	33.23	30.78	24.02	34.88	35.41
Mass(dry soil + can)(gm)	26.6	26.7	26.03	22.84	33.62	33.92
Mass of can(gm)	19.45	19.56	19.27	19.43	30	29.62
Mass of dry soil(gm)	7.15	7.14	6.76	3.41	3.62	4.3
Mass of water(gm)	7.14	6.53	4.75	1.181	1.26	1.49
Water content (%)	99.86	91.46	70.27	34.63	34.81	34.65
Number of blows (counts)	19.00	22.00	31.00	34.70		
Liquid limit (%)	84.20					

Table D-14: Liquid limit and plastic limit of natural soil from TP-14

	Liquid limit			Plastic Limit		
Can Id	1	2	3	4	5	6
Mass(wet soil + can)(gm)	32.88	32.5	31.55	24.03	34.90	35.31
Mass(dry soil + can)(gm)	26.7	26.6	26.14	22.86	33.69	33.85
Mass of can(gm)	19.56	19.66	19.37	19.45	30.16	29.59
Mass of dry soil(gm)	7.14	6.94	6.77	3.41	3.53	4.26
Mass of water(gm)	6.18	5.9	5.41	1.17	1.21	1.458
Water content (%)	86.55	85.01	79.91	34.31	34.28	34.23
Number of blows (counts)	19.00	22.00	34.00	34.27		
Liquid limit (%)	83.80					

Table D-15: Liquid limit and plastic limit of natural soil from TP-15

	Liquid limit			Plastic Limit		
Can Id	1	2	3	4	5	6

Mass(wet soil + can)(gm)	32.74	32.29	30.95	23.88	34.76	35.08
Mass(dry soil + can)(gm)	26.46	26.45	26.08	22.8	33.59	33.76
Mass of can(gm)	19.56	19.63	19.27	19.55	30.06	29.76
Mass of dry soil(gm)	6.9	6.82	6.81	3.25	3.53	4
Mass of water(gm)	6.28	5.84	4.87	1.075	1.167	1.321
Water content (%)	91.01	85.63	71.51	33.08	33.06	33.03
Number of blows (counts)	17.00	21.00	33.00	33.05		
Liquid limit (%)	81.00					

Table D-16: Liquid limit and plastic limit of natural soil from TP-16

Can Id	Liquid limit			Plastic Limit		
	1	2	3	4	5	6
Mass(wet soil + can)(gm)	32.56	32.14	30.85	33.91	34.85	35.09
Mass(dry soil + can)(gm)	26.52	26.42	26.04	32.78	33.64	33.68
Mass of can(gm)	19.66	19.75	19.57	29.45	30.06	29.51
Mass of dry soil(gm)	6.86	6.67	6.47	3.33	3.58	4.17
Mass of water(gm)	6.04	5.72	4.81	1.126	1.21	1.409
Water content (%)	88.05	85.76	74.34	33.81	33.80	33.79
Number of blows (counts)	18.00	21.00	32.00	33.80		
Liquid limit (%)	81.60					

Parameters and formulas used for LS calculation

NB. Length was measured in both sides.

Average length of oven dry soil=L_D

Length of wet sample=L_O=134.72mm

Linear shrinkage (%)=(L_O-L_D)/(L_O))*100%

Table D-17: Linear shrinkage of natural soil samples

Test pits	L_O (mm)	L_{O1} (mm)	L_{O2} (mm)	L_O (mm)	LS (%)
TP-1	134.72	102.60	102.26	102.43	23.97
TP-2	134.72	103.32	103.24	103.28	23.34
TP-3	134.72	105.70	104.57	105.14	21.96
TP-4	134.72	100.90	100.87	100.89	25.12
TP-5	134.72	103.69	103.67	103.68	23.04
TP-6	134.72	108.97	108.92	108.95	19.13
TP-7	134.72	104.76	104.69	104.73	22.26
TP-8	134.72	110.22	110.00	110.11	18.27
TP-9	134.72	105.22	105.22	105.22	21.90
TP-10	134.72	106.72	106.42	106.57	20.90
TP-11	134.72	107.95	108.18	108.07	19.79
TP-12	134.72	106.95	106.82	106.89	20.66
TP-13	134.72	103.04	103.17	103.11	23.47
TP-14	134.72	104.38	104.40	104.39	22.51
TP-15	134.72	107.72	107.72	107.72	20.04

TP-16	134.72	106.15	106.20	106.18	21.19

Appendix-E: Compaction Test Results

Table E-1: Compaction test results of soil collected from TP-1

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5255	5305	5375	5430	5428
	Mass of soil (gm)	1500	1550	1620	1675	1673
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.59	1.64	1.72	1.77	1.77
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	30.11	30.22	30.08	29.96	30.01
	Weight of (wet soil + can) (gm)	68.26	66.65	65.67	67.56	69.09
	Weight of (dry soil + can) (gm)	59.72	58.01	56.59	57.35	57.68
	Weight of water (gm)	8.54	8.64	9.08	10.21	11.41
	Weight of dry soil (gm)	29.61	27.79	26.51	27.39	27.67
	Average moisture content (%)	28.85	31.10	34.25	37.28	41.25
Dry density of soil (gm/cm^3)		1.23	1.25	1.28	1.29	1.25
ZAV	Specific gravity of soil, G_s	2.606	2.606	2.606	2.606	2.606
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.49	1.44	1.38	1.32	1.26

Table E-2: Compaction test results of soil collected from TP-2

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5275	5330	5400	5450	5448
	Mass of soil (gm)	1520	1575	1645	1695	1693
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.61	1.67	1.74	1.80	1.79
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	30.11	30.22	30.08	29.96	30.01
	Weight of (wet soil + can) (gm)	68.26	66.65	65.69	67.50	68.79
	Weight of (dry soil + can) (gm)	59.72	58.01	56.59	57.35	57.68
	Weight of water (gm)	8.54	8.64	9.10	10.15	11.11
	Weight of dry soil (gm)	29.61	27.79	26.51	27.39	27.67
	Average moisture content (%)	28.84	31.09	34.33	37.06	40.15
Dry density of soil (gm/cm^3)		1.25	1.27	1.30	1.31	1.28
ZAV	Specific gravity of soil, G_s	2.602	2.602	2.602	2.602	2.602
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.49	1.44	1.37	1.32	1.29

Table E-3: Compaction test results of soil collected from TP-3

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5295	5355	5423	5475	5450

	Mass of soil (gm)	1540	1600	1668	1720	1695
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.63	1.69	1.77	1.82	1.80
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	19.44	19.27	19.67	19.43	19.31
	Weight of (wet soil + can) (gm)	64.93	67.21	67.17	63.51	65.81
	Weight of (dry soil + can) (gm)	55.08	56.05	55.29	51.84	53.03
	Weight of water (gm)	9.85	11.16	11.88	11.67	12.78
	Weight of dry soil (gm)	35.64	36.78	35.62	32.41	33.72
	Average moisture content (%)	27.64	30.34	33.35	36.00	37.90
Dry density of soil (gm/cm^3)		1.28	1.30	1.33	1.34	1.30
ZAV	Specific gravity of soil, G_S	2.61	2.61	2.61	2.61	2.61
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.52	1.46	1.40	1.35	1.31

Table E-4: Compaction test results of soil collected from TP-4

	Trial number	1	2	3	4	5
DENSITY	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5290	5340	5398	5441	5423
	Mass of soil (gm)	1535	1585	1643	1686	1668
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.63	1.68	1.74	1.79	1.77
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	29.12	29.4	30.05	29.85	30.15
	Weight of (wet soil + can) (gm)	63.29	65.84	65.29	66.78	68.20
	Weight of (dry soil + can) (gm)	55.17	56.73	56.01	56.65	57.40
	Weight of water (gm)	8.12	9.11	9.28	10.13	10.80
	Weight of dry soil (gm)	26.05	27.33	25.96	26.80	27.25
	Average moisture content (%)	31.17	33.33	35.75	37.79	39.63
Dry density of soil (gm/cm^3)		1.24	1.26	1.28	1.30	1.27
ZAV	Specific gravity of soil, G_S	2.618	2.618	2.618	2.618	2.618
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.44	1.40	1.35	1.32	1.28

Table E-5: Compaction test results of soil collected from TP-5

	Trial number	1	2	3	4	5
DENSITY	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5270	5330	5400	5458	5456
	Mass of soil (gm)	1515	1575	1645	1703	1701
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.60	1.67	1.74	1.80	1.80
MOISTURE CONT	Can identity	A	B	C	D	E
	Weight of can (gm)	30.62	30.39	29.81	28.56	30.31
	Weight of (wet soil + can) (gm)	75.35	76.11	77.98	79.68	79.49

	Weight of (dry soil + can) (gm)	65.75	65.56	65.97	66.06	65.42
	Weight of water (gm)	9.60	10.55	12.01	13.62	14.07
	Weight of dry soil (gm)	35.13	35.17	36.16	37.50	35.11
	Average moisture content (%)	27.33	30.00	33.21	36.32	40.07
Dry density of soil (gm/cm^3)		1.26	1.28	1.31	1.32	1.29
ZAV	Specific gravity of soil, G_S	2.5	2.5	2.5	2.5	2.5
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.49	1.43	1.37	1.33	1.30

Table E-6: Compaction test results of soil collected from TP-6

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5300	5368	5430	5500	5495
	Mass of soil (gm)	1545	1613	1675	1745	1740
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.64	1.71	1.77	1.85	1.84
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	19.14	19.72	19.34	19.26	19.51
	Weight of (wet soil + can) (gm)	54.65	42.71	40.64	54.02	73.37
	Weight of (dry soil + can) (gm)	47.49	37.63	35.58	45.05	58.64
	Weight of water (gm)	7.16	5.08	5.06	8.97	14.73
	Weight of dry soil (gm)	28.35	17.91	16.24	25.79	39.13
	Average moisture content (%)	25.26	28.36	31.16	34.79	37.64
Dry density of soil (gm/cm^3)		1.31	1.33	1.35	1.37	1.34
ZAV	Specific gravity of soil, G_S	2.7	2.7	2.7	2.7	2.7
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.61	1.53	1.47	1.39	1.35

Table E-7: Compaction test results of soil collected from TP-7

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5283	5342	5396	5470	5468
	Mass of soil (gm)	1528	1587	1641	1715	1713
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.62	1.68	1.74	1.82	1.81
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	19.53	19.63	19.54	19.17	19.43
	Weight of (wet soil + can) (gm)	51.43	54.07	53.79	77.82	86.45
	Weight of (dry soil + can) (gm)	44.52	46.11	45.41	62.27	67.59
	Weight of water (gm)	6.91	7.96	8.38	15.55	18.86
	Weight of dry soil (gm)	24.99	26.48	25.87	43.10	48.16
	Average moisture content (%)	27.65	30.06	32.39	36.09	39.16
Dry density of soil (gm/cm^3)		1.27	1.29	1.31	1.33	1.30
ZAV	Specific gravity of soil, G_S	2.7	2.7	2.7	2.7	2.7
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.54	1.48	1.43	1.36	1.31

Table E-8: Compaction test results of soil collected from TP-8

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5336	5394	5456	5519	5517
	Mass of soil (gm)	1581	1639	1701	1764	1762
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.67	1.74	1.80	1.87	1.87
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	30.14	29.34	30.4	29.8	29.84
	Weight of (wet soil + can) (gm)	70.20	81.45	77.19	73.79	74.57
	Weight of (dry soil + can) (gm)	61.94	69.86	66.07	62.61	62.41
	Weight of water (gm)	8.26	11.59	11.12	11.18	12.16
	Weight of dry soil (gm)	31.80	40.52	35.67	32.81	32.57
	Average moisture content (%)	25.97	28.60	31.17	34.06	37.33
Dry density of soil (gm/cm^3)		1.33	1.35	1.37	1.39	1.36
ZAV	Specific gravity of soil, G_S	2.801	2.801	2.801	2.801	2.801
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.62	1.56	1.50	1.43	1.37

Table E-9: Compaction test results of soil collected from TP-9

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5300	5355	5424	5485	5480
	Mass of soil (gm)	1545	1600	1669	1730	1725
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.64	1.69	1.77	1.83	1.83
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	29.85	29.81	30.06	30.33	30.63
	Weight of (wet soil + can) (gm)	63.49	64.29	68.67	85.21	79.51
	Weight of (dry soil + can) (gm)	56.37	56.47	59.23	70.80	65.89
	Weight of water (gm)	7.12	7.82	9.44	14.41	13.62
	Weight of dry soil (gm)	26.52	26.66	29.17	40.47	35.26
	Average moisture content (%)	26.85	29.33	32.36	35.61	38.63
Dry density of soil (gm/cm^3)		1.29	1.31	1.34	1.35	1.32
ZAV	Specific gravity of soil, G_s	2.463	2.463	2.463	2.463	2.463
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.48	1.43	1.37	1.36	1.33

Table E-10: Compaction test results of soil collected from TP-10

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5312	5375	5435	5508	5505
	Mass of soil (gm)	1557	1620	1680	1753	1750
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.65	1.72	1.78	1.86	1.85

MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	19.18	18.62	19.49	19.22	19.43
	Weight of (wet soil + can) (gm)	53.21	52.84	69.84	72.32	75.63
	Weight of (dry soil + can) (gm)	46.32	45.30	57.96	58.72	60.41
	Weight of water (gm)	6.89	7.54	11.88	13.60	15.22
	Weight of dry soil (gm)	27.14	26.68	38.47	39.50	40.98
	Average moisture content (%)	25.39	28.26	30.88	34.43	37.14
Dry density of soil (gm/cm^3)		1.32	1.34	1.36	1.38	1.35
ZAV	Specific gravity of soil, G_s	2.70	2.70	2.70	2.70	2.70
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.60	1.53	1.47	1.40	1.36

Table E-11: Compaction test results of soil collected from TP-11

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5335	5390	5455	5525	5519
	Mass of soil (gm)	1580	1635	1700	1770	1764
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.67	1.73	1.80	1.88	1.87
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	18.85	19.63	18.75	19.5	19.57
	Weight of (wet soil + can) (gm)	55.39	62.38	73.75	79.59	62.66
	Weight of (dry soil + can) (gm)	47.90	52.95	60.68	64.17	50.83
	Weight of water (gm)	7.49	9.43	13.07	15.42	11.83
	Weight of dry soil (gm)	29.05	33.32	41.93	44.67	31.26
	Average moisture content (%)	25.78	28.30	31.17	34.52	37.84
Dry density of soil (gm/cm^3)		1.33	1.35	1.37	1.39	1.36
ZAV	Specific gravity of soil, G_S	2.68	2.68	2.68	2.68	2.68
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.58	1.52	1.46	1.39	1.33

Table E-12: Compaction test results of soil collected from TP-12

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5285	5340	5405	5475	5467
	Mass of soil (gm)	1530	1585	1650	1720	1712
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.62	1.68	1.75	1.82	1.81
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	18.85	19.63	18.75	19.5	19.57
	Weight of (wet soil + can) (gm)	55.69	62.68	74.25	80.13	62.86
	Weight of (dry soil + can) (gm)	47.90	52.95	60.78	64.17	50.83
	Weight of water (gm)	7.79	9.73	13.47	15.96	12.03
	Weight of dry soil (gm)	29.05	33.32	42.03	44.67	31.26

	Average moisture content (%)	26.82	29.20	32.05	35.73	38.48
Dry density of soil (gm/cm³)		1.28	1.30	1.32	1.34	1.31
ZAV	Specific gravity of soil, G_S	2.69	2.69	2.69	2.69	2.69
	Density of water (gm/cm³)	1	1	1	1	1
	ZAV dry density	1.56	1.51	1.44	1.37	1.32

Table E-13: Compaction test results of soil collected from TP-13

	Trial number	1	2	3	4	5
DENSITY	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5285	5340	5405	5468	5465
	Mass of soil (gm)	1530	1585	1650	1713	1710
	Volume of mold (cm³)	944	944	944	944	944
	Bulk density (gm/cm³)	1.62	1.68	1.75	1.81	1.81
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	18.85	19.63	18.75	19.5	19.57
	Weight of (wet soil + can) (gm)	56.19	63.28	75.05	80.71	63.60
	Weight of (dry soil + can) (gm)	47.90	52.95	60.78	64.17	50.83
	Weight of water (gm)	8.29	10.33	14.27	16.54	12.77
	Weight of dry soil (gm)	29.05	33.32	42.03	44.67	31.26
	Average moisture content (%)	28.54	31.00	33.95	37.02	40.85
Dry density of soil (gm/cm³)		1.26	1.28	1.30	1.32	1.29
ZAV	Specific gravity of soil, G_S	2.65	2.65	2.65	2.65	2.65
	Density of water (gm/cm³)	1	1	1	1	1
	ZAV dry density	1.51	1.45	1.39	1.34	1.30

Table E-14: Compaction test results of soil collected from TP-14

	Trial number	1	2	3	4	5
DENSITY	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5285	5340	5405	5468	5465
	Mass of soil (gm)	1530	1585	1650	1713	1710
	Volume of mold (cm³)	944	944	944	944	944
	Bulk density (gm/cm³)	1.62	1.68	1.75	1.81	1.81
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	18.85	19.63	18.75	19.5	19.57
	Weight of (wet soil + can) (gm)	55.89	62.99	74.70	80.49	63.20
	Weight of (dry soil + can) (gm)	47.90	52.95	60.78	64.17	50.83
	Weight of water (gm)	7.99	10.04	13.92	16.32	12.37
	Weight of dry soil (gm)	29.05	33.32	42.03	44.67	31.26
	Average moisture content (%)	27.50	30.13	33.12	36.54	39.57
Dry density of soil (gm/cm³)		1.27	1.29	1.31	1.33	1.30
ZAV	Specific gravity of soil, G_S	2.71	2.71	2.71	2.71	2.71
	Density of water (gm/cm³)	1	1	1	1	1
	ZAV dry density	1.55	1.49	1.43	1.36	1.31

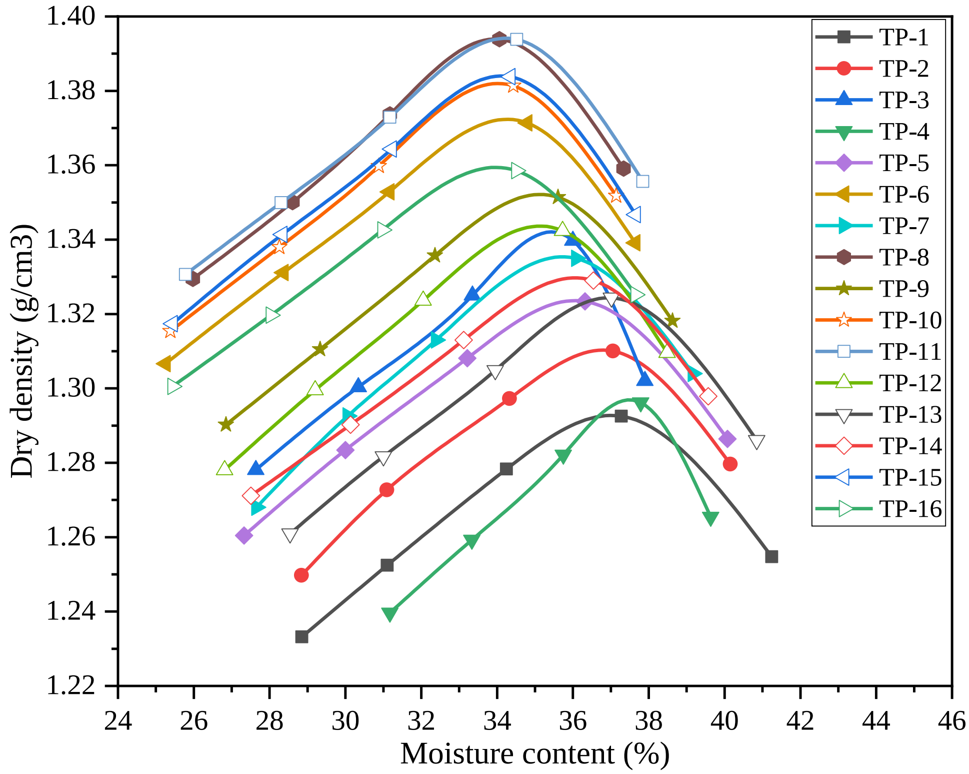
Table E-15: Compaction test results of soil collected from TP-15

	Trial number	1	2	3	4	5
DEN						

	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5315	5380	5445	5510	5505
	Mass of soil (gm)	1560	1625	1690	1755	1750
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.65	1.72	1.79	1.86	1.85
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	18.85	19.63	18.75	19.5	19.57
	Weight of (wet soil + can) (gm)	55.29	62.39	73.90	79.51	62.60
	Weight of (dry soil + can) (gm)	47.90	52.95	60.78	64.17	50.83
	Weight of water (gm)	7.39	9.44	13.12	15.34	11.77
	Weight of dry soil (gm)	29.05	33.32	42.03	44.67	31.26
	Average moisture content (%)	25.44	28.33	31.22	34.35	37.65
Dry density of soil (gm/cm^3)		1.32	1.34	1.36	1.38	1.35
ZAV	Specific gravity of soil, G_S	2.70	2.70	2.70	2.70	2.70
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.60	1.53	1.47	1.40	1.36

Table E-16: Compaction test results of soil collected from TP-16

DENSITY	Trial number	1	2	3	4	5
	Mass of mold (gm)	3755	3755	3755	3755	3755
	Mass of (mold + soil) (gm)	5295	5350	5415	5480	5477
	Mass of soil (gm)	1540	1595	1660	1725	1722
	Volume of mold (cm^3)	944	944	944	944	944
	Bulk density (gm/cm^3)	1.63	1.69	1.76	1.83	1.82
MOISTURE CONTENT	Can identity	A	B	C	D	E
	Weight of can (gm)	18.85	19.63	18.75	19.5	19.57
	Weight of (wet soil + can) (gm)	55.29	62.29	73.80	79.59	62.60
	Weight of (dry soil + can) (gm)	47.90	52.95	60.78	64.17	50.83
	Weight of water (gm)	7.39	9.34	13.02	15.42	11.77
	Weight of dry soil (gm)	29.05	33.32	42.03	44.67	31.26
	Average moisture content (%)	25.44	28.03	30.98	34.51	37.65
Dry density of soil (gm/cm^3)		1.30	1.32	1.34	1.36	1.33
ZAV	Specific gravity of soil, G_S	2.65	2.65	2.65	2.65	2.65
	Density of water (gm/cm^3)	1	1	1	1	1
	ZAV dry density	1.58	1.52	1.46	1.38	1.34



Appendix-F: Consolidation Test Results

Parameters and formulas used for consolidation test

Weight of specimen ring + soil = M_{rs}

Weight of specimen ring = M_r

Weight of specimen = M_s

Diameter of specimen = D

Initial height of specimen = H

Total volume of specimen = $V=\frac{\pi D^2}{4} * H$

Initial wet density = $\rho_{wet}=\frac{M_s}{V}$

Initial moisture content = $w_{initial}$

weight of container = w_c

weight of (container + wet soil) = w_{cw}

weight of (container + dry soil) = w_{cd}

Length of drainage path= H_{dr}

Change in void ratio=$\Delta e=\frac{\Delta H*(1+e_0)}{H}$

Void ratio=e=e_0-Δe

Deformation at 50% consolidation= d_{50}

Final moisture content = w_{final}

Initial dry density of specimen = $\rho_{dry}=\frac{\rho_{wet}}{1+w_{initial}}$

Specific gravity = G_s

Density of water = ρ_w

Volume of solid in soil specimen = $V_s=\frac{M_s}{G_s*\rho_w}$

Height of solid soil mass = $H_s=\frac{4V_s}{\pi D^2}$

Volume of voids in soil specimen = $V_v= V - V_s$

Initial void ratio = $e_0=\frac{V_v}{V_s}$

weight of water = w_w

weight of soil = w_s

Moisture content = $w=\frac{w_w}{w_s}*100\%$

Depth of specimen at 50% consolidation=H_{50}

Deformation at 100% consolidation=$\Delta H = d_{100}$

Elapsed time to reach 50% consolidation=t_{50}

Coefficient of consolidation=$C_v=\frac{0.197*H_{dr}^2}{t_{50}}$

Table F-1: Moisture content result for samples from TP-1 to TP-8

Parameters		TP-1	TP-2	TP-3	TP-4	TP-5	TP-6	TP-7	TP-8
Initial moisture content	w_c (gm)	30.11	30.07	30.06	27.07	23.04	23.82	23.37	30.11
	w_{cw} (gm)	67.05	53.41	94.8	64.22	183.43	124.38	148.28	69.05
	w_{cd} (gm)	57.75	47.27	77.77	54.34	139.94	96.62	114.15	59.13
	w_w (gm)	9.3	6.14	17.03	9.88	43.49	27.77	34.13	9.92
	w_s (gm)	27.64	17.2	47.71	27.27	116.90	72.80	90.78	29.02
	w (%)	33.65	35.70	35.69	36.23	37.20	38.14	37.60	34.18
Final moisture content	w_c (gm)	29.29	27.08	30.01	30.01	42.21	42.11	42.48	42.32
	w_{cw} (gm)	134.74	131.21	134.64	134.86	145.21	152.11	148.28	156.10
	w_{cd} (gm)	104.08	101.33	104.69	104.47	115.25	120.35	118.00	123.08
	w_w (gm)	30.66	29.88	29.95	30.39	29.963	31.763	30.28	33.02
	w_s (gm)	74.79	74.25	74.68	74.46	73.04	78.24	75.52	80.76
	w (%)	40.99	40.24	40.10	40.81	41.02	40.60	40.10	40.89

Table F-2: Moisture content result for samples from TP-9 to TP-16

Parameters		TP-9	TP-10	TP-11	TP-12	TP-13	TP-14	TP-15	TP-16
Initial moisture content	w_c (gm)	23.13	23.02	23.16	22.97	21.97	20.97	21.97	20.07
	w_{cw} (gm)	166.36	106.55	179.01	99.85	98.85	99.45	99.85	97.94
	w_{cd} (gm)	128.59	83.25	140.25	80.11	80.11	80.11	80.11	79.01
	w_w (gm)	37.77	23.30	38.76	19.74	18.74	19.34	19.74	18.93
	w_s (gm)	105.47	60.23	117.09	57.14	58.14	59.14	58.14	58.94
	w (%)	35.81	38.69	33.10	34.54	32.22	32.70	33.94	32.12
Final moisture content	w_c (gm)	42.19	42.33	42.21	43.01	43.11	42.01	41.64	41.83
	w_{cw} (gm)	142.16	150.77	149.69	152.95	151.35	153.05	150.98	154.03
	w_{cd} (gm)	112.65	119.17	118.40	120.97	120.27	121.27	119.77	119.93
	w_w (gm)	29.51	31.6	31.29	31.98	31.08	31.78	31.21	34.1
	w_s (gm)	70.46	76.84	76.19	77.96	77.16	79.26	78.13	78.1
	w (%)	41.88	41.12	41.07	41.02	40.28	40.10	39.95	43.66

Table F-3: Specimen data and properties result for soil from TP-1 to TP-8

Parameters	TP-1	TP-2	TP-3	TP-4	TP-5	TP-6	TP-7	TP-8
M_{rs} (gm)	168.1	168.14	168.25	168.16	165.69	165.59	168.92	175.14
M_r (gm)	76.57	76.54	76.36	76.36	76.36	76.36	76.36	76.57
M_s (gm)	91.53	91.6	91.89	91.8	89.33	89.23	92.56	98.57
D (cm)	6	6	6	6	6	6	6	6
H (cm)	2	2	2	2	2	2	2	2
V (cm^3)	56.52	56.52	56.52	56.52	56.52	56.52	56.52	56.52
ρ_{wet} (gm/cm^3)	1.619	1.621	1.626	1.624	1.581	1.579	1.638	1.744
$w_{initial}$, %	33.65	35.70	35.69	36.23	37.20	38.14	38.14	34.18
ρ_{dry} (gm/cm^3)	1.212	1.194	1.198	1.192	1.152	1.143	1.186	1.300
G_s	2.606	2.602	2.61	2.618	2.500	2.700	2.670	2.801
ρ_w (gm/cm^3)	1	1	1	1	1	1	1	1
V_s (cm^3)	28.70	28.54	28.61	28.44	29.22	28.98	28.28	28.83
H_s (cm)	1.02	1.01	1.01	1.01	1.03	1.03	1.00	1.02
V_v (cm^3)	27.82	27.98	27.91	28.08	27.30	27.54	28.24	27.69
e_0	0.969	0.981	0.98	0.99	0.935	0.950	0.998	0.960
w_{final}, %	42.91	40.24	40.10	40.81	41.02	40.60	40.10	40.89

Table F-4: Specimen data and properties result for soil from TP-9 to TP-16

Parameters	TP-9	TP-10	TP-11	TP-12	TP-13	TP-14	TP-15	TP-16
M_{rs} (gm)	170.14	173.14	172.14	171.14	170.14	174.14	174.14	169.14
M_r (gm)	76.57	76.57	76.57	76.57	76.57	76.57	76.57	76.57
M_s (gm)	93.57	96.57	95.57	94.57	93.57	97.57	97.57	92.57
D (cm)	6	6	6	6	6	6	6	6
H (cm)	2	2	2	2	2	2	2	2
V (cm^3)	56.52	56.52	56.52	56.52	56.52	56.52	56.52	56.52
ρ_{wet} (gm/cm^3)	1.656	1.709	1.691	1.673	1.656	1.726	1.726	1.638
$w_{initial}$, %	35.81	38.69	33.10	34.54	32.22	32.70	33.94	32.12
ρ_{dry} (gm/cm^3)	1.219	1.232	1.270	1.244	1.252	1.301	1.289	1.240
G_s	2.463	2.7	2.68	2.69	2.65	2.71	2.7	2.65
ρ_w (gm/cm^3)	1	1	1	1	1	1	1	1
V_s (cm^3)	28.61	28.46	28.43	28.98	29.12	29.25	28.94	29.47
H_s (cm)	1.01	1.01	1.01	1.03	1.03	1.03	1.02	1.04
V_v (cm^3)	27.91	28.06	28.09	27.54	27.40	27.27	27.58	27.05
e_0	0.976	0.986	0.988	0.950	0.941	0.932	0.953	0.918
w_{final}, %	41.88	41.12	41.07	41.02	40.28	40.10	39.95	43.66

Table F-5: Recorded specimen data of TP-1

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.015	0.032	0.19	0.887	1.96	2.993
0.25	0.016	0.034	0.197	0.923	2.006	3.016
0.5	0.0175	0.038	0.212	0.963	2.09	3.058
1	0.02	0.044	0.232	1.053	2.201	3.105
2	0.022	0.051	0.258	1.149	2.308	3.193
4	0.0235	0.057	0.276	1.216	2.373	3.291
8	0.0247	0.061	0.289	1.287	2.429	3.401
15	0.0256	0.065	0.298	1.346	2.478	3.479
30	0.0267	0.069	0.306	1.414	2.528	3.583
60	0.0276	0.073	0.318	1.485	2.576	3.699
120	0.0289	0.077	0.328	1.548	2.621	3.852
240	0.03	0.0795	0.336	1.614	2.663	3.973
480	0.031	0.081	0.341	1.652	2.689	4.053
1440	0.0317	0.082	0.345	1.687	2.709	4.094
	Unloading					
	3.303	3.429	3.524	3.626	3.765	3.983

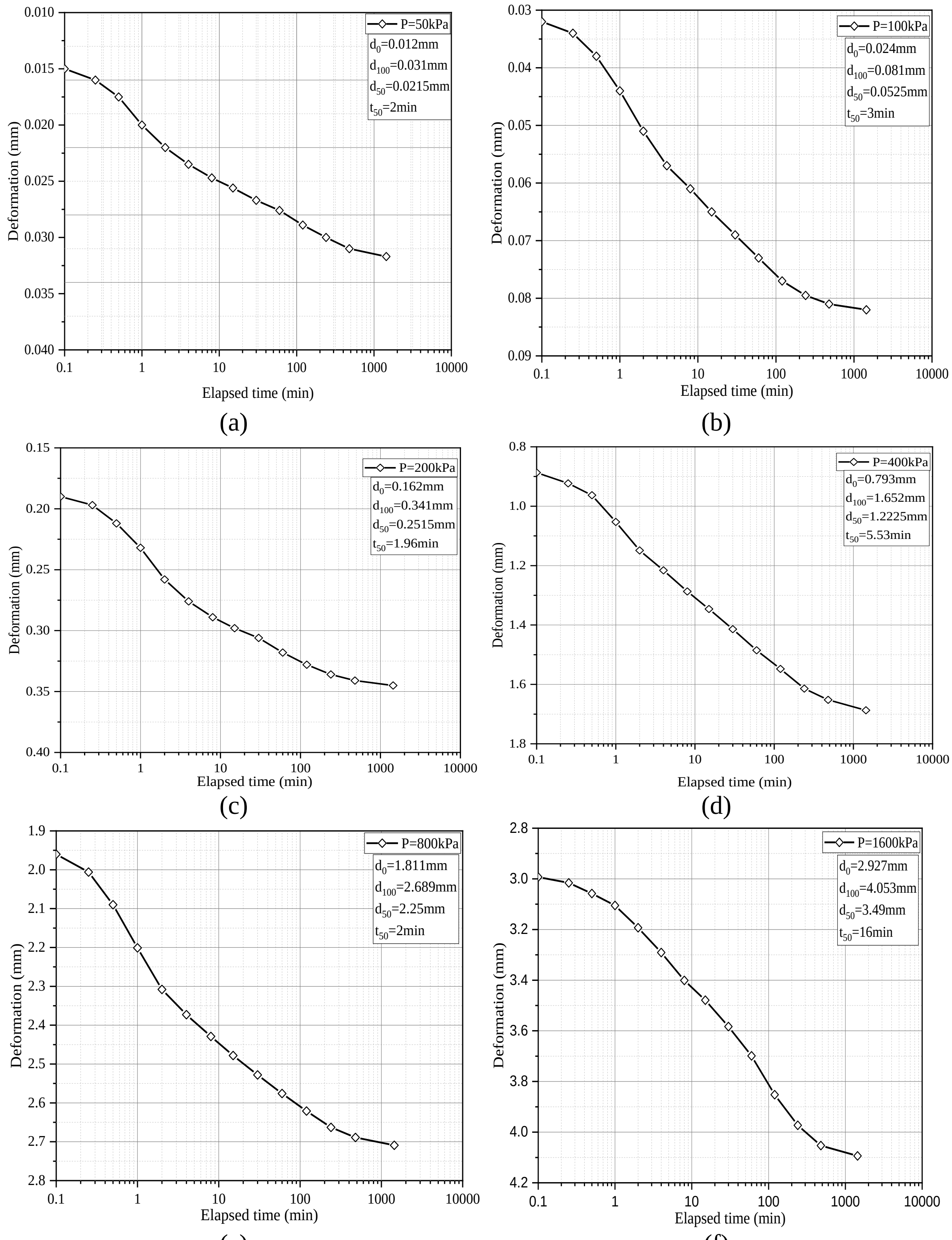
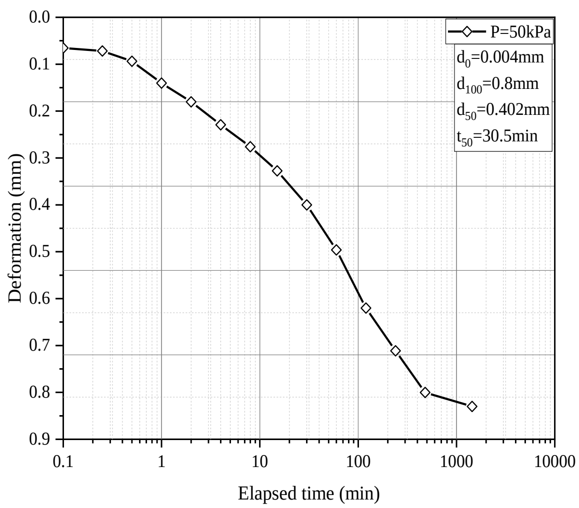


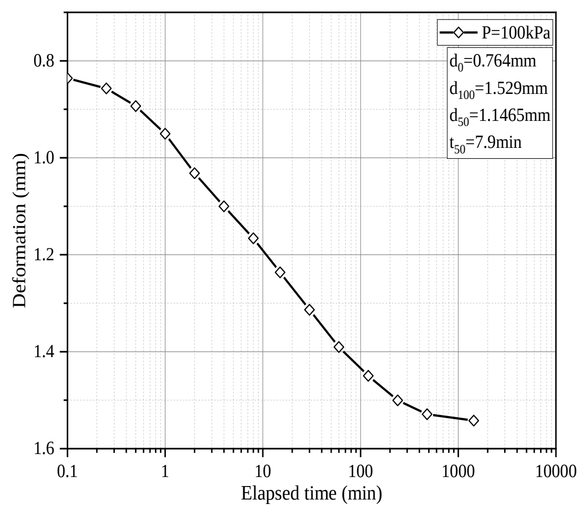
Figure F-1: Deformation versus log time curves of soil from TP-1 for different P

Table F-6: Recorded specimen data of TP-2

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.066	0.836	1.56	2.75	3.916	3.996
0.25	0.072	0.857	1.584	2.765	3.918	4
0.5	0.094	0.893	1.621	2.83	3.924	4.023
1	0.140	0.950	1.7	2.94	3.932	4.08
2	0.180	1.032	1.78	3.02	3.941	4.13
4	0.229	1.100	1.85	3.109	3.948	4.17
8	0.276	1.166	1.94	3.188	3.954	4.197
15	0.328	1.236	2.03	3.272	3.961	4.213
30	0.400	1.313	2.14	3.368	3.968	4.226
60	0.496	1.390	2.25	3.483	3.975	4.237
120	0.620	1.450	2.36	3.624	3.983	4.244
240	0.711	1.500	2.45	3.7	3.989	4.252
480	0.800	1.529	2.51	3.76	3.993	4.258
1440	0.830	1.542	2.532	3.801	3.995	4.26
	Unloading					
	3.989	3.999	4.025	4.132	4.197	4.257



(a)



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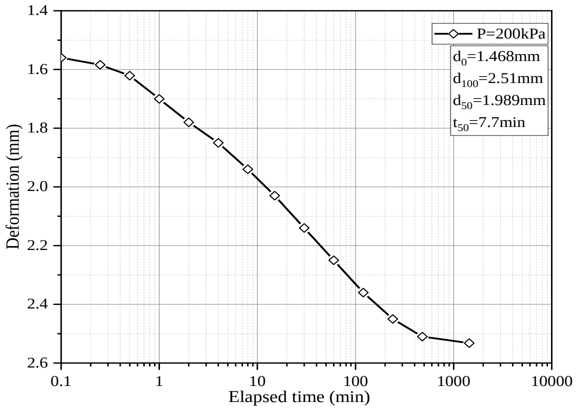

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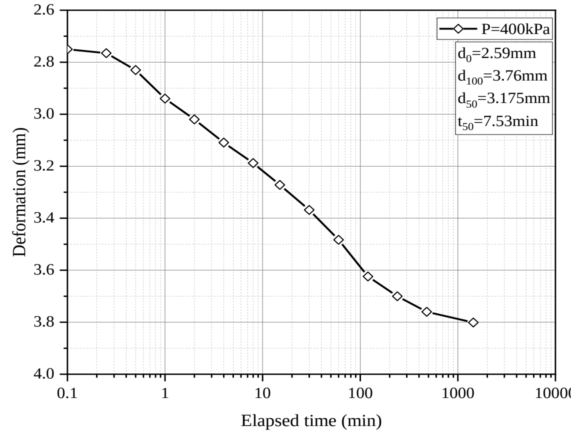

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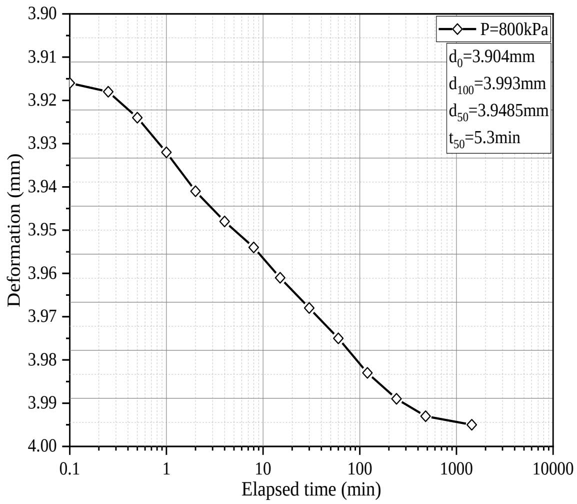

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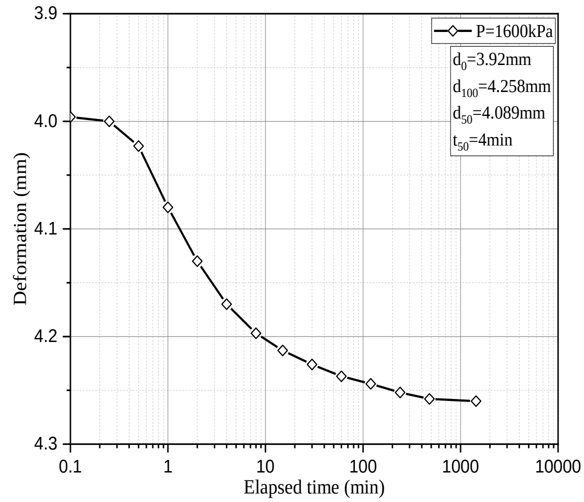


(f)

Figure F-2: Deformation versus log time curves of soil from TP-2 for different P

Table F-7: Recorded specimen data of TP-3

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.38	0.55	1.56	2.87	3.903	4.016
0.25	0.387	0.57	1.61	2.88	3.906	4.057
0.5	0.402	0.6	1.65	2.92	3.91	4.193
1	0.432	0.65	1.721	2.96	3.916	4.359
2	0.465	0.71	1.803	3.02	3.924	4.492
4	0.49	0.76	1.9	3.101	3.932	4.582
8	0.52	0.813	2	3.22	3.939	4.668
15	0.545	0.859	2.11	3.34	3.947	4.747
30	0.57	0.9	2.22	3.485	3.956	4.859
60	0.596	0.937	2.327	3.634	3.964	4.948
120	0.619	0.97	2.4	3.75	3.972	5.064
240	0.642	0.995	2.45	3.83	3.979	5.161
480	0.655	1.02	2.496	3.88	3.986	5.232
1440	0.66	1.03	2.531	3.9	3.989	5.26

Unloading					
4.472	4.358	4.745	4.934	5.064	5.08

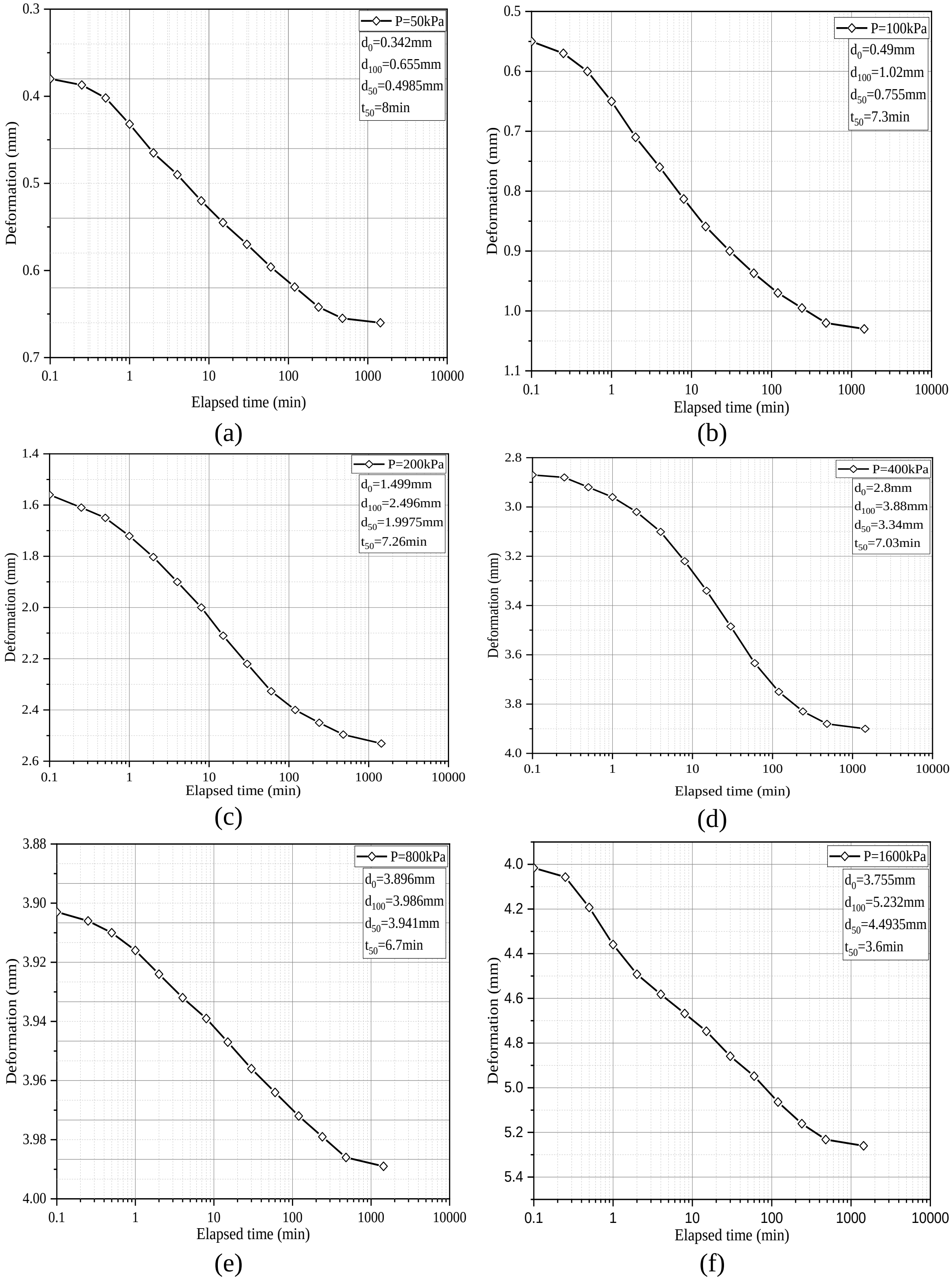
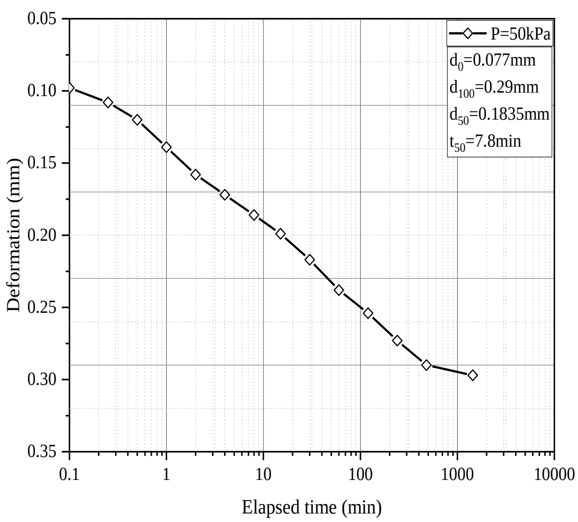


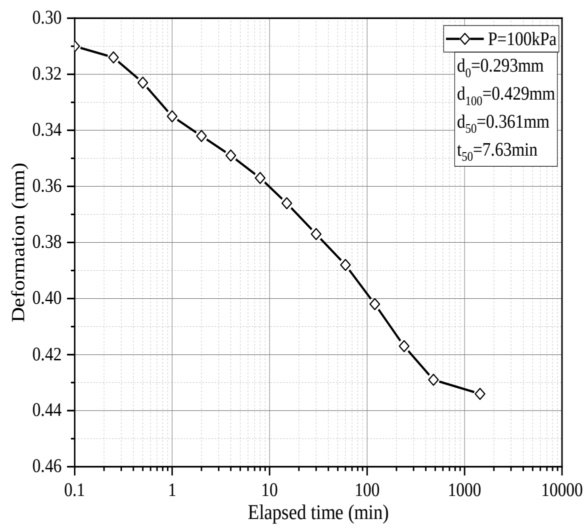
Figure F-3: Deformation versus log time curves of soil from TP-3 for different P

Table F-8: Recorded specimen data of TP-4

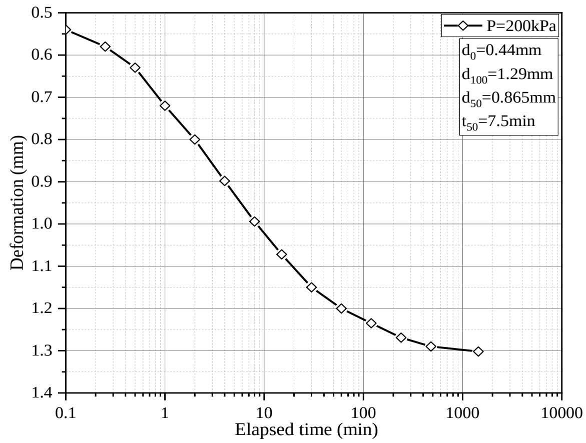
time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.098	0.31	0.54	1.95	3.12	4.25
0.25	0.108	0.314	0.58	1.98	3.16	4.29
0.5	0.12	0.323	0.63	2.03	3.21	4.359
1	0.139	0.335	0.72	2.1	3.289	4.492
2	0.158	0.342	0.8	2.163	3.37	4.582
4	0.172	0.349	0.898	2.278	3.45	4.668
8	0.186	0.357	0.994	2.375	3.54	4.757
15	0.199	0.366	1.072	2.529	3.63	4.859
30	0.217	0.377	1.15	2.69	3.75	4.948
60	0.238	0.388	1.2	2.81	3.848	5.064
120	0.254	0.402	1.235	2.89	3.98	5.161
240	0.273	0.417	1.269	2.96	4.09	5.232
480	0.29	0.429	1.29	2.99	4.17	5.29
1440	0.297	0.434	1.302	3.02	4.22	5.32
	Unloading					
	4.463	4.596	4.757	4.964	5.064	5.08



(a)



(b)



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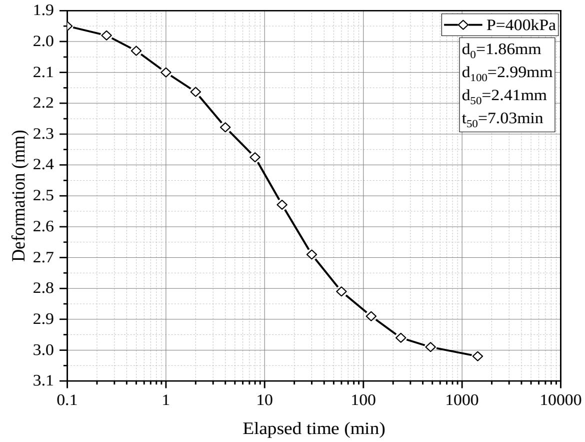

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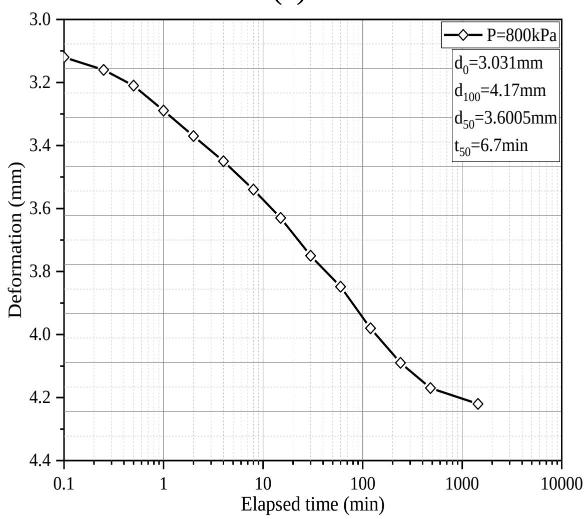

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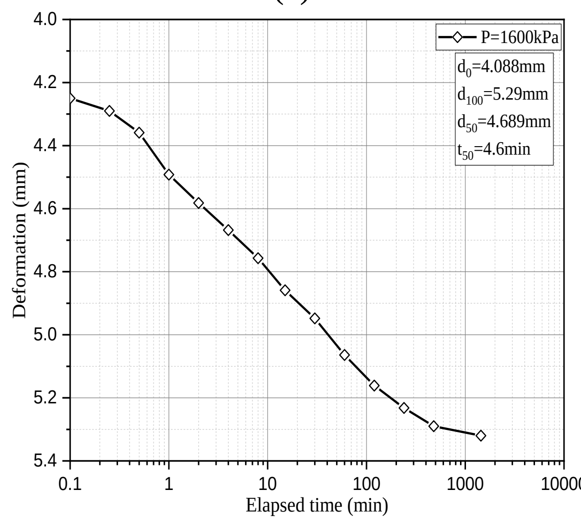


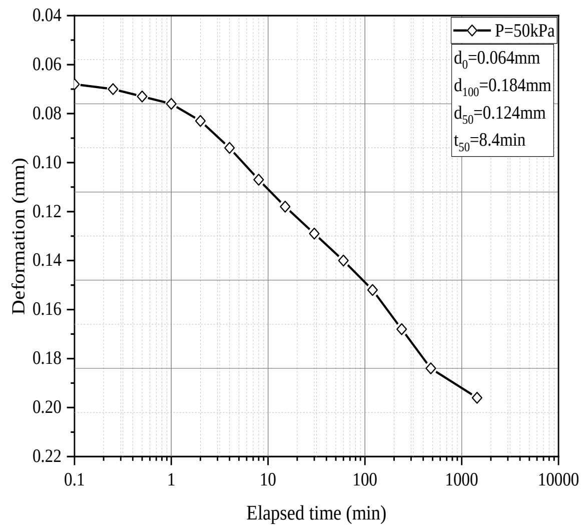
(f)

Figure F-4: Deformation versus log time curves of soil from TP-4 for different P

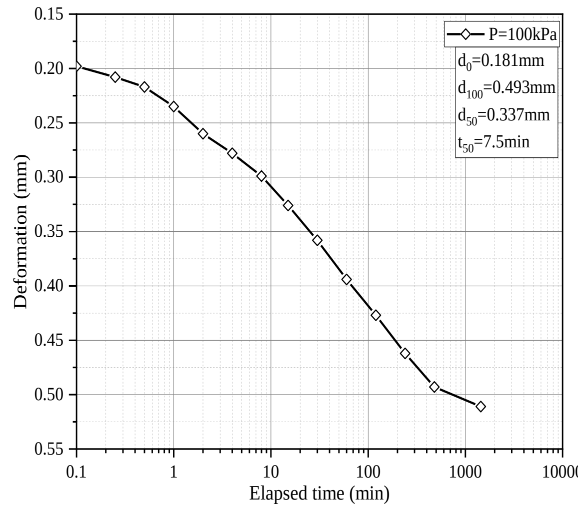
Table F-9: Recorded specimen data of TP-5

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.068	0.198	0.551	1.173	2.075	2.993
0.25	0.07	0.208	0.567	1.193	2.107	3.016
0.5	0.073	0.217	0.593	1.208	2.136	3.058
1	0.076	0.235	0.635	1.231	2.186	3.105
2	0.083	0.26	0.726	1.253	2.25	3.193
4	0.094	0.278	0.806	1.301	2.346	3.291
8	0.107	0.299	0.88	1.376	2.44	3.401
15	0.118	0.326	0.936	1.453	2.51	3.479
30	0.129	0.358	0.995	1.541	2.581	3.583
60	0.14	0.394	1.056	1.657	2.658	3.699
120	0.152	0.427	1.099	1.788	2.741	3.852
240	0.168	0.462	1.13	1.9	2.821	3.973
480	0.184	0.493	1.156	1.993	2.883	4.053

1440	0.196	0.511	1.172	2.035	2.923	4.094
	Unloading					
	3.016	3.105	3.291	3.479	3.683	3.852



(a)



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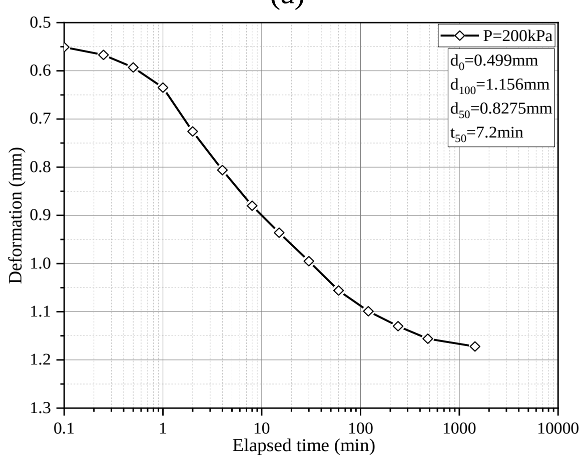

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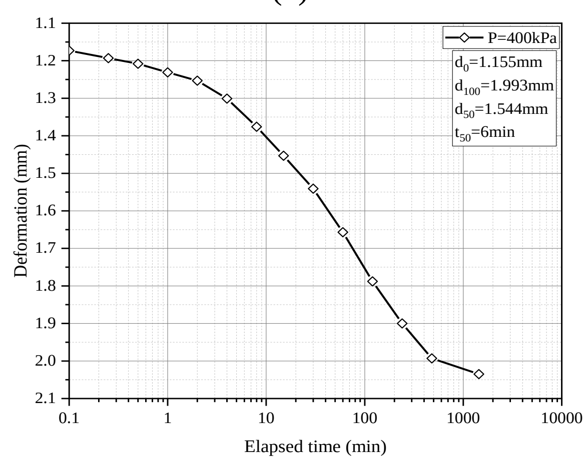

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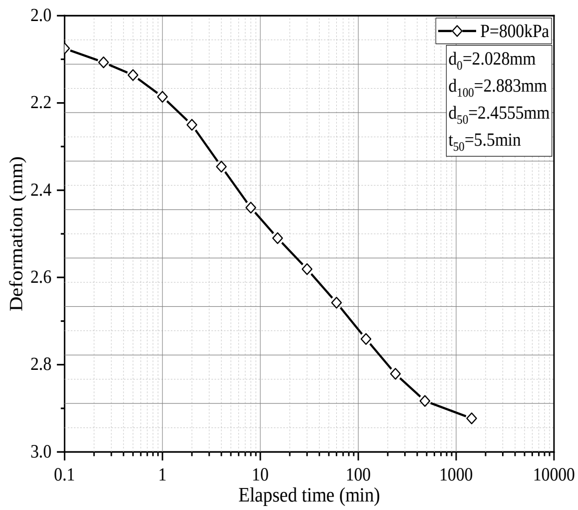
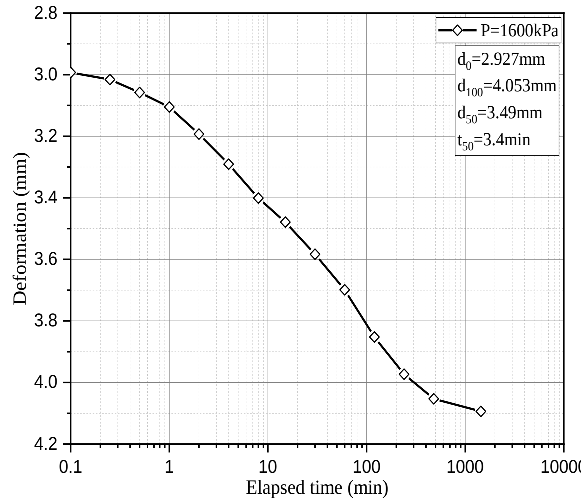


(e)



(f)

Figure F-5: Deformation versus log time curves of soil from TP-5 for different P

Table F-10: Recorded specimen data of TP-6

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.125	0.313	0.645	1.215	1.96	2.759
0.25	0.133	0.328	0.691	1.265	2.006	2.785
0.5	0.146	0.347	0.7527	1.324	2.09	2.839
1	0.164	0.396	0.848	1.429	2.201	2.948
2	0.189	0.447	0.93	1.518	2.308	3.05
4	0.21	0.495	0.98	1.605	2.373	3.136
8	0.235	0.526	1.02	1.669	2.429	3.198
15	0.248	0.547	1.056	1.708	2.478	3.26
30	0.262	0.562	1.086	1.738	2.528	3.326
60	0.274	0.578	1.117	1.769	2.576	3.384
120	0.287	0.596	1.146	1.802	2.621	3.448
240	0.298	0.616	1.169	1.836	2.663	3.509
480	0.307	0.63	1.188	1.858	2.689	3.556
1440	0.312	0.635	1.204	1.872	2.709	3.586
	Unloading					
	3.067	3.139	3.261	3.397	3.468	3.546

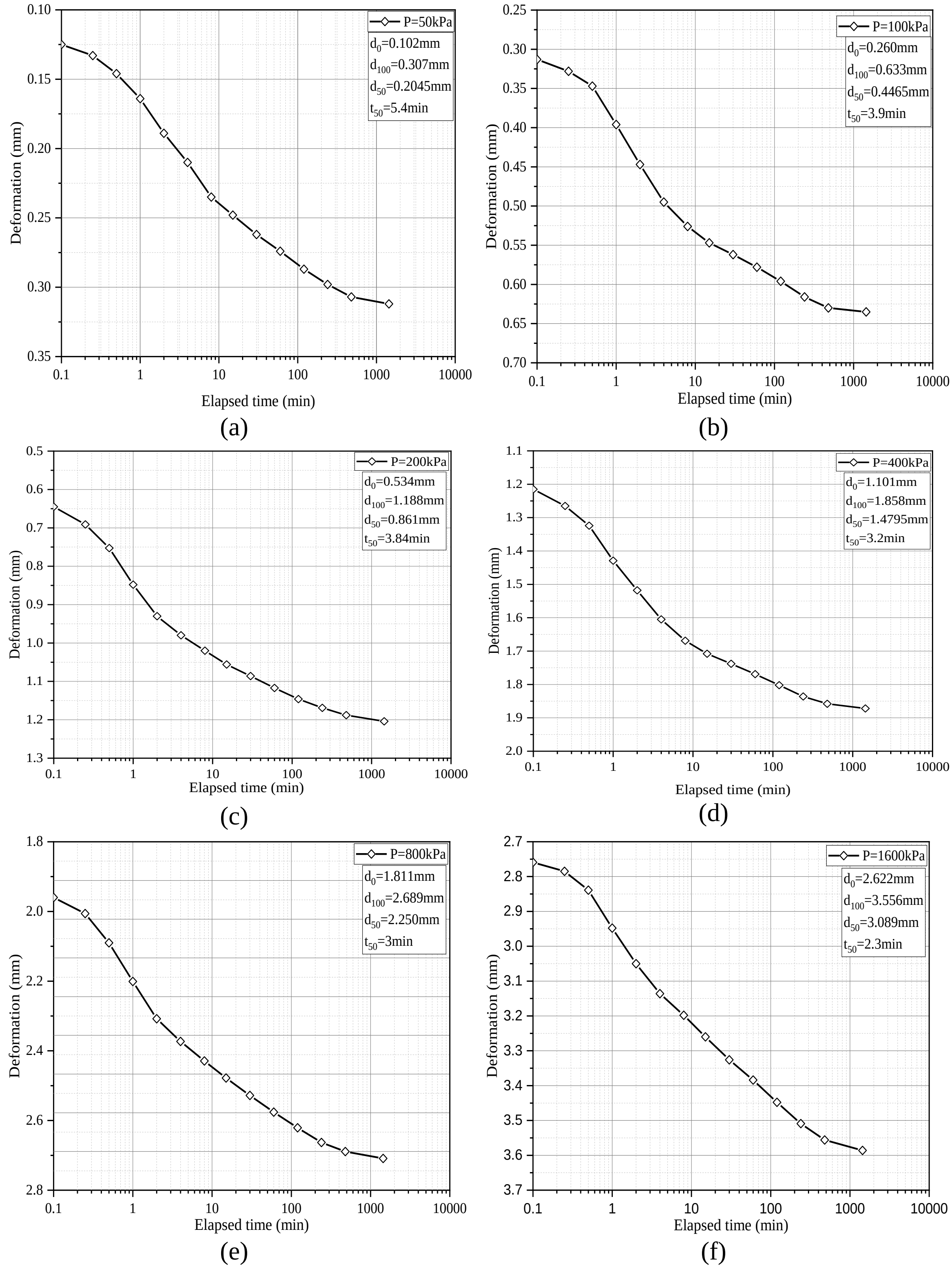
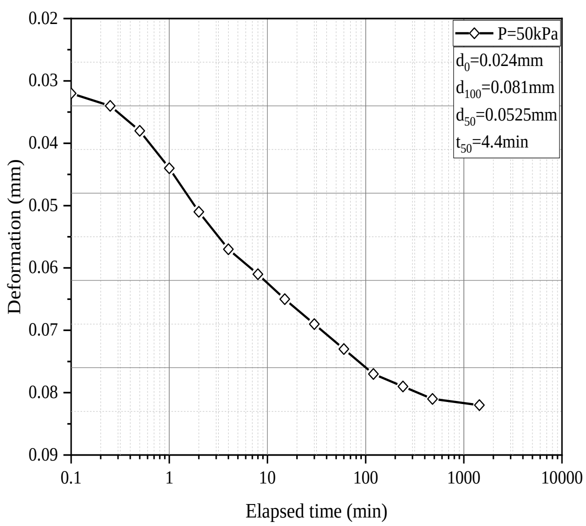


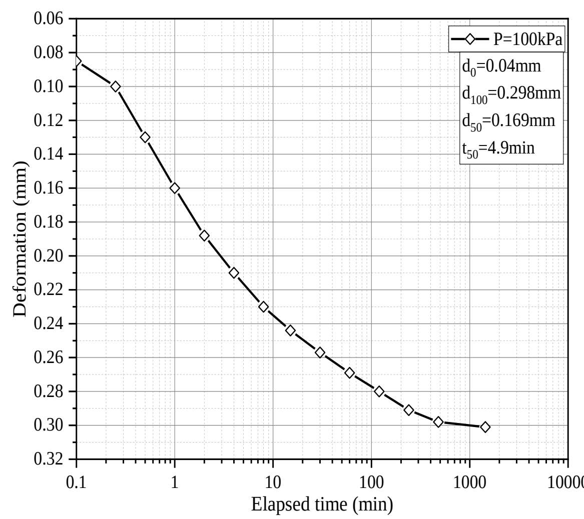
Figure F-6: Deformation versus log time curves of soil from TP-6 for different P

Table F-11: Recorded specimen data of TP-7

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.032	0.085	0.311	0.925	1.613	2.293
0.25	0.034	0.1	0.346	0.964	1.653	2.346
0.5	0.038	0.13	0.431	1.014	1.735	2.426
1	0.044	0.16	0.53	1.098	1.855	2.545
2	0.051	0.188	0.631	1.187	2.001	2.658
4	0.057	0.21	0.713	1.293	2.105	2.74
8	0.061	0.23	0.782	1.393	2.163	2.799
15	0.065	0.244	0.82	1.461	2.191	2.84
30	0.069	0.257	0.846	1.512	2.215	2.885
60	0.073	0.269	0.868	1.548	2.235	2.921
120	0.077	0.28	0.887	1.565	2.254	2.948
240	0.079	0.291	0.901	1.579	2.267	2.975
480	0.081	0.298	0.911	1.586	2.279	2.998
1440	0.082	0.301	0.915	1.588	2.288	3.008
	Unloading					
	2.842	2.876	2.912	2.948	2.972	2.987



(a)



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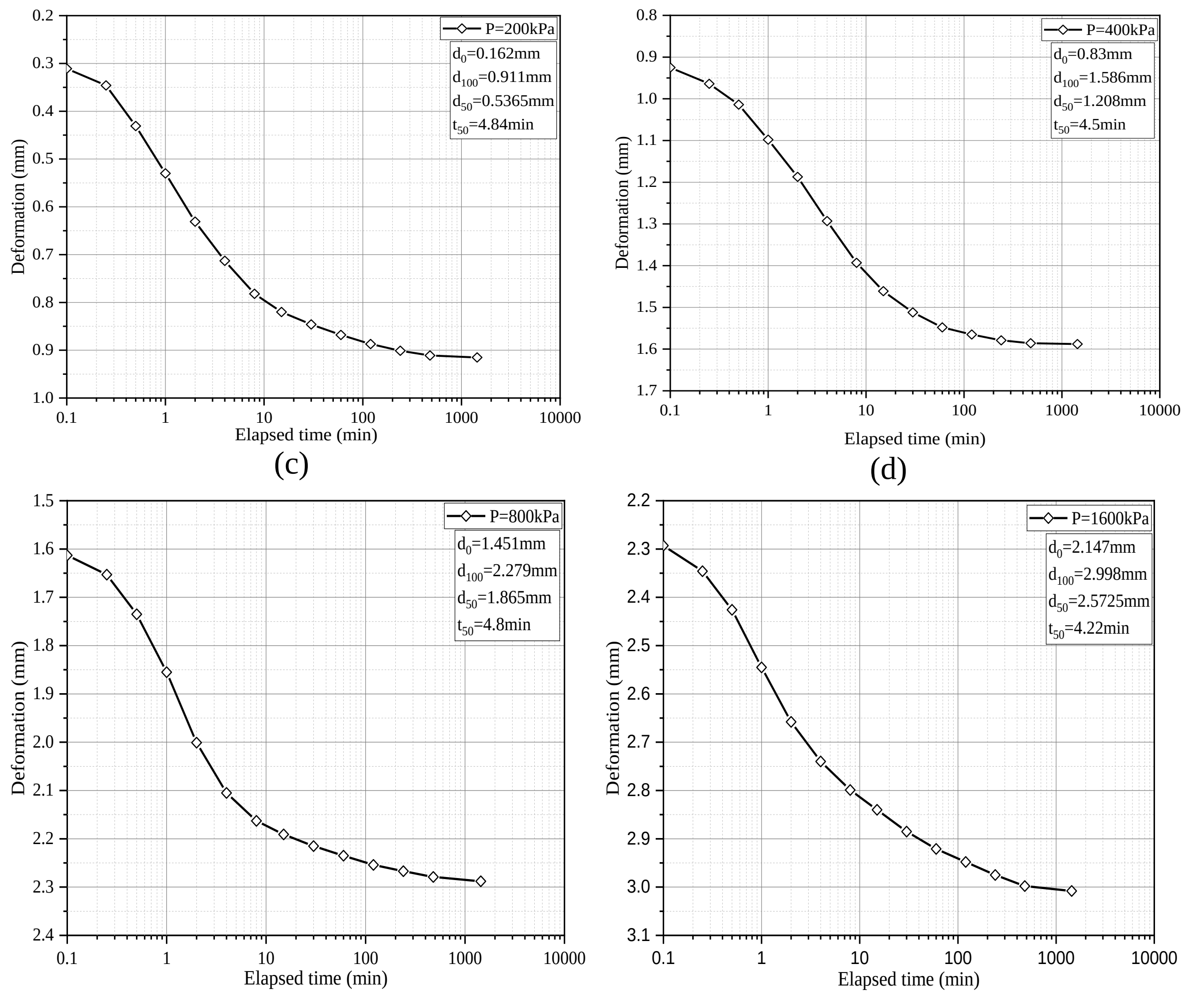


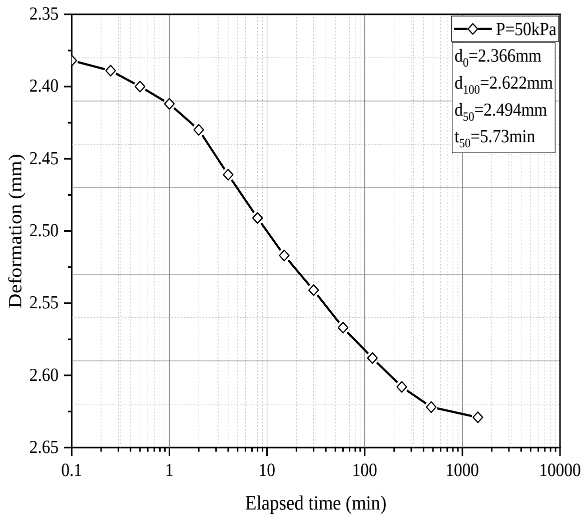
(c) (d) (e) (f)

Figure F-7: Deformation versus log time curves of soil from TP-7 for different P

Table F-12: Recorded specimen data of TP-8

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	2.382	2.646	2.7321	2.796	2.958	3.305
0.25	2.389	2.649	2.7338	2.8	2.962	3.314
0.5	2.4	2.654	2.7363	2.805	2.971	3.332
1	2.412	2.662	2.7398	2.816	2.988	3.362
2	2.43	2.671	2.7432	2.829	3.01	3.399
4	2.461	2.681	2.746	2.839	3.04	3.432
8	2.491	2.69	2.7486	2.849	3.065	3.466
15	2.517	2.698	2.7505	2.857	3.086	3.493
30	2.541	2.706	2.7527	2.865	3.116	3.522
60	2.567	2.712	2.7549	2.873	3.14	3.544
120	2.588	2.716	2.7569	2.88	3.167	3.564
240	2.608	2.719	2.7586	2.885	3.19	3.579
480	2.622	2.722	2.7602	2.8878	3.21	3.588

1440	2.629	2.723	2.7613	2.8894	3.22	3.5894
			Unloading			
	3.4743	3.493	3.532	3.556	3.568	3.589



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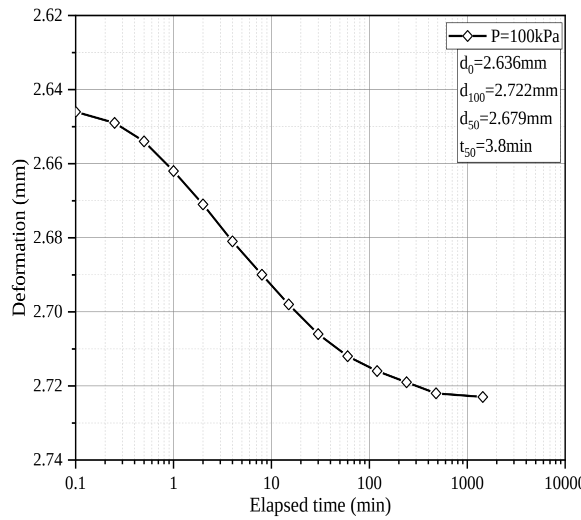
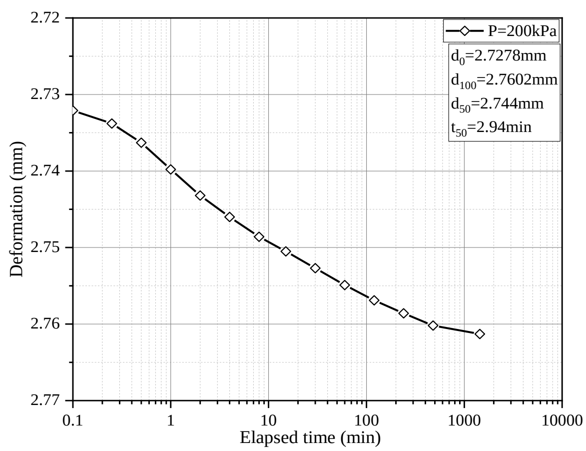


(b)



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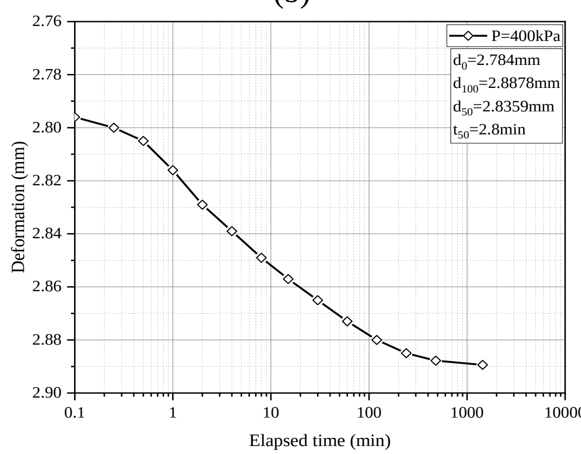

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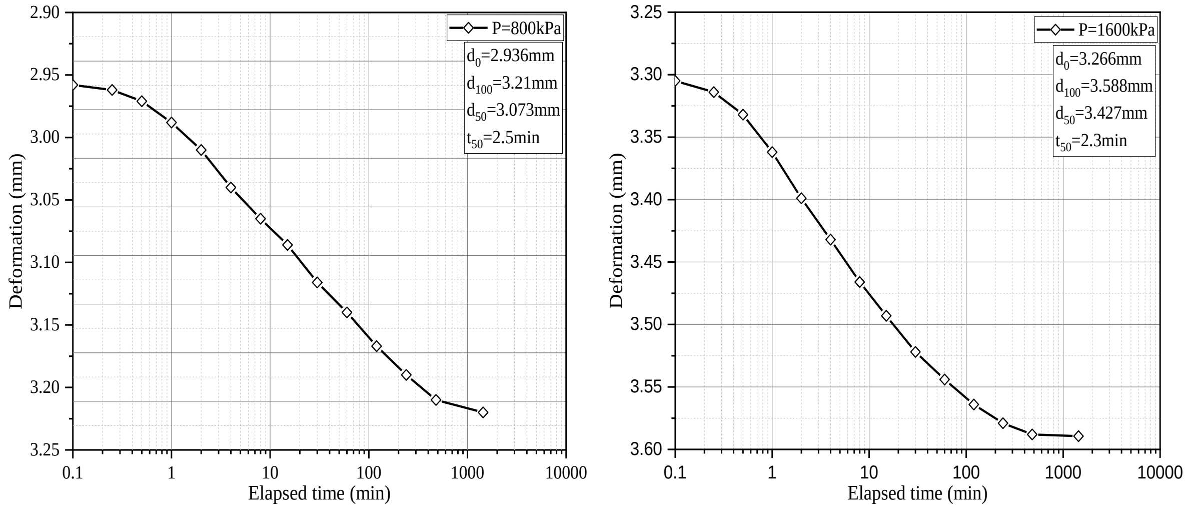
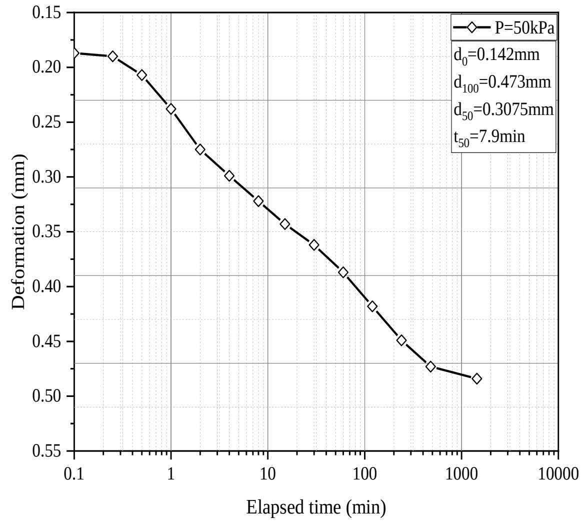


(e) (f)

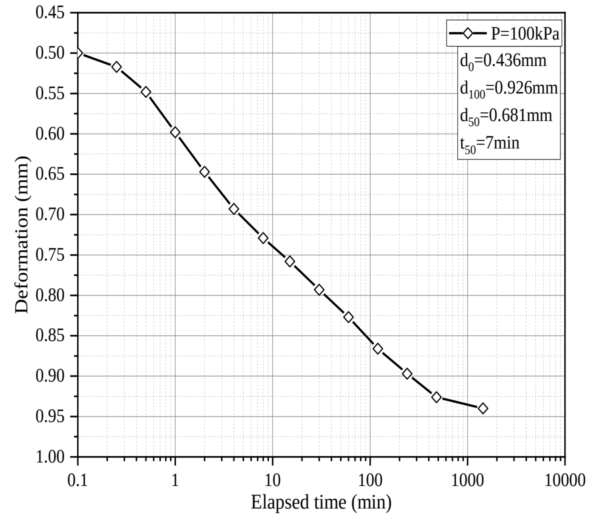
Figure F-8: Deformation versus log time curves of soil from TP-8 for different P

Table F-13: Recorded specimen data of TP-9

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.187	0.5	0.98	1.688	2.473	3.3
0.25	0.19	0.517	1.006	1.709	2.487	3.308
0.5	0.207	0.548	1.059	1.759	2.526	3.333
1	0.238	0.598	1.141	1.85	2.586	3.379
2	0.275	0.647	1.229	1.94	2.679	3.451
4	0.299	0.693	1.281	1.998	2.749	3.509
8	0.322	0.729	1.33	2.037	2.836	3.552
15	0.343	0.758	1.378	2.079	2.923	3.603
30	0.362	0.793	1.43	2.126	3.016	3.657
60	0.387	0.827	1.487	2.157	3.083	3.708
120	0.418	0.866	1.541	2.189	3.15	3.758
240	0.449	0.897	1.595	2.226	3.209	3.816
480	0.473	0.926	1.64	2.268	3.266	3.869
1440	0.484	0.94	1.658	2.287	3.29	3.884
	Unloading					
	3.364	3.433	3.532	3.656	3.758	3.858



(a)



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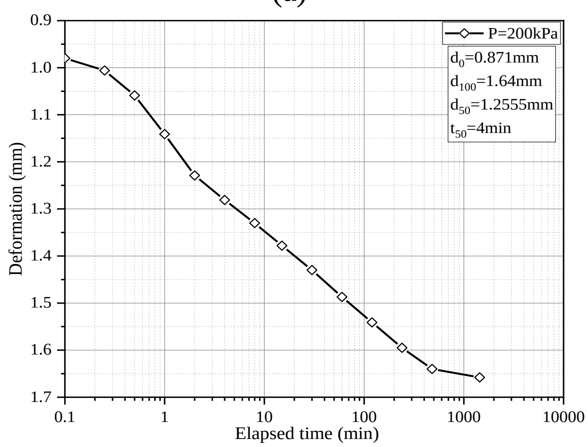

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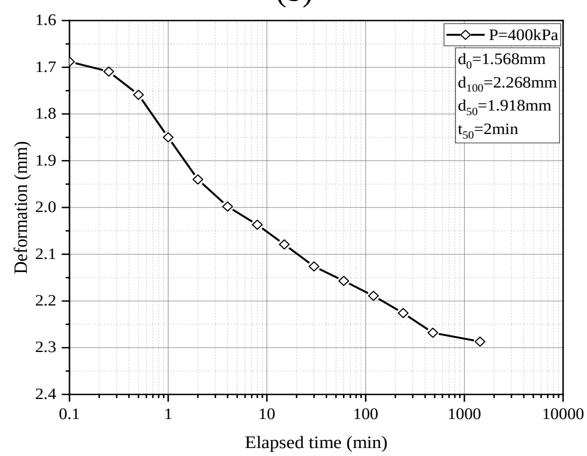

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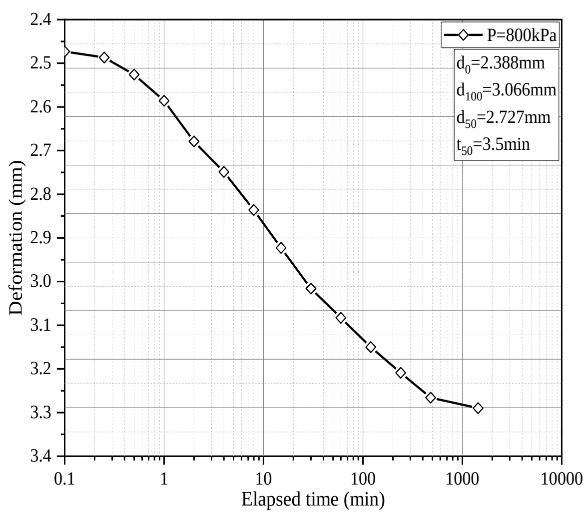

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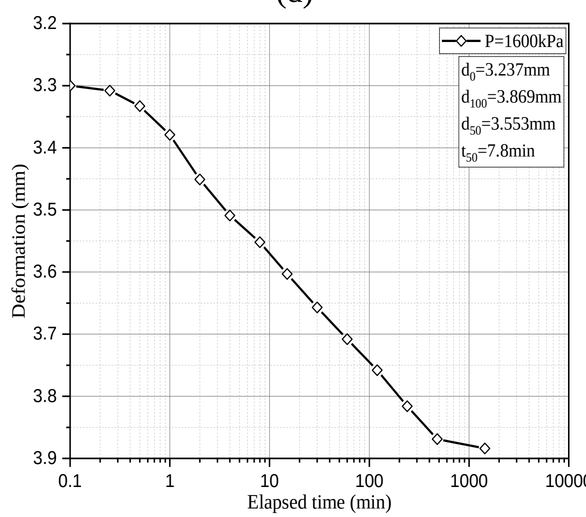
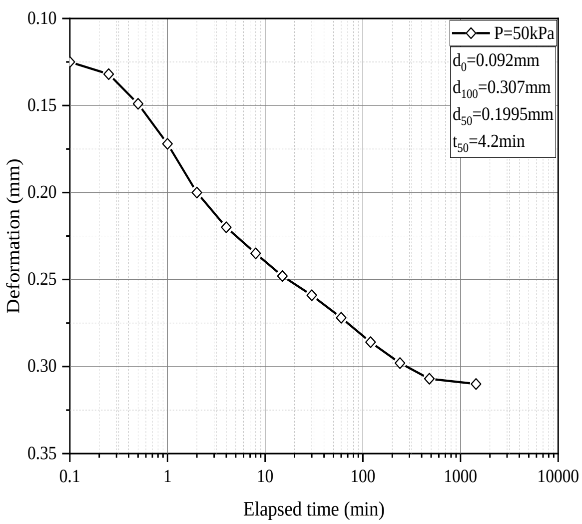


(f)

Figure F-9: Deformation versus log time curves of soil from TP-9 for different P

Table F-14: Recorded specimen data of TP-10

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.125	0.313	0.645	1.215	1.96	2.759
0.25	0.132	0.318	0.676	1.254	2	2.78
0.5	0.149	0.332	0.727	1.31	2.094	2.839
1	0.172	0.37	0.808	1.409	2.221	2.928
2	0.2	0.417	0.899	1.5	2.308	3.02
4	0.22	0.469	0.96	1.596	2.373	3.1
8	0.235	0.512	1.01	1.662	2.429	3.157
15	0.248	0.539	1.046	1.708	2.478	3.208
30	0.259	0.562	1.079	1.743	2.528	3.255
60	0.272	0.582	1.112	1.779	2.576	3.296
120	0.286	0.598	1.14	1.818	2.621	3.348
240	0.298	0.616	1.169	1.846	2.663	3.399
480	0.307	0.627	1.188	1.868	2.689	3.446
1440	0.31	0.632	1.195	1.878	2.702	3.459
	Unloading					
	3.028	3.124	3.208	3.296	3.376	3.432



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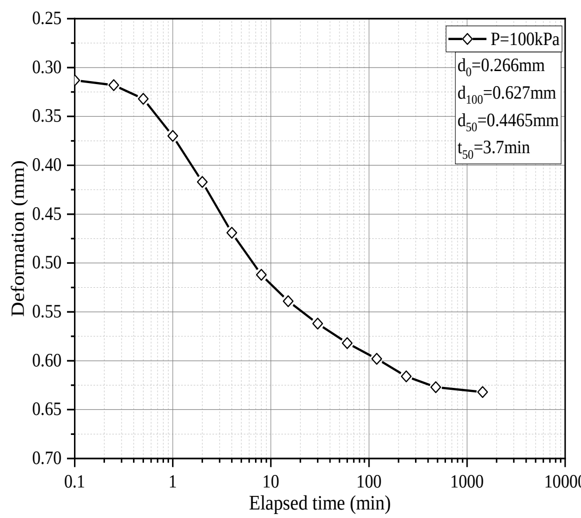

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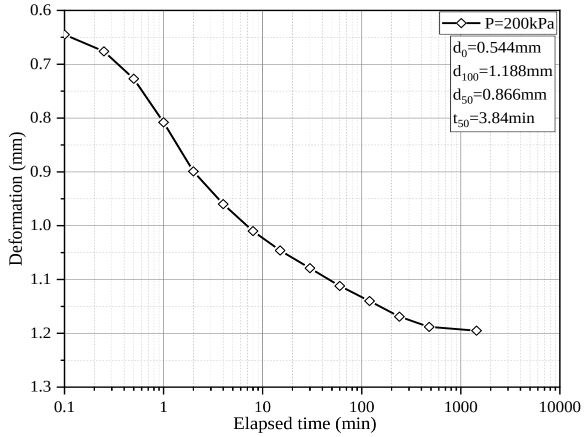

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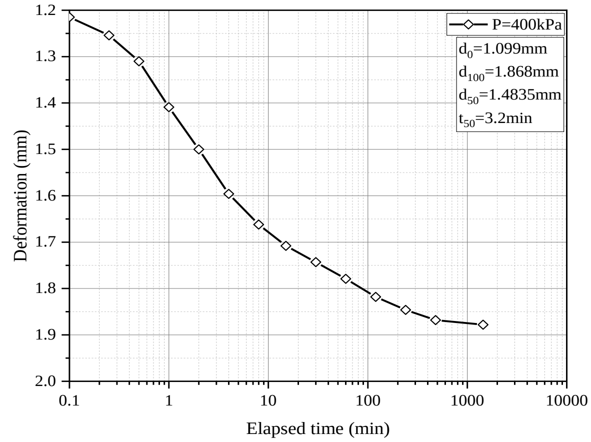

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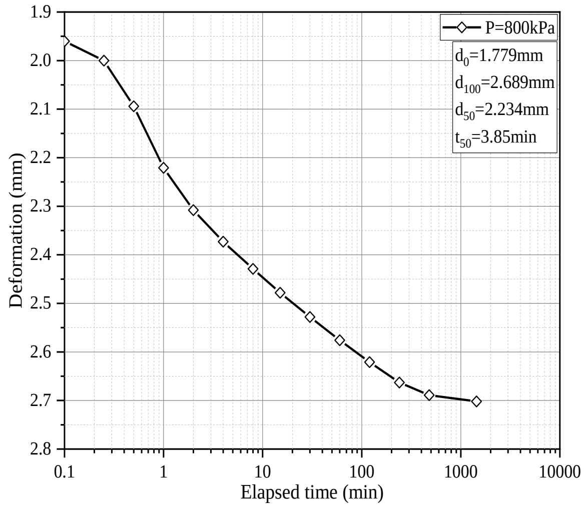

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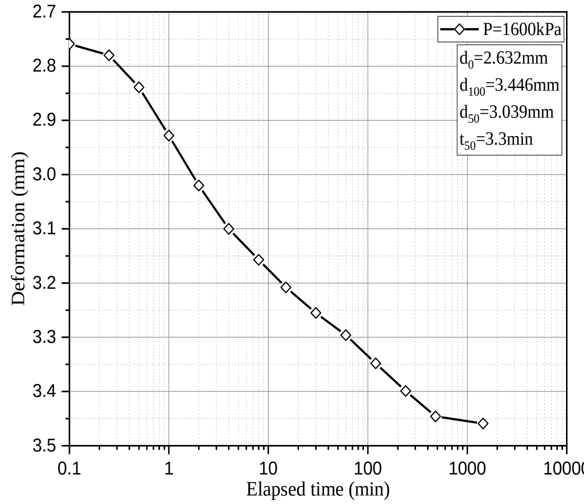


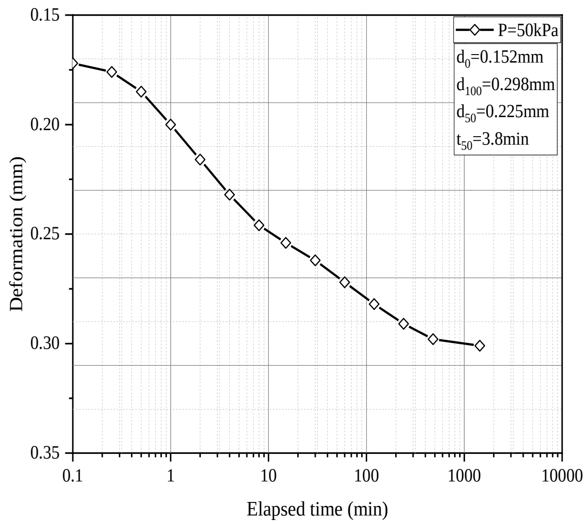
(f)

Figure F-10: Deformation versus log time curves of soil from TP-10 for different P

Table F-15: Recorded specimen data of TP-11

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.172	0.311	0.589	1.096	1.463	2.05
0.25	0.176	0.316	0.599	1.102	1.481	2.067
0.5	0.185	0.327	0.623	1.113	1.533	2.136
1	0.2	0.352	0.673	1.141	1.603	2.238
2	0.216	0.385	0.736	1.175	1.68	2.351
4	0.232	0.412	0.78	1.213	1.736	2.44
8	0.246	0.441	0.818	1.246	1.783	2.505
15	0.254	0.463	0.859	1.287	1.833	2.555
30	0.262	0.486	0.899	1.326	1.875	2.606
60	0.272	0.51	0.933	1.358	1.911	2.64
120	0.282	0.526	0.976	1.396	1.957	2.683
240	0.291	0.546	1.015	1.423	1.996	2.726
480	0.298	0.559	1.043	1.445	2.028	2.759

1440	0.301	0.569	1.056	1.453	2.039	2.777
	Unloading					
	2.268	2.421	2.553	2.624	2.683	2.748



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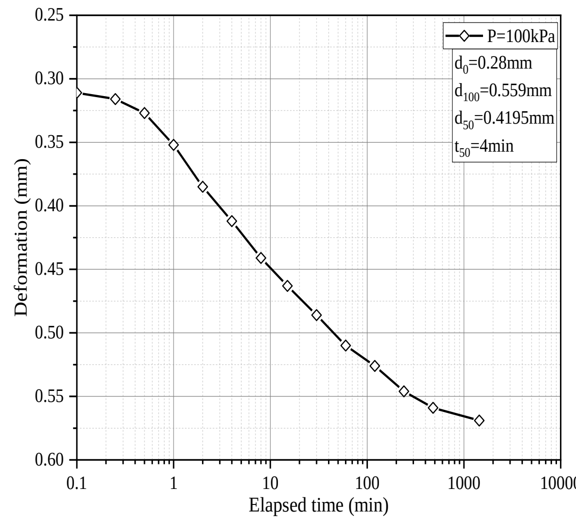

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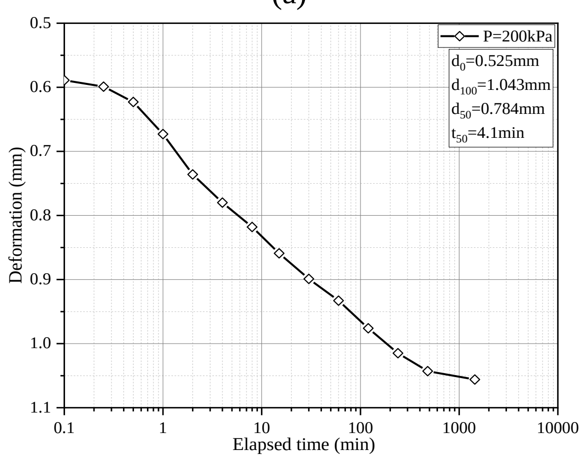

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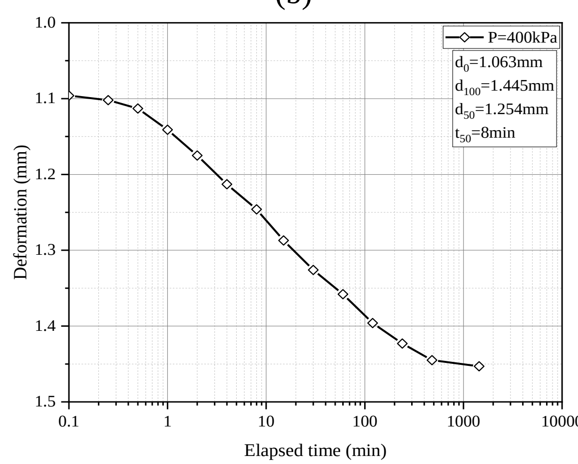

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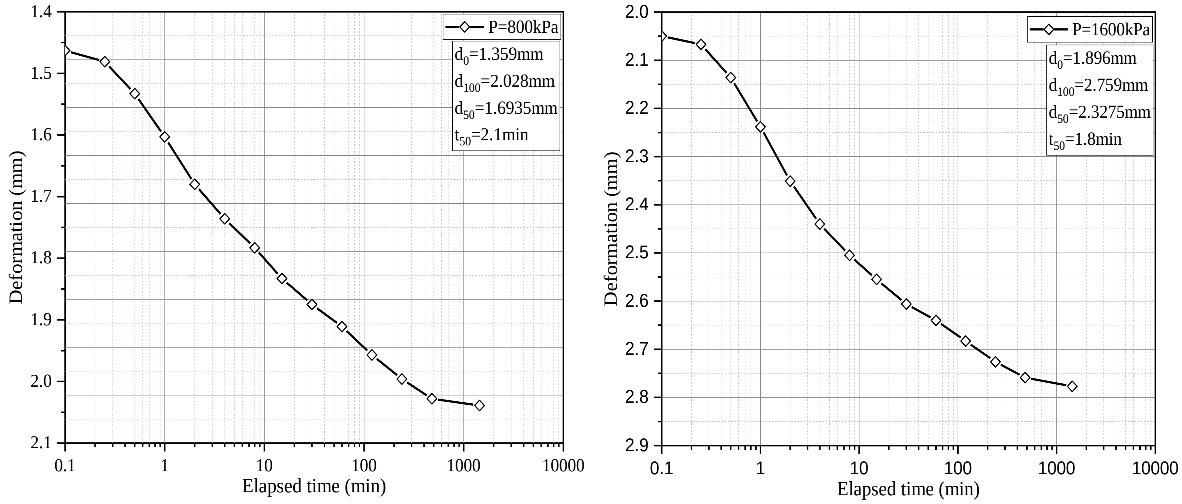
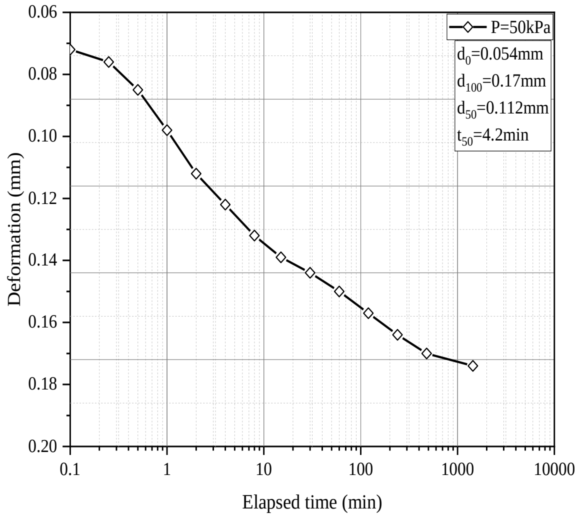


(e) (f)

Figure F-11: Deformation versus log time curves of soil from TP-11 for different P

Table F-16: Recorded specimen data of TP-12

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.072	0.181	0.409	0.783	1.338	2.063
0.25	0.076	0.192	0.417	0.809	1.387	2.084
0.5	0.085	0.209	0.446	0.866	1.456	2.133
1	0.098	0.245	0.489	0.947	1.574	2.266
2	0.112	0.278	0.536	1.019	1.676	2.439
4	0.122	0.303	0.588	1.088	1.768	2.606
8	0.132	0.323	0.635	1.146	1.823	2.741
15	0.139	0.335	0.666	1.183	1.857	2.848
30	0.144	0.347	0.686	1.218	1.896	2.951
60	0.15	0.359	0.702	1.247	1.928	3.062
120	0.157	0.373	0.72	1.278	1.963	3.156
240	0.164	0.384	0.74	1.307	1.996	3.237
480	0.17	0.396	0.755	1.326	2.018	3.312
1440	0.174	0.402	0.763	1.334	2.033	3.332
	Unloading					
	2.547	2.725	2.897	3.034	3.142	3.257



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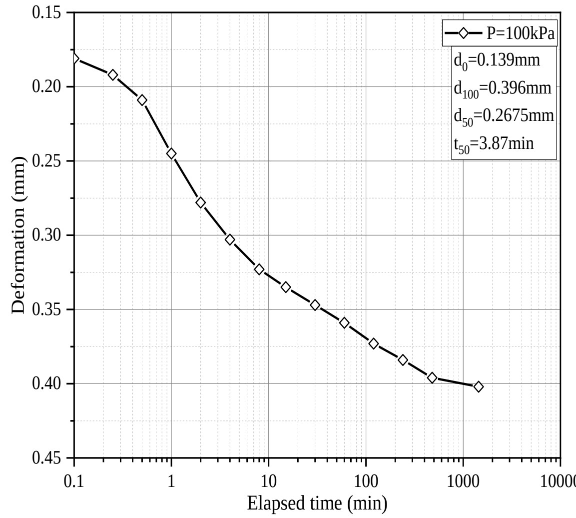

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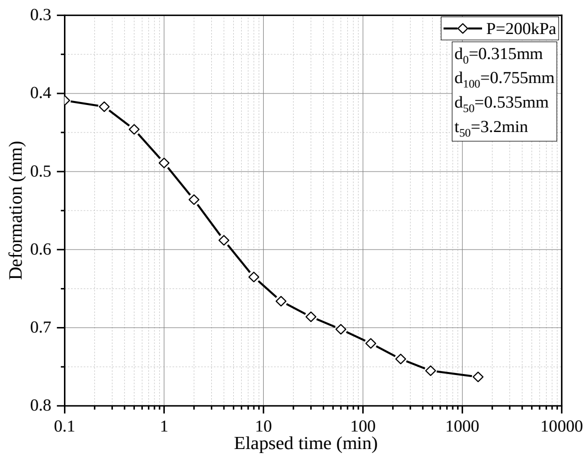

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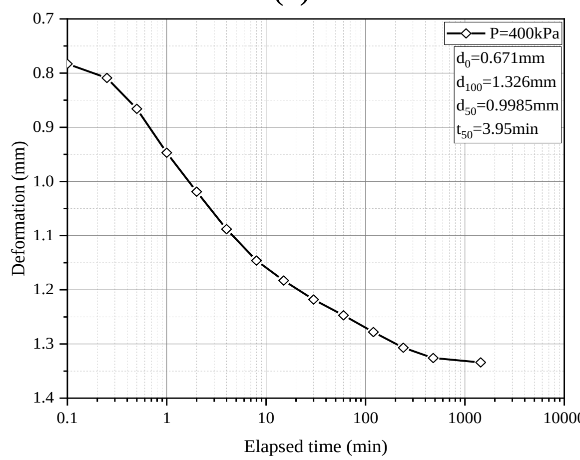

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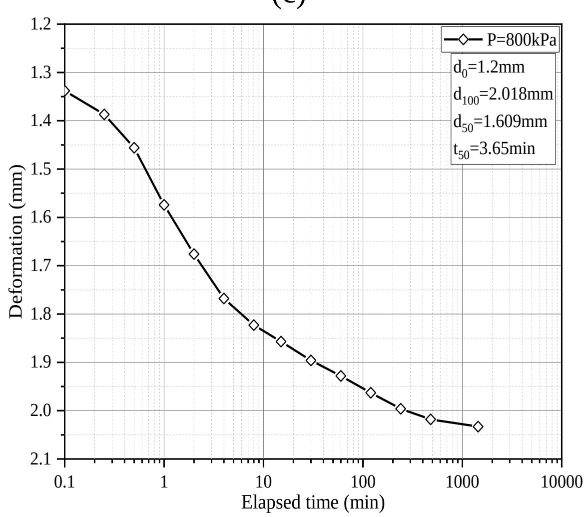

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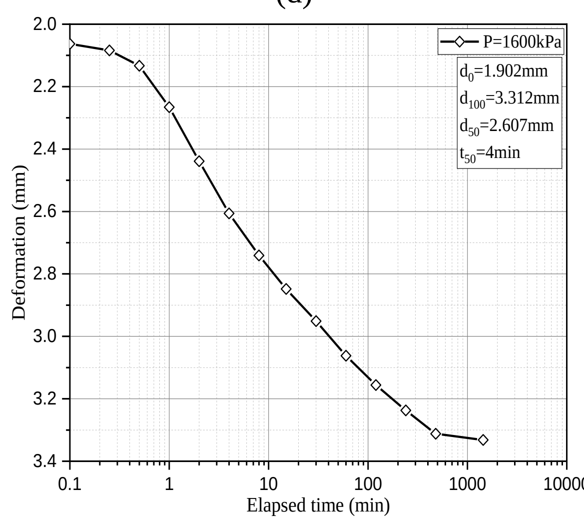
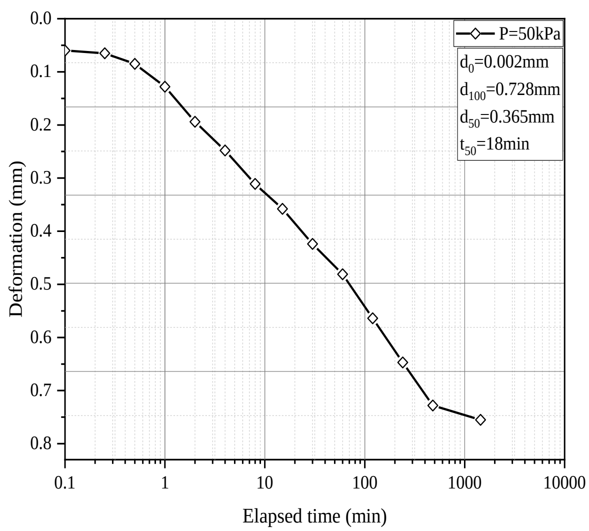


(f)

Figure F-12: Deformation versus log time curves of soil from TP-12 for different P

Table F-17: Recorded specimen data of TP-13

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.060	0.760	1.418	2.500	3.560	3.632
0.25	0.065	0.779	1.440	2.513	3.561	3.636
0.5	0.085	0.812	1.474	2.572	3.565	3.647
1	0.128	0.864	1.545	2.672	3.573	3.669
2	0.194	0.938	1.618	2.765	3.582	3.702
4	0.248	1.000	1.683	2.846	3.589	3.740
8	0.311	1.060	1.764	2.918	3.595	3.775
15	0.358	1.124	1.845	2.994	3.600	3.805
30	0.424	1.193	1.945	3.081	3.607	3.821
60	0.481	1.264	2.045	3.186	3.613	3.831
120	0.564	1.318	2.145	3.274	3.620	3.838
240	0.647	1.364	2.227	3.363	3.626	3.845
480	0.728	1.390	2.282	3.418	3.630	3.850
1440	0.755	1.402	2.302	3.455	3.631	3.852
	Unloading					
	3.41	3.517	3.622	3.723	3.811	3.865



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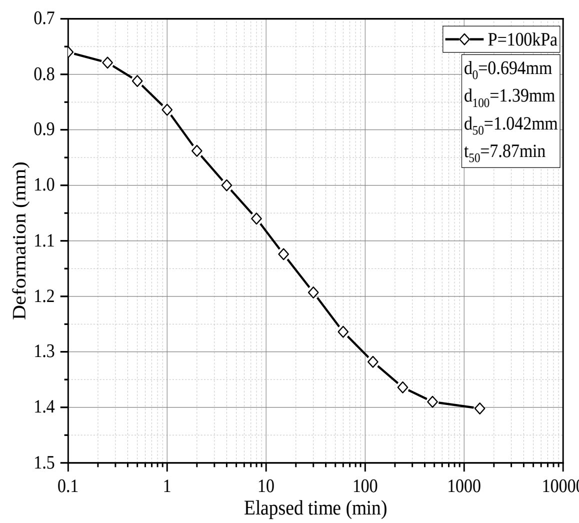

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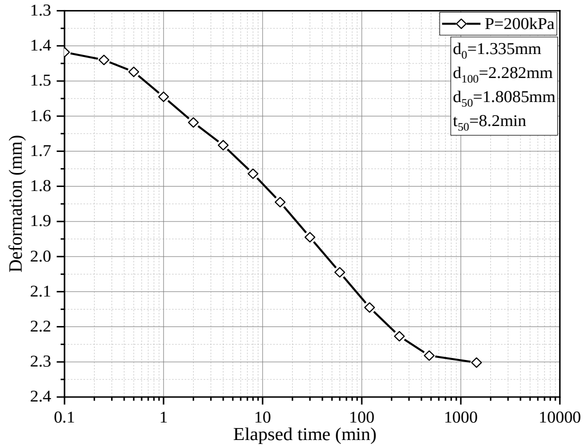

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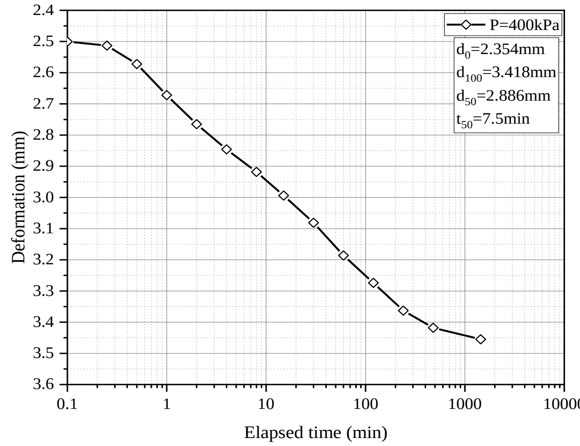

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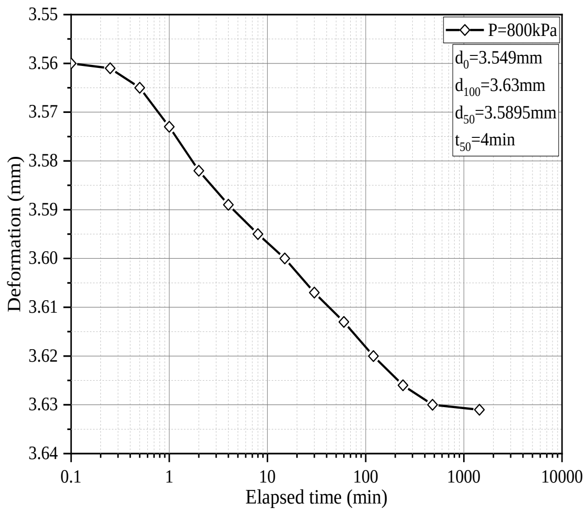

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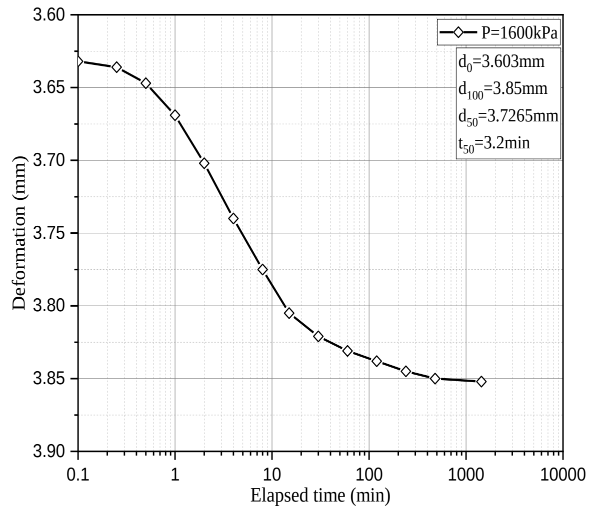


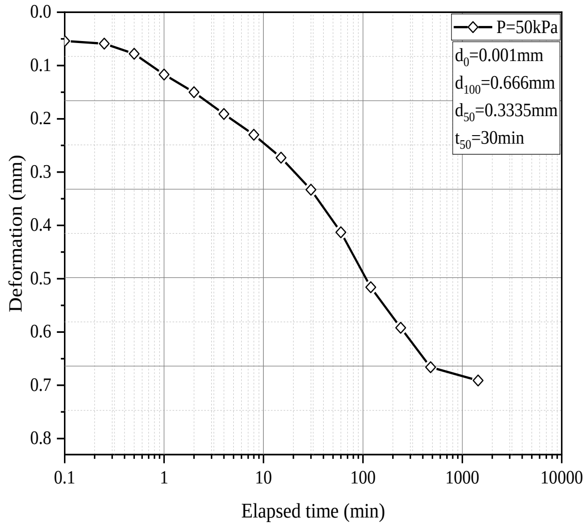
(f)

Figure F-13: Deformation versus log time curves of soil from TP-13 for different P

Table F-18: Recorded specimen data of TP-14

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.054	0.696	1.300	2.291	3.263	3.330
0.25	0.059	0.714	1.320	2.304	3.265	3.333
0.5	0.078	0.744	1.350	2.358	3.270	3.352
1	0.117	0.792	1.416	2.450	3.276	3.382
2	0.150	0.859	1.483	2.516	3.284	3.410
4	0.191	0.916	1.541	2.590	3.290	3.438
8	0.230	0.971	1.616	2.656	3.295	3.466
15	0.273	1.030	1.691	2.726	3.300	3.490
30	0.333	1.094	1.783	2.806	3.306	3.511
60	0.413	1.158	1.875	2.902	3.312	3.526
120	0.516	1.208	1.966	3.010	3.319	3.536
240	0.592	1.250	2.041	3.083	3.324	3.543
480	0.666	1.274	2.091	3.133	3.327	3.548

1440	0.691	1.285	2.110	3.167	3.329	3.550
	Unloading					
	3.236	3.341	3.409	3.456	3.51	3.543



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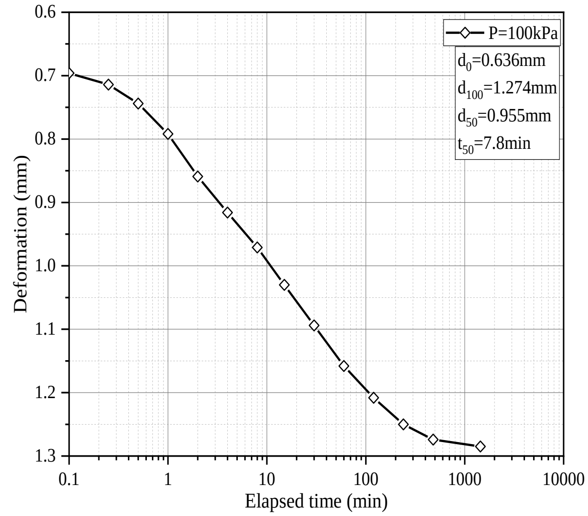

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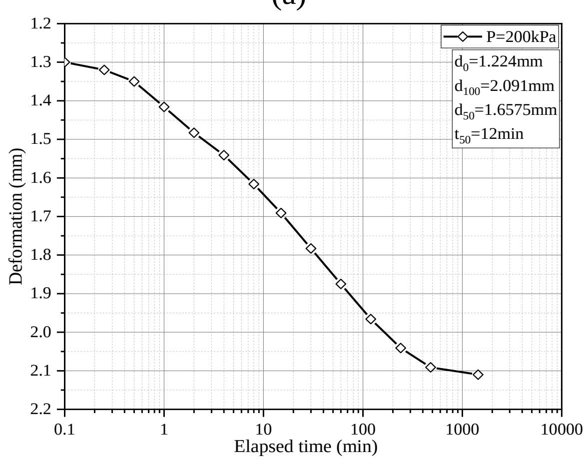

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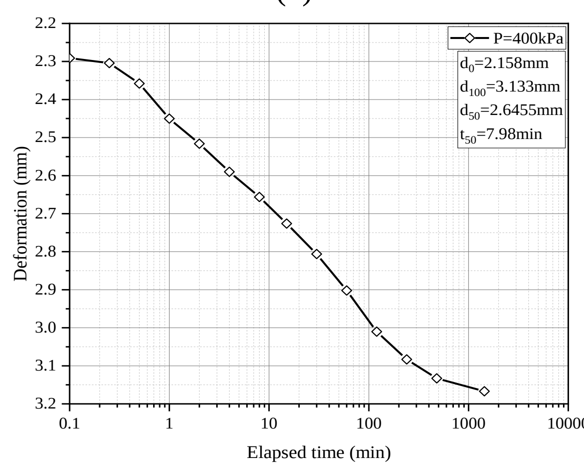

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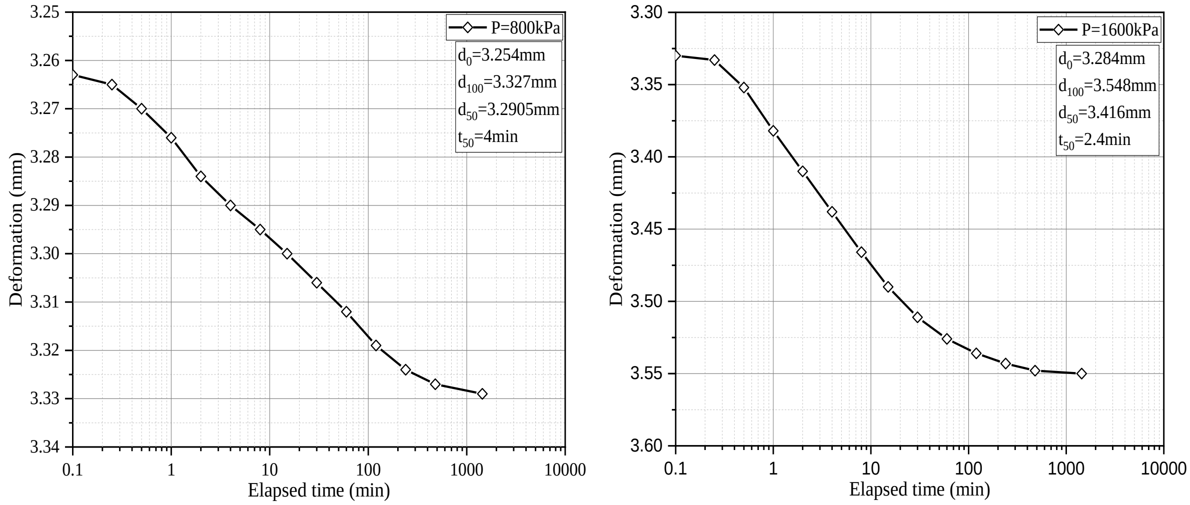
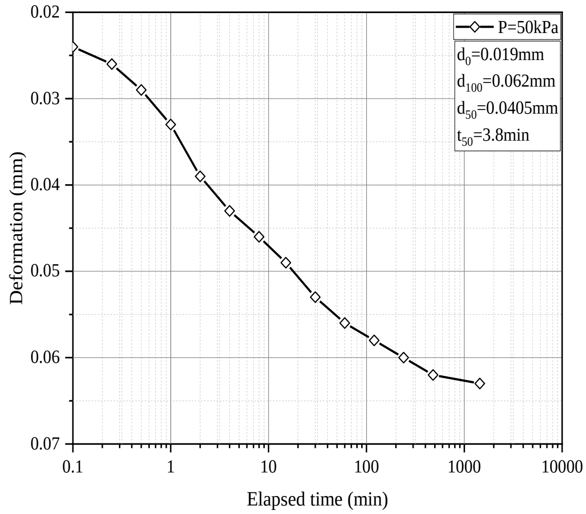


(e) (f)

Figure F-14: Deformation versus log time curves of soil from TP-14 for different P

Table F-19: Recorded specimen data of TP-15

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.024	0.065	0.239	0.711	1.240	1.763
0.25	0.026	0.074	0.256	0.743	1.283	1.804
0.5	0.029	0.089	0.311	0.784	1.343	1.866
1	0.033	0.113	0.397	0.849	1.416	1.957
2	0.039	0.134	0.475	0.921	1.500	2.044
4	0.043	0.157	0.538	1.006	1.572	2.107
8	0.046	0.173	0.591	1.078	1.633	2.153
15	0.049	0.187	0.625	1.129	1.675	2.184
30	0.053	0.197	0.650	1.162	1.703	2.219
60	0.056	0.206	0.667	1.190	1.722	2.246
120	0.058	0.215	0.682	1.203	1.735	2.267
240	0.060	0.223	0.693	1.214	1.747	2.288
480	0.062	0.229	0.700	1.220	1.755	2.306
1440	0.063	0.231	0.703	1.221	1.760	2.313
	Unloading					
	1.632	1.893	2.064	2.155	2.247	2.296



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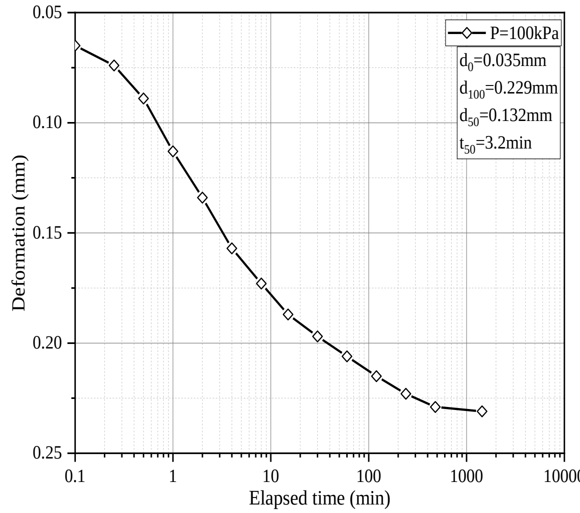

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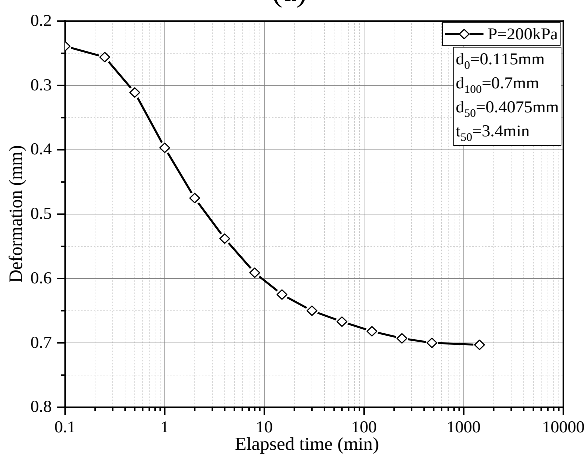

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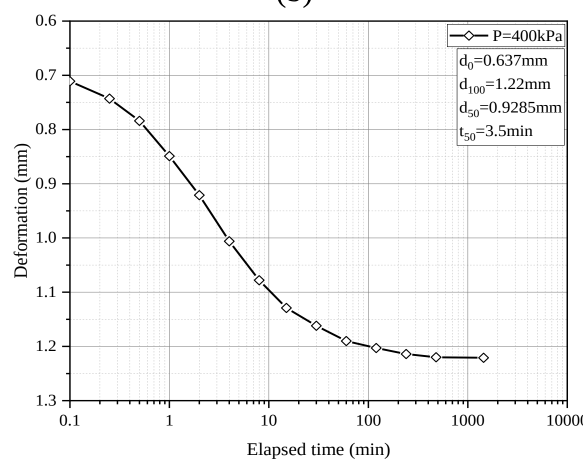

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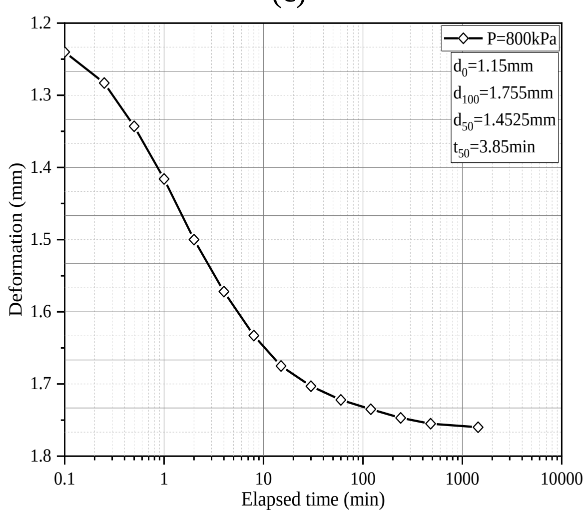

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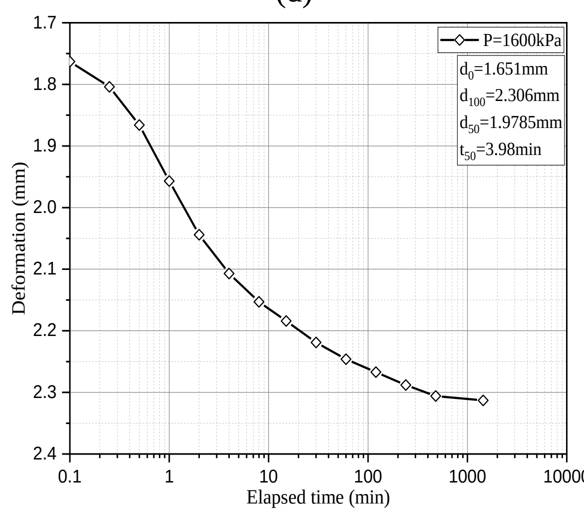
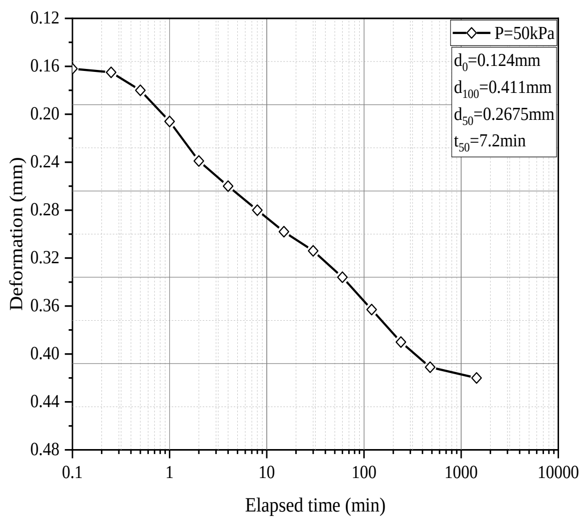


(f)

Figure F-15: Deformation versus log time curves of soil from TP-15 for different P

Table F-20: Recorded specimen data of TP-16

time (min)	Loading					
	50kPa	100kPa	200kPa	400kPa	800kPa	1600kPa
	Deformation (mm)					
0.1	0.162	0.434	0.852	1.467	2.150	2.869
0.25	0.165	0.449	0.874	1.486	2.162	2.876
0.5	0.180	0.476	0.920	1.529	2.196	2.898
1	0.206	0.520	0.992	1.608	2.248	2.938
2	0.239	0.562	1.068	1.686	2.329	3.000
4	0.260	0.602	1.113	1.737	2.390	3.051
8	0.280	0.633	1.156	1.771	2.466	3.088
15	0.298	0.659	1.198	1.807	2.541	3.133
30	0.314	0.689	1.243	1.848	2.622	3.180
60	0.336	0.719	1.293	1.875	2.680	3.224
120	0.363	0.753	1.340	1.903	2.739	3.267
240	0.390	0.780	1.386	1.935	2.790	3.318
480	0.411	0.805	1.426	1.972	2.840	3.364
1440	0.420	0.817	1.441	1.988	2.860	3.377
	Unloading					
	2.823	2.899	3	3.088	3.196	3.318



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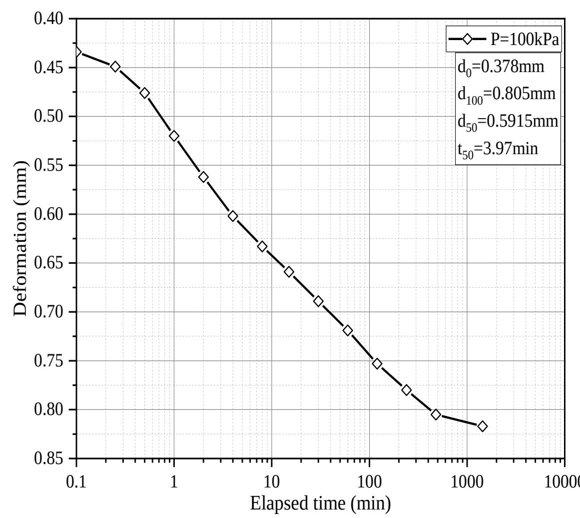

(b)

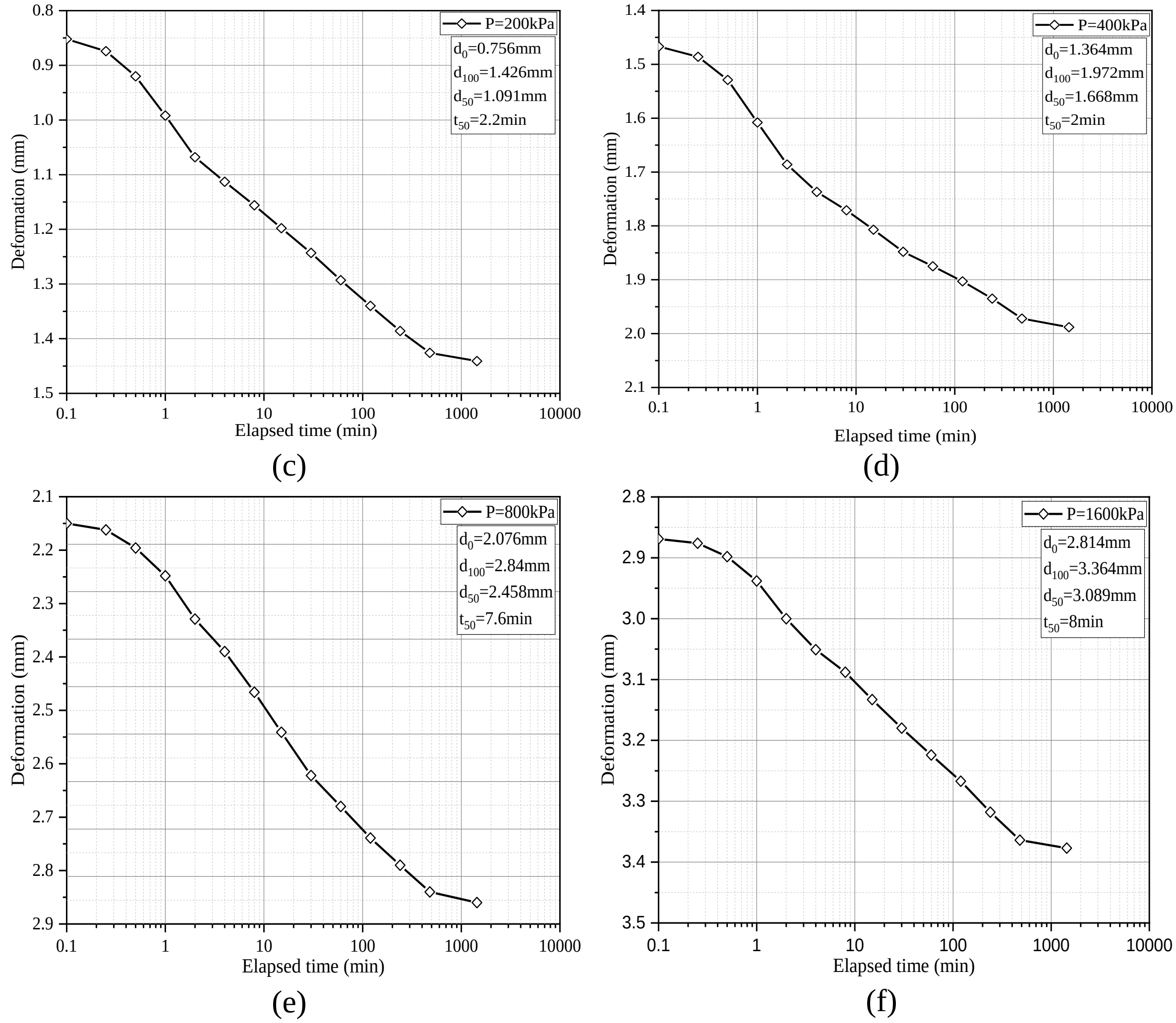

Figure F-16: Deformation versus log time curves of soil from TP-16 for different P