ADDIS ABABA UNIVERSITY

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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

IMPROVING THE STRENGTH CHARACTERISTICS OF RED CLAY SOIL USING WASTE PLASTIC STRIPS

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A Thesis Submitted to the Addis Ababa University School of Graduate Studies for the partial fulfillment of a Degree of Masters of Science in Civil Engineering

(Geotechnical engineering)

June, 2020
Addis Ababa
Ethiopia

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DECLARATION

I, the undersigned, declare that this thesis is my own original work performed under the supervision of my research advisor Dr.-Ing Samuel Tadesse, School of Civil and Environmental Engineering, Addis Ababa University as part of the Degree of Master of Science in Geotechnical Engineering Program in accordance with the rule and regulation of the institute and all sources of materials used for this thesis have also been duly acknowledged.

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Date: June, 2020

ACKNOWLEDGEMENT

Above all I am very thankful to Almighty God who is always with me in each and every step of my life.

I would like to express my sincere and deepest gratitude to my advisor Dr.-Ing Samuel Tadesse for all his limitless efforts in guiding, supervise throughout my research work and for providing me useful reference materials.

I gratefully acknowledge Addis Ababa University for providing me the sponsorship and also I would like to forward my appreciation to the geotechnical laboratory staffs of Addis Ababa institute of technology for their support and encouraging advice during conducting different tests for this thesis.

Special thanks go to CORE Consulting engineers for letting me to use and carry out relevant material tests in their central laboratory and Huayang Recycled Plastic Manufacturing PLC for giving me the plastic strip material I used in the study. I also would like to thank the National Meteorological Service Agency of Ethiopia for giving me all the data required for the research work free of charge.

Finally, I would like to thank my family specially my mother, friends and all who supported me in the course of this study.

ABSTRACT

Soil stabilization is the physical and chemical alteration of soils to enhance their physical properties. Stabilization can increase the shear strength of a soil and control the shrink-swell properties of a soil, thus improving the load-bearing capacity of a sub-grade to support pavements and foundations. Stabilization can be used to treat a wide range of sub-grade materials from expansive clays to granular materials. The cost of introducing traditionally available stabilizers has increased in recent years which opened the door widely for the development of other kinds of soil stabilizers such as plastics, bamboo etc.

The research is basically conducted by waste plastic strip and red clay soil found in Kechene-Ras Desta road. The significance of the study is to provide alternative stabilization material in construction industry. The objective of this study is to improve the strength characteristics of soil using the stabilization of plastic strips.

In this regard an attempt has been made to evaluate the effect of plastic strip as a stabilizer on the geotechnical properties of red clay soil in stabilized form mainly strength and compaction characteristics. The preliminary investigation of the soil to be stabilized shows that it belongs to A-7-5 class of soil in the AASHTO soil classification system. Soils under this class are generally of poor engineering use. Therefore, series of laboratory tests such as Atterberg limits, free swell index, compaction, UCS and soaked and unsoaked CBR tests for different percentages of plastic were performed. The soil was stabilized with plastic in stepped concentration of 0%, 0.5%, 1.5%, 2.5%, 3.5%, 5%, and 7.5% by dry weight of the soil.

The analysis shows slight improvement on the geotechnical properties of plastic stabilized soil. The plastic strip is found to increase the unconfined compressive strength of the soil up to 5% of plastic (75.01 kPa to 196.14 kPa) and CBR result of the red clay soil up to 2.5% (soaked CBR from 3.5% to 5% and unsoaked CBR from 80.3% to 108.7%). Due to plastic's light weight property the MDD of the soil shows slight increase up to 2.5% of plastic from 1.4g/cm3 to 1.53 g/cm3, and as the ratio of the plastic increased in the clay soil the result decreases.

Key words*:* Red clay Soil, Plastic strip, Soil stabilization, Atterberg limit, Compaction, UCS and CBR value.

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LIST OF ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CAH	Calcium aluminate hydrate
CBR	California Bearing Ratio
CSH	Calcium Silicate Hydrate
E	Easting
ERA	Ethiopian Roads Authority
GPS	Global Position System
LL	Liquid Limit
MDD	Maximum Dry Density
N	Northing
OMC	Optimum Moisture Content
PI	Plastic Index
PL	Plastic Limit
Qu	Unconfined compressive strength
UCS	Unconfined compressive strength
USCS	Unified Soil Classification System
USA	United States of America

Units

gm	Gram
Kg	Kilo gram
kN	Kilo Newton
mm	millimeter
g/cm3	Gram per centimeter cube
kg/cm^2	Kilo gram per centimeter square
µm	micrometer
kN/m2	Kilo Newton per meter square
kPa	Kilo Pascal
°C	Degree Centigrade
cc	Centimeter cube
cm3	Centimeter cube
%	Percent
m	Meter
m/s	meter per second

CHAPTER 1 INTRODUCTION

1.1 General

As a result of rapid industrial growth in various fields together with population growth, an obvious increase in waste generation rates for various types of waste materials is observed. Plastic consumption is increasing day to day due to rapid growth in population and urbanization, recycling of these plastics is very less compared to its production and a large quantity of plastic is dumped in to landfills as waste. Disposal of that large amount of wastes especially non-decaying waste materials become a problem of great concern in developed as well as in developing countries. Recycling waste into useful products is considered to be one of the most sustainable solutions for this problem.

Plastic is everywhere in today's lifestyle, it has numerous applications in various sectors such as packaging, protecting, agriculture, construction and even disposing of all kinds of consumer goods. Hence there is a real need for innovative and sustainable approaches to use these growing quantities of wastes. One solution to this crisis is recycling waste into useful products. In other side, the increase in traffic loading repetitions in combination with an insufficient degree of maintenance caused an accelerated deterioration of the road network.

Scientists and engineers are constantly searching for different methods to improve the performance of soil in the world. This study will be conducted to investigate the possible use of waste plastic as soil stabilizer and to review the feasibility of incorporating waste plastic to improve the performance of soil. So, use of recycled waste materials in road pavements is nowadays considered not only as positive option in terms of sustainability, but also, as an attractive option in means of providing enhanced performance in service. This is especially true in the case of recycled plastic.

Soil stabilization can be done in many ways. But the stabilization using plastic waste is an economical method since the stabilizer used here is waste plastic materials, which are easily available. A plastic material is any of a wide range of synthetic or semi-synthetic organic solids that are moldable. Plastics are typically organic plastics of high molecular mass but they often contain other substances. They are usually synthetic, most commonly derived from petro chemicals, but many are partially natural.

1.2 Back ground of the study

For many years, road engineers have used additives such as lime, cement and cement kiln dust to improve the qualities of readily available local soils. Laboratory and field performance tests have confirmed that the addition of such additives can increase the strength and stability of such soils. However, the cost of introducing these additives has also increased in recent years.

Soil stabilization can be adopted on earthen bunds, retaining walls, highway embankments, soil under the footing and layers of sub grade. Stabilization of soil using fibers was first explained by Henri Vidal which includes introduction of tensile materials into soil mass to improve its strength behaviors like stability, increased bearing capacity and reduced lateral deformation [18]. Technically, tensile strength of soil is negligible whereas it has comparatively higher compressive strength which is limited by shear resistance of soil.

Soil stabilization using raw plastic bottles is an alternative method for the improvement of sub grade soil of pavement. It can significantly enhance the properties of the soil used in the construction of road infrastructure. Results include a better and longer lasting road with increased loading capacity and reduced soil permeability. This new technique of soil stabilization can be effectively used to meet the challenges of society, to reduce the quantities of waste, producing useful material from non-useful waste materials that lead to the foundation of sustainable society. It can be effectively used in strengthening the soil for road embankments and in preparing a suitable base for the upper pavement structure. Since it increases the bearing capacity of soil considerably, the land use can be increased. It can lower the road construction and maintenance costs while increasing the overall quality of its structure and surface.

The most important point is the environmental concern regarding the effects of waste plastic in soil and the problems and threats that is related with their excessive usage and disposal. This gives an effective solution to waste treatment with the advent of soil stabilization.

Therefore, this study work can be conspicuous as one of the resources on the engineering geological characteristics of red soil in Northern part of Addis Ababa so that it acts as background knowledge for future engineering studies in the area.

1.3 Significance of the Study

Significance of the study can be summarized as;

- Cost savings, because Plastic strip is typically by far cheaper than traditional stabilizers such as cement and lime;
- The production of traditional stabilizers, such as cement and lime, is environmental unfriendly processes;
- The extraction of substantial amounts of non-renewable natural resources for road construction creates significant damaging impacts on the local environment and its inhabitants;
- Waste management can be done economically;

Therefore, using Plastic waste for improving engineering properties of the soils is an economical solution for Ethiopia as it is available everywhere.

1.4 Statement of the problem

Although plastic is non-biodegradable material that cannot be decomposed and many countries have recently incorporated waste plastic into their roadway specifications, till now there is no use of recycled plastic in Ethiopia, and also here no enough data to incorporate. There are many applications that could make use of the recycled plastic such as using waste plastic as soil stabilizer. The use of plastic in these applications will contribute in minimizing the area of landfills and saving the natural resources by reducing the demand of raw materials. This study will conduct to investigate the effect of using waste plastic as soil stabilizer as an idea to find out the best percentage of waste plastic that could be used to produce the plastic soil stabilizer under the local conditions in our country Ethiopia since plastic is everywhere in today's lifestyle.

1.5 Hypothesis

Large amount of plastic waste is produced in cities like Addis Ababa and there is a greater need to find new methods for either re use or disposal. Soil stabilization is one of the methods in Civil engineering field where plastic wastes can be used. Hence more emphasis is given on reuse discarded plastic as stabilizer and to improve tensile behavior, Shear strength of soil.

Question statements

- Is blending of waste plastic strip with soil mechanical stabilization?
- What is the effect of waste plastic strip on the properties of soil?

Hypothesis:

- Waste plastic with soil has significant effect on the strength and performance of soil.

1.6 Objective of the study

1.6.1 General Objectives

The general objective of the study is to improve the strength characteristics of soil using the stabilization of plastic strips.

1.6.2 Specific objectives

- Study the effect of adding different percentages of waste plastic as stabilizer on the soil comparing it with conventional mix properties.
- Identify the optimum percent of waste plastic to be added in the soil and percentage of replacement.
- To improve the strength characteristics of soil using plastic stabilization.
- To provide an alternative solution for the disposal of plastic waste.

1.7 Methodology

1.7.1 Investigation procedure

The following procedures are employed to achieve the objectives of the research.

i. literature review

A comprehensive literature review was made to understand the previous efforts, which include the review of textbooks, periodicals and academic journals, seminar, conference and research papers.

ii. Laboratory test

These methods are followed to achieve the objectives:

- ✓ On the field, the borrow soil and sample of waste plastic were collected from different plastic production factories.
- ✓ Disturbed samples were collected and tests were conducted in the laboratory.

In this thesis various laboratory tests are conducted to find the stabilization of the soil using waste plastic strips the various test conducted to find the stabilization of the soil such as:

1. Liquid Limit
2. Plastic Limit
3. Sieve Analysis
4. Specific Gravity
5. Standard Proctor Compaction Test
6. California Bearing Ratio Test
7. Unconfined compression test

1.7.2 Data acquisition and analysis

In this stage the results are presented in different form and interpretation and discussions are conducted on the research findings.

1.8 Scope of the study

The scope of the present work includes addition of plastic bottle strips to the locally available red clay soils to enhance the engineering properties. The research work focuses on Addis Ababa where red clay soil is found around Kechene-Ras Desta Road. In order to achieve the general as well as specific objectives disturbed samples were collected at depths of 1 m. The remolded samples were prepared by compacting the undisturbed samples using standard compaction and it was assumed that the remolded samples are nearly of the same moisture content and density to that of the undisturbed samples even if there may be very little variation due to sample preparation.

1.9 Limitation

The present study investigates the effectiveness of waste plastic strips in improving the behavior of red clay soil. Following are the limitations of the present study:

- The tests are done with only one type of soil i.e. locally available red clay soil in Addis Ababa. The effectiveness of waste plastic bottle strips as stabilizing materials with other types of soils need further tests and research.
- Further tests are needed to quantify the cost reduction due to use of waste plastic bottle strips as stabilizing materials in soil improvement.

1.10 Organization of the Thesis

The thesis has been divided in to six Chapters each covering a specific topic of the research work. The first Chapter is the introduction part and it discusses the general background of the research, statement of the problem, hypothesis, objective, research methodology, scope of the study, limitations and organization of the thesis work. The second Chapter gives a brief literature review which discusses about clay mineralogy, origin and mineral composition of Ethiopian Red clay and stabilization techniques. Sampling area description is dealt with in Chapter three. In Chapter four materials and methods briefly discussed. In the fifth Chapter the types of laboratory tests conducted with results for the different blended soils with plastic material at various ratios starting from 0.5% to 7.5% are described in detail. Chapter six consists of the conclusion and recommendation of the thesis. At last in the appendix the raw data is shown.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Soil can be described as residual or transported on the basis of the mode of formation. Residual soils are derived from weathering of parent rock at the original location. Whereas transported soils are those which are formed from the rock weathering at one location and transported by wind, water, ice, or gravity to the present site [9].

Residual red soils are tropically weathered soils with a high concentration of sesquioxides of iron and alumina. They exist in wide range of chemical composition. Silica content varies from low to medium and exists usually as kaolinite, whenever it is found in substantial amounts [7].

The engineering properties of residual soils vary considerably from the top layer to the bottom layer. Residual soils have a gradual transition from relatively fine material near the surface to large fragments of stones at greater depth. The properties of the bottom layer resemble to that of the parent rock in many aspects. Its thickness is generally limited to few meters [7].

The red soils normally occur on sloping ground close to local high points where there is good drainage, with a vegetative cover of little organic matter and high temperature and rainfall. Water removes the more soluble bases and silica, leaving the soil rich in iron, in the form of iron oxide, and aluminum, as clay minerals of the kaolin group.

2.2 Origin and Formation of Residual Soils

Particles of residual soil often consist of aggregates or crystals of weathered mineral matters that breakdown and become progressively finer if the soil is manipulated [7]. Residual soils are usually originated and formed through the effect of weathering process, climate, and topography.

2.2.1 Weathering Process

As stated by Blight [7], residual soils are formed by the in-situ weathering of rocks, through physical, chemical and biological processes. Most commonly, residual soils are formed from igneous or metamorphic parent rocks. However, residual soils formed from sedimentary rocks are also common. Chemical processes tend to predominate in the weathering of igneous rocks.

Physical weathering, which is the outcome of mechanical development, generates end products consisting of angular blocks, cobbles, gravel, sand, silt and even clay sized rock flour. These end products have mineral compositions which are exactly like those of the original rock. On the other hand, chemical weathering produces the decomposition of rock and the formation of new minerals. Intemperate or semi- tropical zones, the chemical changes in primary minerals tend to produce end products consisting of clay minerals that prevail Kaolinite and occasionally by Halloysite and by hydrated or dehydrous-oxides of Iron and Aluminum [7].

On volcanic rock or ash deposits which have undergone a relatively short period of weathering, or at altitudes where cooler climatic conditions prevail, amorphous allophane and amorphous or crystalline halloysite clay minerals may be dominant. Smectites (montmorillonites) may also develop during the early weathering stages of volcanic materials. Ultimately, with prolonged weathering under appropriate conditions, kaolinite and gibbsite may form.

2.2.2 Climate

As mentioned by Fredlundand [15], climate exerts a considerable influence on the rate of weathering. Physical weathering is more predominant in dry climates while the extent and rate of chemical weathering is largely controlled by the availability of moisture and by the temperature. He asserts that climate has further effect on the properties of tropical residual soils. In sub humid tropical and subtropical areas water tables are often deeper than 5 to 10 m and the effects of un-saturation, desiccation and seasonal or longer term rewetting have to be taken into account in geotechnical design. There are many accounts of the effect of un-saturation on the behavior of soils [15].

2.2.3 Topography

Topography determines the amount of available water for each zone of weathering. The accumulation of soils in valleys and hollows is the effect of precipitation. On hillsides, the depth of weathering increases down the slope, whereas, Kaolinite/Halloysite is the predominant clay minerals at the top of the slope and Smectite at the bottom of the slope [7]. On slopes, a relative decrease in silica content may be achieved at lower elevations by the deposition of sesquioxides transported down the slope by groundwater. Although kaolinite is the dominant clay mineral formed as a result of prolonged tropical weathering.

2.3 Clay Mineralogy

The term clay can refer both to a size and to a class of minerals. As a size term, it refers to all constituents of a soil smaller than a particular size, usually 0.002 mm in engineering classifications. As a mineral term, it refers to specific clay minerals that are distinguished by small particle size, an electrical charge, plasticity when mixed with water and high weathering resistance. Clay minerals are produced mainly from the chemical weathering and decomposition of feldspars, such as orthoclase and plagioclase, and some micas. They are small in size and very flaky in shape [35].

The thickness of clays is very small relative to their length and breadth, in some cases as thin as 1/100th of the length. Therefore, they have high to very high specific surface values. These surfaces carry a small negative electrical charge that will attract the positive end of water molecules. This charge depends on the soil mineral and may be affected by an electrolyte in the pore water. This causes some additional forces between the soil grains which are proportional to the specific surface. Thus, a lot of water may be held as adsorbed water within clay mass. Table 2-1 shows examples of mineral grain specific surfaces. The more elongated or flaky a particle is the greater will be its specific surface. The various clay minerals are formed by the stacking combinations of basic sheet structures with different forms of bonding between the combined sheets. The main clay minerals are: Kaolinite, Illite and Montmorillonite [30].

Table 2-1: Examples of clay mineral grain specific surfaces [30].

Mineral/Soil	Grain width, d (μm)	Thickness	Specific Surface m^2/N
Kaolinite	2.0 - 0.3	≈0.2d	2
Illite	2.0 - 0.2	≈0.1d	8
Montmorillonite	1.0 - 0.01	≈0.01d	80

Minerals are crystalline and make up the solid constituent of a soil. The mineral particles of fine grained soils are platy. Minerals are classified according to chemical composition and structure. Most minerals of interest to geotechnical engineers are composed of oxygen and silicon. Silicates are a group of minerals with a structural unit called the Silica Tetrahedral. A central silica cation (positively charged ion) is surrounded by four oxygen anions (negatively charged ions), one at each corner of the tetrahedron. Silicate minerals are formed by addition of cations and interaction of tetrahedrons. Silica tetrahedrons combine to form sheets, called silicate sheets, which are thin layers of silica tetrahedrons in which three oxygen ions are shared between adjacent tetrahedrons. Silicate sheets may contain other structural units such as alumina sheets. Alumina sheets are formed by combination of alumina minerals, which consists of an aluminum ion surrounded by six oxygen or hydroxyl atoms in an octahedral [19].

Most soil classification system arbitrarily defines clay particles as having an effective diameter of two microns (0.002mm) or less. Particle size alone does not guarantee the classification of fine grained materials. The most important grain property for fine grained soils is the mineralogical composition [12]. Clay minerals are classified as; Two-layer clays which consist of one tetrahedral layer bonded to one aluminum octahedral layer. Kaolinite is the most common mineral under this category, Three-layer clays which consist of one octahedral layer sandwiched between two tetrahedral layers. Illite, montmorillonite and vermiculite are the common minerals under this category, Mixed-layer clays which consist of interstratifications of the two- and three-layer clay minerals previously described. The mixing may be regular or random. Common mineral under these classes are chlorite, montmorillonite-chlorite of the clay mineral. The mineral configurations of these clay types are shown in Figure 2-1 [22].

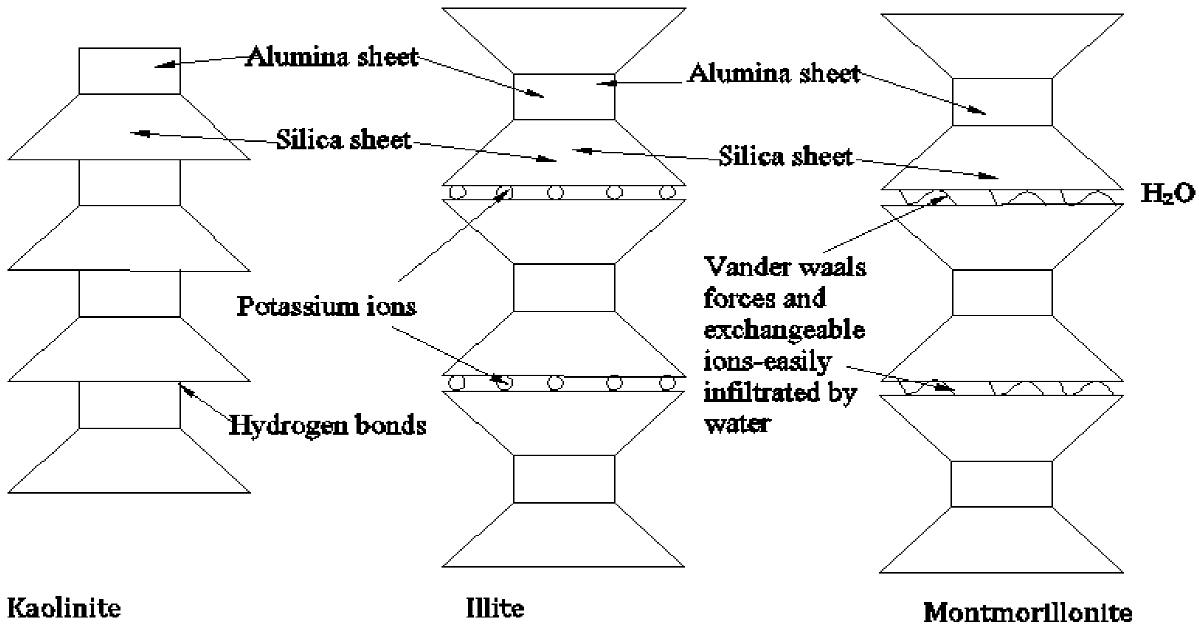


Figure 2-1: Schematic Representation of Clay Minerals [13].

2.4 Clay Structures

There are three structural groups of clay minerals that are important for engineering purposes. These three groups are; Kaolinite group - usually non-expansive, Mika like group - includes illites and vermiculites, which can be expansive but generally do not pose significant problems, Smectite group - includes montmorillonites, which are highly expansive and are the most troublesome clay minerals.

2.4.1 Kaolinite Group

The kaolin minerals are a group of clay minerals consisting of hydrous aluminum silicates. A common kaolin mineral is kaolinite. Kaolite is a typical two-layer mineral having a single tetrahedral sheet joined by a single octahedral sheet to form what is called a 2 to 1 lattice structure. The bonding combination of hydrogen and Vander Waals forces results in considerable strength and stability with little tendency for inter layers to take on water and swell. The bonding is sufficiently strong that there is no interlayer swelling in the presence of water. Kaolinite is the least active of the clay minerals. Kaolinite can be produced by weathering of certain of the more active clay minerals as well as being directly formed as a byproduct of rock weathering. Kaolinite tends to be found in regions of heavier rainfall [38].

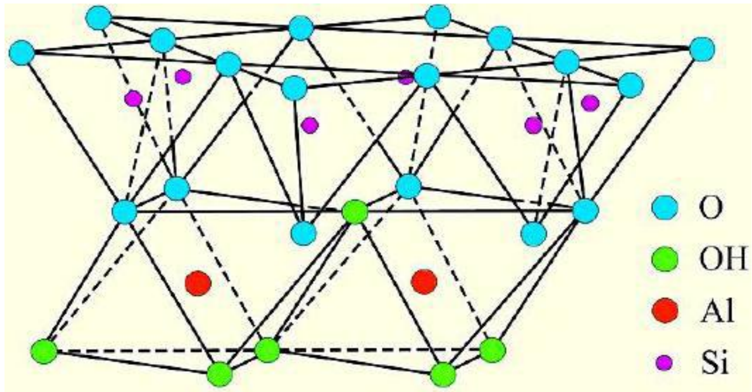


Figure 2-2: Diagrammatic Skectch of the Kaolinite [38].

2.4.2 Illite Group

Illite has a basic structure consisting of a sheet of alumina octahedrons between and combined with two sheets of silica tetrahedrons. This clay mineral has a structure similar to montmorillonite, but the layers are more strongly bonded together. In terms of cation exchange capacity, inability to absorb and retain water and in physical characteristics. Illite is intermediate in activity between clays of kaolin and montmorillonite groups. In the octahedral sheet there is partial substitution of aluminum by magnesium and iron. And in the tetrahedral sheet there is partial substitution of silicon by aluminum. The combined sheets are linked together by fairly weak bonding due to (non-exchangeable) potassium ions held between them [37].

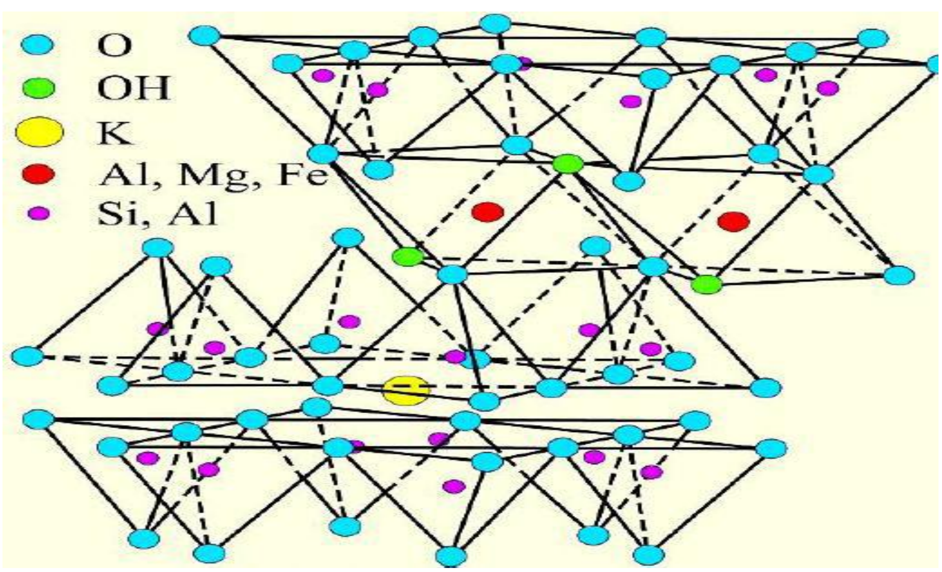


Figure 2-3: Diagrammatic Skectch of the Illite [38].

2.4.3 Smectite Group

Montmorillonite are a group of clay minerals that are characterized by weekly bonded layers. It is formed from weathering of volcanic ash under poor drainage conditions or in marine waters. Each layer consists of two silica sheets with an aluminum (gibbsite) sheet in the middle. Water and exchangeable cations can enter and separate the layers, creating a very small crystal that has a strong attraction to water. Montmorillnite has the highest activity and it can have the highest water content, greatest compressibility and lowest shear strength of all clay minerals [37]. The space between the combined sheets is occupied by water molecules and exchangeable cations. There is a very weak bond between the combined sheets due to these ions. Considerable swelling of montmorillonite being can occur due to additional water absorbed between the combined sheets [37].

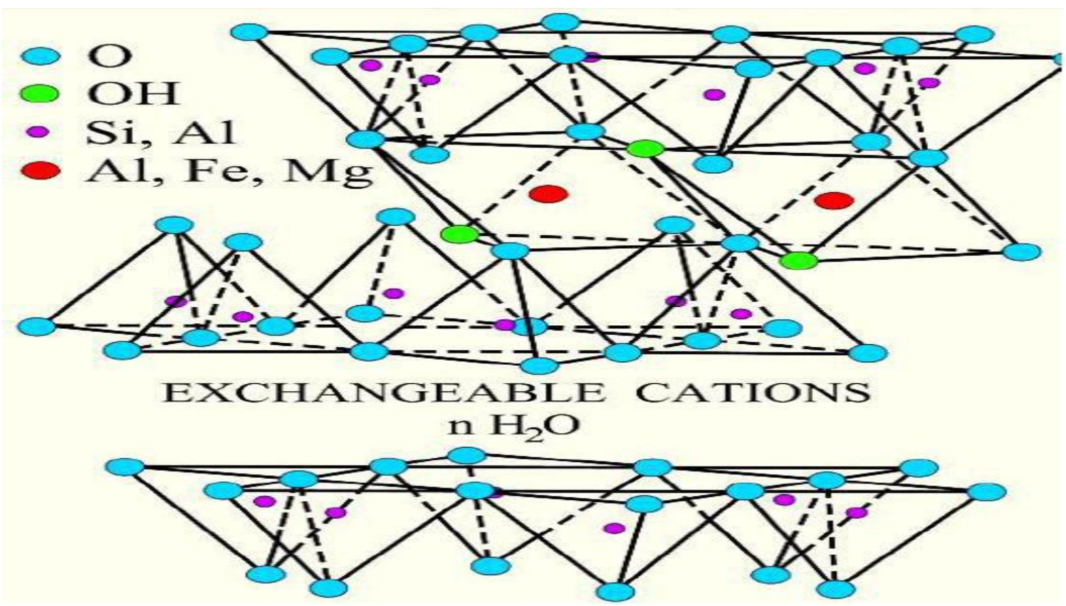


Figure 2-4: Diagrammatic Skectch of the Montmorillonite [38].

2.5 Engineering Characteristics of Soils

A soil mass, as explained by Blight [7], is always subjected to changing environment, depending upon the chemical and physical properties of the soil, the necessary actions for construction purposes will be taken. Soil properties need to be studied to improve the workability of the soil, therefore studying soil properties inside out is very important. Soil properties can broadly be divided into two categories depending upon their properties achieved during soil formation process; physical properties and chemical properties of soil. One of the physical properties of soils is color. Its reddish color is mainly associated with the weathering condition, drainage and wetness. According to Gilloth [21], greenish, bluish, and grayish colors in the soil indicate wetness, whereas, bright colors (reds and yellows), on the other hand, indicate well-drained soils. Dark colors in the soil usually indicate organic matter. They may also indicate wetness for wetter soils can accumulate more organic matter.

The tests required for determination of engineering properties of soils are generally elaborated and time consuming. Sometimes the geotechnical engineer is interested to have some rough assessment of the engineering properties without conducting elaborate tests. This is possible if index properties are determined. The properties of soils which are not of primary interest to the geotechnical engineer but which are indicative of the engineering properties are called index properties. The most widely used are the particle size distribution and the soil consistency tests. Moisture and density relationships are also commonly used as index properties both in evaluating foundations and to control compaction, even though their determination is required in connection with other test results [4].

Determination of the moisture content is required as a guide to classification of soils and to evaluate the behavior of soils during construction. This is determined by using the oven drying method. The moisture content relates only to the water which is removable by oven drying at 105-110°C [14].

Soil laboratory test analysis is an examination by which the quality of soil is determined. The process of examining a soil under known conditions in order to determine quality, identify its constituents. The physical properties of material are tested in order to determine their ability to satisfy particular requirements [4].

Free swell characteristics to estimate swell potential of a soil were classified accordingly by Holtz and Gibbs, [25]. Those soils with free swell of less than 50% are considered to have low degree of expansion. (Table 2-2)

Table 2-2: Free Swell Classification [25]

Free Swell Value	Free swell characteristics	Potential Expansiveness
<50	Low	Low
50-100	Medium	Medium
100-200	High	High
>200	Very High	Very High

Depending on the initial moisture content of the soil, the material may exist in four possible states: solid, semi-solid, plastic and liquid. In each state the consistency and behavior of the soil is different, these influence the engineering properties of the soil. The boundary between each state signifies a change in the soil's characteristics and behavior at that specific moisture content, and these are known as the Atterberg Limits [14].

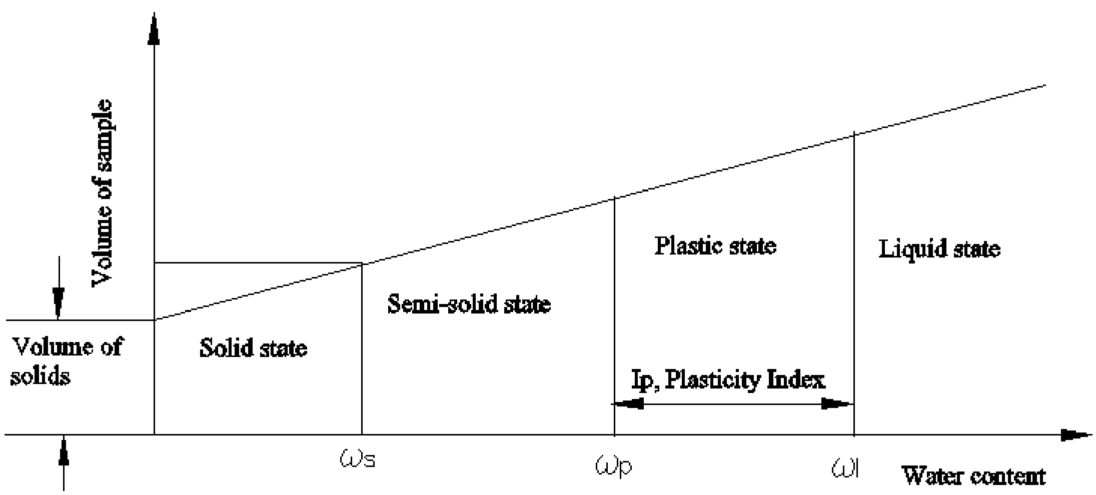


Figure 2-5: Consistency of cohesive soils [3].

Table 2-3: Relation between the swelling potential of clays and the plasticity index [20].

Swelling Potential	Plasticity index
Low	0-15
Medium	10-35
High	20-35
Very high	35 and above

Table 2-4: Qualitative classification of plasticity index [10].

Plasticity Index, %	Description
0	Non plastic
1_5	Slightly plastic
5_10	Low plasticity
10_20	Medium plasticity
20-40	High plasticity
Above 40	Very high plasticity

The shear strength of soil is an important aspect in many foundation-engineering problems related to stability such as the bearing capacity of shallow foundations and deep foundation.

Different authors used different classification techniques to classify residual tropical soils on the basses of the mineralogical composition alone. As stated by Lyon [31], the AASHTO classification system is convenient as the bases for classifying residual soils in addition to the Unified soil classification method.

i. AASHTO Classification

As shown on Table 2-5 soils rated A-6 or A-7 by AASHTO can be considered potentially expansive [26].

Table 2-5: AASHTO soil classification chart [26].

General Classificaton	Granural Materials (35 percent or less passing No. 200)							Silt- clay Materials (More than 35 percent passing No. 200)			
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											
No. 10	50 Max										
No. 40	30 Max	50 Max	51 Min								
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 No. 40 sieve											
Liquid limit				40 Max	41 Min	40 Max	41 Min	40 Max	41 Min	40 Max	41 Min
Plasticity Index	6 Max		N.P	10 Max	10 Max	11 Min	11 Min	10 Max	10 Max	11 Min	11 Min
Usual types 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			
The A-7 group is subdivided in to A-7-5 or A-7-6 depending on the plastic limit. For PL<30, the classification is A-7-6; for PL>=30, it is A-7-5.											

ii. Unified Soil Classification Systems

In this classification system a correlation is made between swell potential and unified soil classification as follows.

<u>**Category Soil classification system**</u>

Little or no expansion	GW, GP, GM, SW, SP, SM
Moderate expansion	GW, SC, ML, MH
High volume change	CL OL, CH, OH
No rating	Pt

The above classification system can be summarized as follow:

a. All clay soil and organic soils exhibit high volume change.

b. All clayey gravels and sands and all silts exhibit moderate volume changes.

c. All sands and gravels exhibit little or no expansion.

2.6 Red Soil Distribution in Ethiopia

Ethiopia is one of the countries in the tropical zone. Consequently, the various soil forming factors in the tropical areas influences the red soil distribution in Ethiopia. Some of the factors are climate, regional landform, local topography and the underlying parent materials. Drainage is an important factor in the formation of some soils.

The first systematic study of tropical weathered residual soils in Ethiopia was carried by Morin [36]. They stated that the Ethiopian red soils have formed as residual from basaltic volcanic rocks in places with plenty of rainfall and good drainage. The principal clay minerals that constitute the Ethiopian red soil are kaolinite and halloysite. Montmorillonite is also found in the Ethiopian red soil in lesser amount. The red color of the Ethiopian soils indicates the presence of iron.

According to ERA, [17] Red soils can be formed from many kinds of rocks if the weathering conditions, climate and drainage are suitable. In Ethiopia, they have developed mainly on volcanic (basalts, ryholites, etc.) and pyroclastic rocks. In the western part of the country they have also been seen on granitic terrains. The iron oxide in these soils, which accounts for their dark red color, occurs in a hydrated (goethite) and an unhydrated form (hematite). Goethite and hydrated halloysite predominate under wetter conditions. The clay mineral is usually kaolin of the halloysite type, which occurs as hydrated and meta-halloysite. Hydrated halloysite is readily converted to meta-halloysite on drying. Kaolin in the form of halloysite has a disordered structure, which gives rise to a soil of higher potential plasticity than well-ordered kaolinites.

Red soil deposits are present in the western and north-western highlands, southern lowlands and southern rift, most part of the central highlands, and in pockets of well drained lands throughout the north-east and eastern highlands of Ethiopia. The southern and western parts of Ethiopia are characterized by residually formed laterites that are widely used as construction materials and have been found satisfactory for many earthworks applications [2].

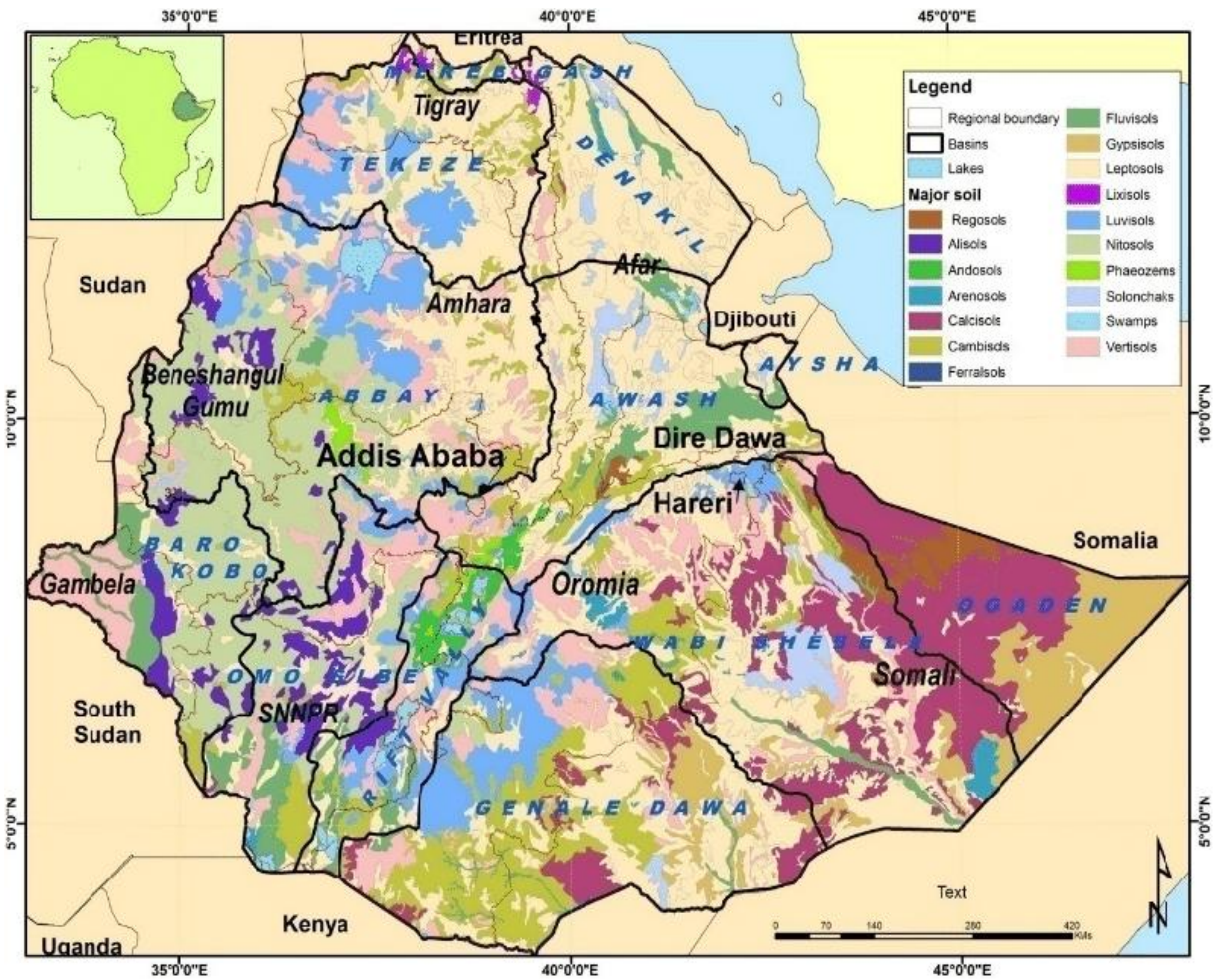


Figure 2-6: Major-soil-types-of-Ethiopia

2.7 Red Soil Distribution in Addis Ababa

The red clay soil in Addis Ababa covers North and North-west of the city. Geotechnical drilling data and engineering geological map of Addis Ababa, reveal that red clays in Addis Ababa are dominantly underlain by basalts; basic (dark colored) igneous rock rich in iron and magnesium [27].

Geotechnical data from 1996 to 2014 shows red clays in Addis Ababa are extensively distributed around Gulele sub-city, Burayu and part of Kolfe Keraniyo specifically around Atanatera. Some part of Addis Ketema and Arada sub-cities are also covered with red clays [29]. Besides, from the engineering geological map of Addis Ababa [27], localities where red clays are found are underlain by dominantly of basalts although there are places in Gulele where red clays are underlain by rhyolite.

Other regions with red soil include parts of localities such as Kokebe-Tsebah and British Embassy through Kotebe College of Teachers Education are underlain by rhyolites. From these observations, it can be roughly generalized that red clays of Addis Ababa are dominantly derived from basalts and rhyolites [29].

Research work by Merihun Lukas [33], titled with the Effect of remolding on mechanical behavior of Addis Ababa red clay, was observed the effect of soil remolding on the mechanical behavior of red clay of Addis Ababa. He tried to identify the effect of remolding by conducting a series of laboratory tests such as triaxial compression and consolidation tests on the undisturbed and remolded soil samples. The soil was remolded by compacting at optimum moisture content and conduct basic tests to see the engineering properties of the soils. The one dimensional consolidation tests were done on samples of diameters of 50mm and 70mm and height of 18mm with the effective consolidation stresses of 50 kPa to 1600 kPa. A total of eight one-dimensional consolidation tests were done. Triaxial test done on soil samples collected from Kolfe areas were conducted on Automatic triaxial testing machines and samples collected from Addisu-gebeya. A total of twenty-four triaxial CU tests were run out of which twelve were undisturbed and twelve were remolded. The results of triaxial tests were used to examine the stress-strain and strength behavior. Table 2-6 shows summary of engineering properties of Addis Ababa red clay soil.

Table 2-6: Properties of Addis Ababa red clay soils from previous research

Properties	Hailemariam (1992)	Medhanit (2009)	Merihun Lukas (2010)		Samuel (1989)		
Location	Addis Ababa	Addis Ababa	Kolfe	Addisu-gebeya	Kolfe	Semen-gebeya	Rufael
Clay content (%)	48 -73	55-65	-	-	58-70	53-68	50-70
Activity	-	0.11-0.70	-	-	-	-	-
LL (%)	54-81	39-106	61	72	61-75	57-76	56-75

PI (%)	21-30	9-40	34	39	30-43	33-47	29-41
Shrinkage limit (%)	14 -22	12-20	12	20	15-21	14-25	14-20
Free swell (%)	10-40	5-80	20	32	15-45	15-50	30-40
Specific gravity	2.61 -2.79	2.6-2.8	2.72	2.71	2.66-2.73	2.70-2.77	2.66-2.74
Unconfined compression strength, qu(kN/m2)	49 - 250	64 - 213	-	-	-	-	-
Plasticity Chart	-	CH, CL, MH	-	-	CH	CH	CH

2.8 Reviews on soil stabilization

2.8.1 Introduction

When unsuitable materials are encountered measures like avoiding the route, redesigning the pavement with thicker sections or replacing the poor soil with good quality materials are viable but increasingly expensive options. With improved technological advances and concern for depletion of non-renewable resources, improving the properties of soil using different type of stabilizer is better [11].

The extraction of substantial amounts of non-renewable natural resources for road construction creates significant damaging impacts on the local environment and its inhabitants. Therefore, construction techniques implemented to solve these socioeconomic problems need to be not only time and cost effective but also environmentally friendly. Using Plastic wastes to stabilize soil reduces environmental effect.

2.8.2 Soil Stabilization

Soil stabilization is the alteration of one or more soil properties, by mechanical or chemical means, to create an improved soil material possessing the desired engineering properties. The process may include blending of soils to achieve a desired gradation or mixing of commercially available additives that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil [23].

2.8.3 Uses of Stabilization

Soil stabilization is the treatment of soil in order to rectify its deficiencies in engineering properties and especially as a road construction material. Improvement attained from soil stabilization are; [23].

- Improve the strength (stability and bearing capacity) for subgrade, subbase, base, and low-cost road surfaces.
- Quality improvement: the most common improvements achieved through stabilization include reduction of plasticity index or swelling potential, and increases in durability and strength with a better soil gradation. In wet weather, stabilization may also be used to provide a working platform for construction operations [26].
- Thickness reduction: the strength and stiffness of a soil layer can be improved through the use of additives to permit a reduction in design thickness of the stabilized material compared with an unstabilized or unbound material. The design thickness can be reduced if the strength, stability and durability requirement of a base or subbase course is indicated to suitable by further analysis [23].
- Improve the volume stability- undesirable properties such as swelling, shrinkage, high plasticity characteristics, and difficulty in compaction, etc. caused by change in moisture.
- Improve durability – increase the resistance to erosion, weathering or traffic Improve high permeability, poor workability, dust nuisance, frost susceptibility,
- Control of dust and protection from erosion etc.

2.8.4 Methods of Soil Stabilization

Stabilization is a process by which the properties of soils are improved so as to meets the construction requirement. Soil stabilization may be broadly classified as chemical and mechanical stabilization [3]. There are several methods of soil stabilization widely used to improve construction quality. Some of the major stabilization techniques are described below.

A) Mechanical Stabilization

Mechanical stabilization can be defined as a process of improving the stability and shear strength characteristics of the soil without altering the chemical properties of the soil. The main methods of mechanical stabilization can be categorized in to compaction, mixing or blending of two or more gradations, applying geo-reinforcement and mechanical remediation [23].

The material should be workable during placement. When properly placed and compacted, the blended materials become mechanically stable, the load carrying capacity is increased, the resistance against temperature and moisture changes also improved.

The mechanical stability of the mixed soil depends on mineral strength of the aggregate, mineral composition, gradation, plasticity characteristics and compaction. Mechanical stabilization is the simplest method; it improves the sub grades of low bearing capacity. It is extensively used in the construction of bases, sub-bases and surfacing of roads.

B) Chemical Stabilization

Chemical stabilization is a method of improving the engineering properties of a material by adding chemical substances. Chemical stabilization is used for a wide range of purposes including: improving the bearing capacity and strength of pavement layers, dry temporary bypasses during rainy periods, delay certain chemical reactions that are detrimental to road soils or aggregates, dry out soil where the moisture content is too high for successful compaction, make soil less permeable where necessary, reduce the plasticity of soils used in road construction and thereby reducing the effect of moisture variations, changing clay to a more granular and workable material and reducing swelling and shrinkage properties [20].

Soil stabilization using chemical admixtures is the oldest and most widespread method of ground improvement. Chemical stabilization is mixing of soil with one or a combination of admixtures of powder, slurry or liquid to improve or control its stability, strength, swelling, permeability and durability. Chemical stabilization can achieve improvement of soil by three chemical reactions [34].

a) Cation Exchange

The excess ions of opposite charge that of the surface of clay, over those of like charge present in the diffuse double layer are called exchangeable ions. These ions can be replaced by a group of different ions having the same total charge, by altering the chemical composition of the equilibrium electrolyte solution. Negatively charged clay particles adsorb cations of specific type and amount. The ease of replacement or exchange of cations depends on several factors, primarily the valence of the cation. Higher valence cations easily replace cations of lower valence. For ions of the same valence, the size of the hydrated ion becomes important; the larger the ion, the greater the replacement power. If other conditions are equal, trivalent cations are held more tightly than divalent and divalent cations are held more tightly than monovalent cations. A typical replaceability series is:

$Na^+ < Li^+ < K^+ < Rb^+ < Cs^+ < Mg^{2+} < Ca^{2+} < Ba^{2+} < Cu^{2+} < Al^{3+}$, [14].

Cation exchange includes an immediate reaction of the clay with the stabilizer within few minutes of mixing, resulting in a soil with improved texture. Generally, sodium or potassium (Na^+ or K^+) are prevalent in clay minerals along with water. However, these cations can be replaced by the higher valance cations like Al^{+3}, Ca^{+2}, Mg^{+2} etc. so called cation exchange. During this process calcium rich chemical stabilizer provides enough cations to replace the monovalent cations resulting in a reduced thickness of diffused double layer [14]. The calcium is released in suspension of stabilizer-soil-water and will be available for the stabilization of soil. The exchangeable cations may be present in the surrounding water or be gained from the stabilizers.

An example of the cation exchange;

$Ca^{2+} + Na^+\text{-Clay} \longrightarrow Ca^{2+}\text{-Clay} + Na^+$

The thickness of the diffused double layer decreases as replacing the divalent ions (Ca^{2+}) from stabilizers with monovalent ions (Na^+) of clay. Thus, swelling potential decreases [34].

b) Flocculation and Agglomeration

Cation exchange reactions result in change in the electrical charge around the clay particles; therefore, result in an increase in the interparticle attraction causing in the flocculation and agglomeration of the soil particles. This leads to the reduction of clay-sized particles and hence the soil surface area, which inevitably accounts for the reduction in plasticity. Due to change in texture, a significant reduction in the swelling of the soil occurs [34].

Flocculation and agglomeration is the rearrangement of the clay particles from face to face orientation to more compact edge-face orientation. The fine grained soil changes to the coarser grained with much more improved strength/stiffness as well as workability. As cation exchange, flocculation and agglomeration is also a short-term process, which takes place within few hours of mixing the stabilizer and water with subgrade soil.

c) Pozzolanic Reactions

Pozzolanic reaction is time dependent long-term reaction that plays a major role in the soil stabilization. They are responsible for the improvement in the various soil properties. Pozzolanic reaction is a long-term process that produces more stable hydrates and aluminates of calcium after few months of mixing of soil, stabilizer and water. The PH environment in the system initiates further reaction of the silica and alumina with the clay particles, hence proving extra strength to the stabilized soils. The minimum PH of 12.4 is necessary in order to maintain the pozzolanic reaction [16]. Pozzolanic constituents produce calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH).

$Ca^{2+} + 2(OH)^- + SiO_2$(Clay Silica) ---------------------------► CSH

$Ca^{2+} + 2(OH)^- + Al_2O_3$ (Clay Alumina) ----------------------► CAH

The calcium silicate gel formed initially coats and binds lumps of clay together. The gel then crystallizes to form an interlocking structure which increases the soil strength [34].

1) Lime Stabilization

Lime is one of the oldest and still popular additives used to improve fine-grained soils. Lime, either alone or in combination with other materials, can be used to treat a range of soil types. Lime treatment of soil facilitates the construction activity in three ways. First, a decrease in the liquid limit and an increase in the plastic limit results in a significant reduction in plasticity index. Reduction in plasticity index facilitates higher workability of the treated soil. Second, as a result of chemical reaction between soil and lime a reduction in water content occurs. This facilitates compaction of very wet soils. Further, lime addition increases the optimum water content but decreases the maximum dry density and finally immediate increase in strength and results in a stable platform that facilitates the mobility of equipment [5].

Lime is produced by burning of lime stone in kilns. The quality of lime obtained depends upon the parent material and production process. Basically there are five types of lime: - High calcium quick lime (CaO), Hydrated or high calcium lime [$Ca(OH)2$], Dolomotic lime ($CaO + MgO$), Normal or Hydrated dolomitic lime [($Ca(OH)2 + MgO$], Pressure hydrated dolomitic lime [($Ca(OH)2 + MgO2$] [4].

The quick lime is more effective as stabilizer than hydrated lime; but the latter is more safe and convenient to handle. Generally, the hydrated lime is used. It is also known as slaked lime, the higher the content of lime, the less is the affinity for water and the less is the heat generated during mixing. The amount of lime required for stabilization varies between 2 to 10% of the soil. However, if the lime is used only to modify some of the physic – chemical characteristics of the soil, the amount of lime is about 1 to 3%.

2) Cement Stabilization

Portland cement is comprised of calcium-silicates and calcium-aluminates that hydrate to form cementitious products [1]. Portland cement stabilization, commonly referred to as soil cement, is a mixture of Portland cement, water and soil compacted to a high density. Soil cement is sometimes referred to as a cement treated subgrade or cement stabilized subbase. When cured, the soil cement mixture becomes a hard, rigid base material. A flexible or rigid pavement surface is placed on top of the soil cement to complete the pavement structure.

Cement stabilization differs from other forms of chemical stabilization in such a way that structural strength is primarily obtained from the cementing action rather than from internal friction, cohesion, chemical ion exchange and/or waterproofing of the materials. Almost all types of soils can be used for cement stabilization except highly organic soils and heavy clay soils.

The four fundamental control factors for the design and construction of soil cement are moisture content, curing procedure and duration, compaction and cement content. Cement stabilization is generally considered to be too expensive for workability improvements alone [42].

C) Stabilization by Geo-textile and Fabrics

Geotextiles are porous fabrics made of synthetic materials such as polyethylene, polyester, nylons and polyvinyl chloride. Woven, non-woven and grid form varieties of geotextiles are available. Geotextiles have a high strength. When properly embedded in soil, it contributes to its stability. It is used in the construction of unpaved roads over soft soils. Reinforcing the soil for stabilization by metallic strips into it and providing an anchor or tie back to restrain a facing skin element. Past research has shown that the strength and load-bearing capacity of subgrades and base course materials can be improved through the inclusion of non-biodegradable reinforcing materials, such as fibers, geotextiles, geogrids, and geo-composites. Use of these materials can improve the performance and durability of future highways and may reduce the cost of construction. At present, most of the research on these materials is based on tests conducted in the laboratory that are only partially complete. Further laboratory tests and evaluations will be necessary to develop design specifications based on material properties, and these specifications will need to be verified using large-scale field tests.

2.8.5 Recycled and Waste Products

Disposal of large quantities of industrial by products as fills on disposal sites adjacent to industries not only require large space but also create a lot of geo-environment problems. Many researchers and organization have made attempts to use them in bulk as soil stabilizers.

Recent research works in the field of geotechnical engineering and construction materials focuses more on the search for cheaper and locally available materials, agricultural and industrial wastes, for use in construction industry. The use of different industrial and agricultural wastes has become a common practice in the construction industry. Fly ash, sugarcane waste ceramic powder, coconut husk ash, waste plastic strips and rice husk can be cited as examples; those by-products are increasingly playing a part in road construction and concrete technology, hence minimizing the problem of resource depletion, environmental degradation and energy consumption. This research focuses on the potential utilization of waste plastic strips in red clay soil stabilization.

A) Waste plastic strip

Plastics are synthetic chemicals extracted mainly from petroleum and made of hydrocarbons (chains of hydrogen and carbon atoms). Most plastics are polymers, long molecules made up of many repetitions of a basic molecule called a monomer. This structure makes plastic particularly durable and long lasting. Plastic is causing serious environmental concerns regarding its slow decomposition rate (recent studies say 500 years) due to its strong bonding molecules.

A word plastic is a material of consists huge range of synthetic organic. It's a very huge issue to whole world as it degrades very slowly to earth. Plastic pollution is gathering of plastic a product that is dangerous to human habitats, animal, plants, etc. Manufactured of plastic is increasing due to low range, easy to produced, imperviousness to water, etc. Since 60-65 years its production is increasing to first stage in pollution. Utilization of plastic waste bottle in geotechnical construction may reduce the problems faced for its disposal as their properties are mostly related to natural material.

Plastic is a non-renewable source and bio-degradable. The disposal of waste plastic bottles causes environmental pollution, it's a sustainable waste. Plastic can be recycled or reused i.e. reprocessing these plastic wastes makes the useful products. Such wastes of plastics can be used as additives for stabilized soil [43].

Thermosets and Thermoplasts

There are two main categories in the world of plastics: thermoplastics and thermosets. Thermoplastics are the plastics that can be recycled. Thermoplastics can be melted back into liquid and moulded multiple times. Thankfully, thermoplastics make up to 90% of global production. Thermosets can melt and take shape only once; after they have solidified, they stay solid forever. In the thermosetting process, a chemical reaction occurs that is irreversible.

Plastic types

Thermoplastics are further grouped in seven different subcategories often referred to as plastic types. Each plastic type has its specific chemical composition, properties and applications and is given a specific number, called SPI code to differentiate between them. Today, most manufacturers should follow this coding system and place the SPI code on their products, usually moulded at the bottom of the product. Knowing what plastic type, you're working with is crucial when working with plastic recycling. The different plastic types with their corresponding notation are:

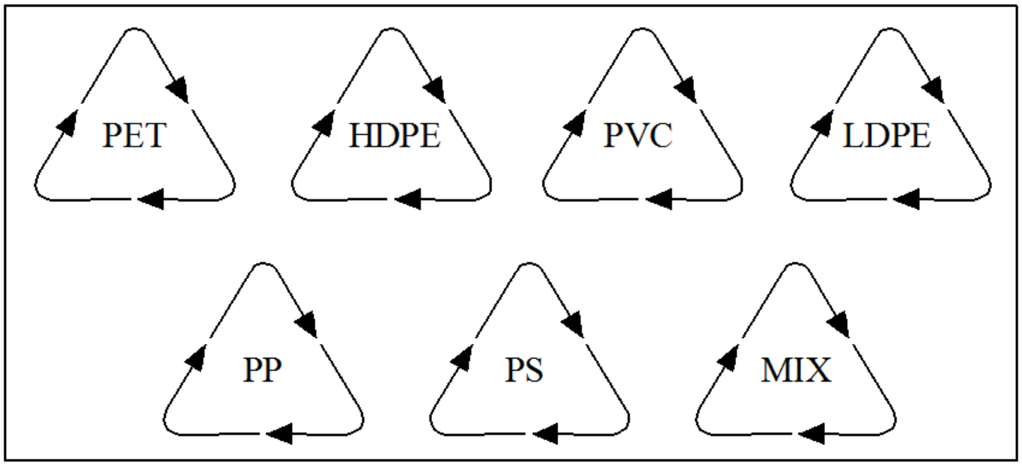


Figure 2-7: Different plastic types with their corresponding notation

1. PET (polyethylene terephthalate)

This is a very strong plastic that can be easily recognized for its transparent look. All beverage bottles containing sodas are PET. This plastic is also used in many other products like jars, combs, bags, tote bags, carpets and ropes. Items made from this plastic are commonly recycled. Most recently, PET is often recycled into yarns to make clothes.

2. HDPE (high-density polyethylene)

This plastic is often used for food or drink containers. Items made from this plastic include containers for milk, motor oil, shampoos, soap bottles, detergents, and bleaches. Many toys are also made from this plastic.

3. PVC (polyvinyl chloride)

This is toxic and we do not work with it. PVC is most commonly found in plumbing pipes and releases chloride when heated up. Do not use with when recycling plastics.

4. LDPE (low-density polyethylene)

Plastic wrap, sandwich bags, squeezable bottles, and plastic grocery bags all are made from LDPE. Usually, LDPE is not recycled from the industry but works rather good with the recycling recommended in this report.

5. PP (polypropylene)

This is one of the most commonly available plastic on the market. This type of plastic is strong and can usually withstand higher temperatures. Among many other applications, it is consistently used for products that get in contact with food and drink (Tupperware, yoghurt boxes, syrup bottles etc.).

6. PS (polystyrene)

PS is most commonly known as Styrofoam. PS can be recycled, but not efficiently; recycling it takes a lot of energy, which means that few places accept it. Disposable coffee cups, plastic food boxes, plastic cutlery and packing foam are made from PS.

7. Other mix

This code is used to identify other types of plastic that are not defined by the other six codes. ABS, Acrylic or Polycarbonate are included in this category and can me more difficult to recycle.

Properties of plastic

Plastic have a numerous property that make them superior to other materials in many applications. The different types of properties are physical properties and chemical properties. Physical properties: Plastic has transparency, flexibility, elasticity, water resistant, electrical resistance and soft when it is hot. Soil is a naturally occurring material's that are used for the construction of all except the surface layers of pavements and that are subject to classification tests to provide a general concept of their engineering characteristics. Chemical properties: Chemical resistance, thermal resistance, reactivity with water, flammability, heat of combustion etc. are the basic chemical properties of plastic.

B) Waste plastic strip as a Soil Stabilizing Material

These days sustainability plays the major role in every aspect of human activities. Many technologies came to end because they were not in harmony with the idea of sustainable development. Sustainability is concerned about the world we will be leaving behind for future generations. It focuses on the social, environmental and economic issues of human activities. Therefore, it requires every activity to be environmentally friendly, economical and safe for the social. Plastic stabilization is one of economical and environmentally friendly stabilization techniques.

2.8.6 Previous Studies

Harish and Ashwini, H.M. (2016) studied the effect of plastic bottles strips as a stabilizer for two soil samples, red soil and black cotton soil. Red soil consists of 4 % gravel, 88% sand and 8% silt and clay and black cotton soil 2.6% gravel, 15.1 %sand and 82.3 % silt and 0.18 % of clay. They used plastic stripes in making the pavement and it was found that there was an increase in the strength of the soil. Authors conducted a CBR ratio test to find out MDD and OMC. They observed an increase in the strength of soil and bearing ratio of 2.9 for red soil and 3.3 for the black cotton soil by mixing 0.7 % of waste plastic strips to red soil and 0.5 % for the black cotton soil.

S.W. Thakare and S. K. Sonule (2013) carried out various laboratory tests to investigate the effect of reinforcement of sandy soil with model plastic water bottle through model plate load tests. The study showed that the ultimate bearing capacity of footing increases with increasing the layer of plastic bottles as reinforcement. The increase in bearing capacity may be due to the additional confinement to the soil in the vicinity of footing similar to that in case of Geocell. The bearing capacity increases with the increase in width of reinforcement and number of layers. Thus, the use of plastic bottles as reinforcement was recommended to reduce the quantity of plastic waste which creates the disposal problems.

Mehndiratta, R. (2005) presents the effect of inclusion of polypropylene fibres with fly ash. Laboratory CBR tests, triaxial shear tests, plate load and field CBR tests were carried out to investigate the effect of fibre inclusion on the strength behavior of fly ash. Tests were conducted on fly ash with different percentages of polypropylene fibres. Laboratory CBR tests were conducted on fly ash in both soaked and unsoaked conditions. The CBR value of fly ash increases with increase in fibre content in both soaked and unsoaked conditions as shown in the percentage increase in CBR value is higher at lower percentage of fibre content in triaxial tests were conducted at optimum moisture content with 0.7 kg/cm², 1.2 kg/cm² and 1.8 kg/cm² confining pressures. Based on the CBR values and shear strength parameters, 0.5% fibre content is seen to be the optimum. Plate load and field CBR tests were conducted on fly ash and fl y ash with 0.5% fibre content. The addition of fibre to fly ash shows significant improvement in CBR value, angle of internal friction and modulus subgrade reaction. Variation of major principal stress at failure with different confining pressures and fibre contents Kumar et al. (2006) studied admixtures and geogrids are frequently used in practice to stabilize soils and to improve their load carrying capacity. In this study, polyester fibers were mixed with soft clay soil to investigate the relative strength gain in terms of unconfined compression. Samples were tested in unconfined compression with 0%, 0.5%, 1.0%, 1.5% and 2.0% plain and crimped polyester fibres. The results presented show that the degree of compaction affected the relative benefits of fiber reinforcement for the subject soil. Samples compacted after mixing various proportions of sand into clay (varying from 0% to 12% of clay) was also tested. It was observed that unconfined compressive strength of clay increases with the addition of fibers and it further increases when fibers are mixed in clay sand mixture. Verification tests performed revealed that even though the fibers were randomly oriented, tests results can be reproduced with reasonable accuracy. Cut length of polyester fibre is 3,6,12 mm plain and 6 mm crimped.

Dr. A.I. Dhatrak (2015) after reviewing performance of plastic waste mixed soil as a geotechnical material, it was observed that for construction of flexible pavement to improve the sub grade soil of pavement using waste plastic bottles chips is an alternative method. In his paper a series of experiments are done on soil mixed with different percentages of plastic (0.5%, 1%, 1.5%, 2%, 2.5%) to calculate CBR. On the basis of experiment that he conducted using plastic waste strips will improve the soil strength and can be used as sub grade. It is economical and eco-friendly method to dispose waste plastic because there is scarcity of good quality soil for embankments and fills.

Jasmin Varghese Kalliyath (2016) studied the effect of plastic fibers. Various tests such as Standard Proctor, UCC were carried out with different samples of silty clay. Authors observed that the replacement of 0.5 % waste plastic fiber to the expansive clayey soil reduce its OMC and increased maximum dry density but UCS of the soil was found to be increased. The test results also showed that with 1% replacement, MDD and UCC were less than the 0.5 % replacement but greater than the untreated soil. Further increase in the plastic replacement showed decrease in the MDD and the UCS. The increase in the MDD of the soil with 1% replacement is due to the decrease in the number of voids with the addition of plastic which leads to effective compaction and also increase in the cohesion. Thus, authors concluded that optimum percentage of plastic was 0.5 % for optimum results.

Hatem Nsaif (2013) concluded by mixing plastic waste pieces with two types of soil (clayey soil and sandy soil) at different mixing ratios (0,2,4,6,8) % by weight respectively that, there is significant improvement in the strength of soils because of increase in internal friction. The percentage of increase in the angle of internal friction for sandy soil is slightly more than that in clayey soil, but there is no significant increase in cohesion for the two types of soils. Also, it was concluded that due to low specific gravity of plastic pieces there is decreases in MDD and OMC of the soil.

Maheshwari, (2011) mixed polyester fibers of 12 mm in length with highly compressible clayey soil vary from 0% to 1%. The results indicated that reinforcement of highly compressible clayey soil with randomly distributed fibers caused an increase in the ultimate bearing capacity and decrease in settlement at the ultimate load. They concluded that the soil bearing capacity and the safe bearing pressure (SBP) both increase with increase in fiber content up to 0.50% and then it decreases with further inclusion of fibres. Japanese scientists have been found that short PET fiber (64 mm) reinforced soil had high piping resistance, and that the short fiber reinforced soil layer increased the stability of levee against seepage of rainfall and flood.

Choudhary, JHA and Gill (2010) demonstrated the potential of HDPE to convert as soil reinforcement by improving engineering properties of sub grade soil. From waste plastic HDPE strips are obtained and mixed randomly with the soil and by varying percentage of HDPE strips length and proportions a series of CBR tests were carried out on reinforced soil. There results of CBR tests proves that inclusion of strips cut from reclaimed HDPE is useful as soil reinforcement HDPE is useful as soil reinforcement in highway application.

Mercy Joseph Poweth (2014) investigated the effect of plastic granules on weak soil sample with plastic and without plastic granules in varying percentage. The percentage of waste plastic was taken as 0.25%, 0.5 %, 0.75%. Maximum dry density was obtained when 0.25 % plastic was added and OMC was less than the soil without plastic for this percentage of soil. Further CBR value decreases when 0.25 % plastic is added but it was found to be increased for 0.75 % of plastic. Authors also observed that for the same percentage of plastic, shear stress was maximum.

F.C. Chebet and D.Kalumba (2014) did laboratory investigations to determine the increase in shear strength and bearing capacity of locally available sand due to random mixing of strips of HDPE (high density polyethylene) material from plastic shopping bags. A visual inspection of the plastic material after tests and analysis indicates that the increased strength for the reinforced soil is due to tensile stresses mobilized in the reinforcements. The factors identified to have an influence on the efficiency of reinforcement material were the plastic properties (concentration, length, width of the strips) and the soil properties (gradation, particle size, shape).

Kumar, R. (1999) based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers, concluded that fibers increased the peak compressive strength, CBR value, peak friction angle and ductility of the specimen. Authors further reported that the optimum fiber content for both silty sand and pond ash was approximately 0.3-0.4 % of dry unit weight [28].

Santoni, R.L. (2001) based on their laboratory unconfined compression tests conducted on sand specimen reinforced with randomly oriented discrete fibers, concluded that the fibers inclusions significantly improved the unconfined compression strength of sand specimens and the maximum benefit was achieved at a fiber content rate between 0.6% and 1% of dry weight [40].

2.8.7 Availability of waste plastic strip in Ethiopia

Plastic waste is found everywhere here in our country. As the population increased and the need of use of bottled drinks increase the plastic waste also increased. There are many plastic recycling companies in our country and I collect the sample from Huayang Recycled Plastic Manufacturing Plc.

CHAPTER 3 DESCRIPTION OF THE STUDY AREA

3.1 Introduction

Addis Ababa, the capital of Ethiopia, is located in the central highlands of Ethiopia. The city is situated in the main highland plateau with an average elevation of 2440m above sea level. It is the highest capital in Africa. Its topography is constituted by hills, rivers and streams. It is the seat of International Organization, high level of governmental and non-governmental organizations. The city is expanding from time to time horizontally in the expansion areas to the east, south, west, and to a limited extent to the north.

This chapter deals with the description about the study area which includes the location of study area, geologic, topographical and climatic conditions which possibly have influenced the formation of Red soil. This section also addresses the distribution of red soil in the study area and its surrounding. In addition, meteorological data which gives information about temperature and rainfall conditions in Addis Ababa is also included. Red soils have various industrial applications in many parts of the country but the most widespread application is in the construction industry.

3.2 Location of the Study Area

The project site is found in the Northern part of the city of Addis Ababa at Gullele sub-city around kechene-Ras Desta road. The site is located at the global UTM [by hand held GPS] coordinates of N 9°02'50.2”, E 38°44'44.2" and at 2522 m above mean sea level. The area is mainly covered with red clay soil. Figure 3-1 shows location of the study area.

Figure 3-1: Location of Study area and source of plastic strip. (Source - Google Earth)

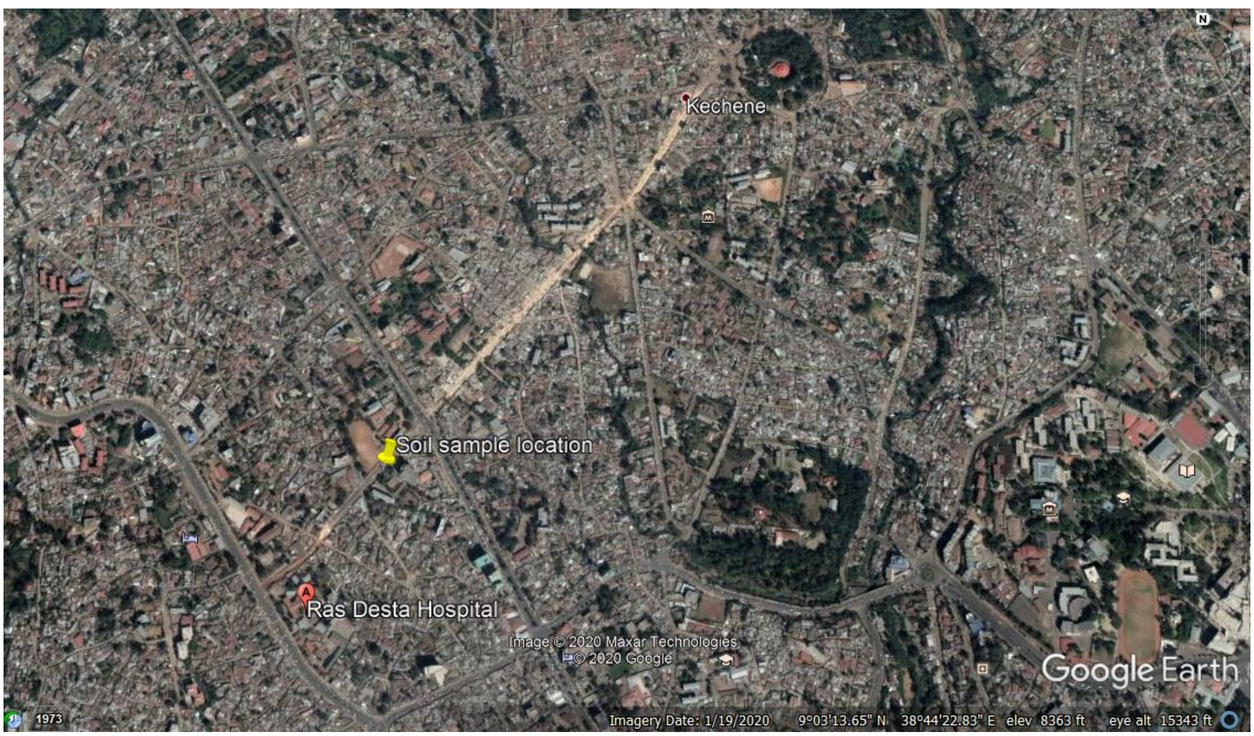


Figure 3-2: Soil sample location. (Source - Google Earth)

Figure 3-3: Plastic strip sample location. (Source - Google Earth)

3.3 Geology of Study Area

The geological history of the study area is an integral part of the evolution and development of the Ethiopian Plateau and the Rift system. Addis Ababa generally lies in the western margin of the Ethiopian Rift Valley and the area is covered by different volcanic rocks with both acidic and basic compositions and overlain by residual soils varying in thickness from a few cm to about several meters [41].

The North and North Eastern area (the Entoto Mountain, the northern and north eastern Addis Ababa) is covered with trachytes, rhyolites, basalts and several episodes of pyroclastic materials of older volcanism occurring in the upper part and foothill sides of Entoto ridge. Overlying these, younger basaltic rocks (Addis Ababa Basalt) are found covering the central and Southern part of the city.

Volcanic mountains such as Wachecha in southwest, Furi in the southern and Yerer in the southeastern parts of Addis Ababa are mainly trachyte in composition. The basalts are outcropping in the central part of Addis Ababa and to the south and north of the Entoto hills some small patches of basalts are capping the Entotosilicic.

The geology in the study area cover with Addis Ababa basalt mainly alkaline and olivene basalt and Addis Ababa Ignimbrite covers part of Gulele, Addis Ketema and Arada subcity. Central volcanics of wechecha, Entoto, pyroclastic trachytic lava flows cover most of Kolfe keraniyo subcity. Moreover, the degree of weathering, fracturing and morphology of the area plays a great role in controlling the development and thickness of soil horizon above the aphanitic basalts. The physical disintegration and chemical decomposition become more pronounced along the surface of the joint sets.

3.4 Soil Distribution in Addis Ababa

The formation of soil in Addis Ababa area is mostly due to the physical disintegration and chemical decomposition of volcanic rocks, the weathering products are either remaining in places and formed residual soils or transported and deposited in low lying flat lands and depressions [41].

The detrital materials derived from elevated areas around the city from Entoto, Wechecha, Furi and Yerer are transported and deposited in the piedmont and along the stream courses of Addis Ababa. The black soil covers most parts of Mekanisa, Ayertena, Akaki, Kality, Lideta and Bole. Old basic and acidic rocks that control in the central, western and south western parts of Addis Ababa are weathered and form thick soil profile. In places where young basalt and welded tuffs occur, the thickness of soil cover is reduced [41].

The engineering geological soil units in Addis Ababa area are grouped into their genetic soil units as alluvial, alluvial Fan, colluvial, lacustrine and Residual soils. Alluvial soils which includes channels and terrace deposits seen in some places along Akaki River and in the south western parts of Addis Ababa and along Kebena River. These soils consist of stratified deposits of gravel and clay transported by streams [27].

The alluvial soils consist of more or less stratified deposits of gravel and clay transported by streams. Alluvial fan is deposited where there is a decrease in gradient from a hill to a plain along a river section. It is coarser near the mouth of the river and become finer outwards and found in the Intoto region dissected by deep gullies [27]. Lacustrine soils, alternatively named as Black cotton soil found around Lideta Bole Mekanisa areas. These areas are flat and relatively low lying. Residual Red soils in Addis Ababa are widely distributed next to Black soil as seen from the engineering geological map of Addis Ababa. Red soil is widely distributed in Western, North western, in the central some parts in the eastern parts of the city. Residual soils mainly located in Gulele and Kolfe area. In some localities reddish brown soil with a thickness of more than 10 meter is commonly seen.

Colluvial soils are found in areas where there is a great contrast in the topography. These are loose and incoherent deposits, consisting of fine to coarse grain particles. Colluvial soils are mainly located at the foot slopes of northeastern part of Entoto silicics and other few places [27].

The low lying flat areas around Addis Ababa are dominated by black cotton soils. These soils have extremely high plasticity and very high degree of swelling as compared to the other identified soil types found in Addis Ababa. The thickness of this soil varies at places from 2 to 10m. The highest thickness is found in Bole area and in Beklo Bet area it is about 5m thick [27].

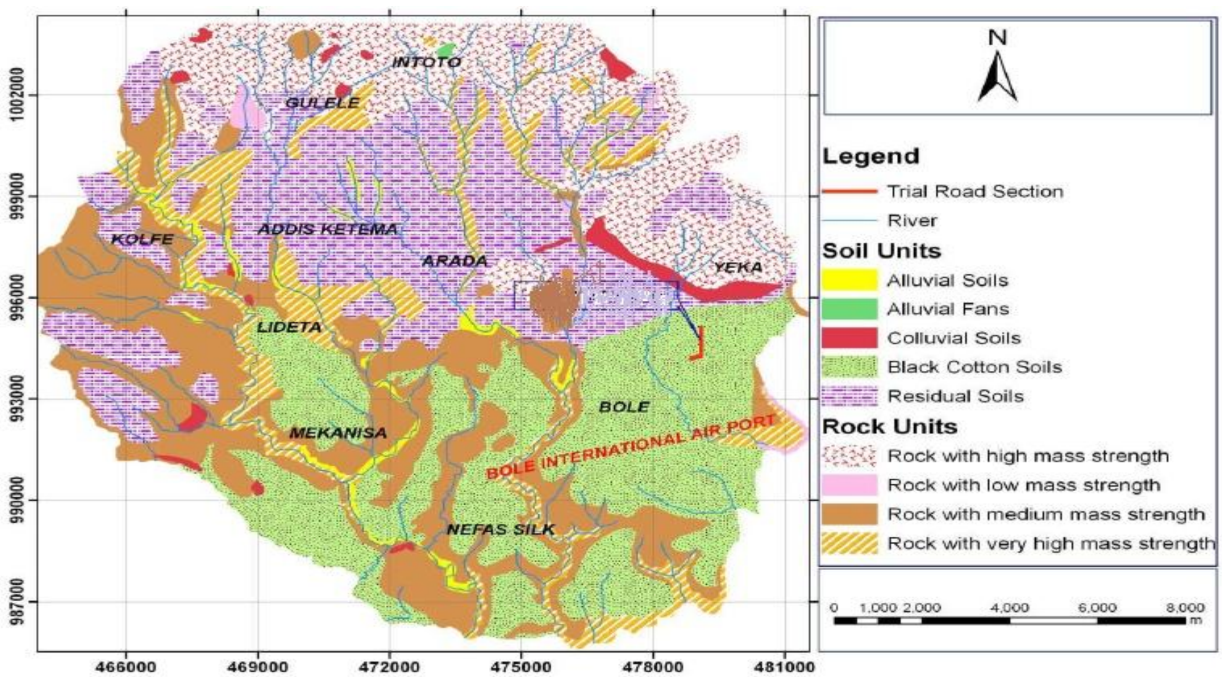


Figure 3-4: Engineering Geological Map of Addis Ababa [27].

3.5 Climate

The Ethiopian climate is mainly controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) and the associated atmospheric circulations of air as well as by the complex topography of the country. The climate in these areas is favorable for the formation of Tropical red soils [2]. Climate is the principal factor governing the rate and type of soil formation. The two most important components of climate are the amount and distribution of precipitation, and temperature [21].

Ethiopia is classified into five climatic zones; These include "Kur" (Alpine), above 3000m mean sea level; "Dega" (Temperate), 2300 m to about 3000 m; "Weina Dega" (Sub tropical), 1500 m to about 2300 m; "Kolla" (Tropical), 800 m to about 1500 m and "Bereha" (Desert), less than 800 m. Most parts of Addis Ababa fall under the Weina Dega (Sub tropical) category [24]. The Rainfall has unimodal pattern, one distinct rainy and dry season. The dry season is October through May and the wet one is from June to September. The rainfall peak is in August.

Wind speed is generally moderate, ranging between 0.5 to 0.9 m/s. The average daily sunshine hours are 9.5 hours in November and December, and far low, 3 hours, in July and August. Pan-evaporation records at Addis Ababa Observatory showed that the average monthly pan-evaporation during dry season (November) is about 180 mm and in wet season (July) falls to 75 mm [24].

3.5.1 Rainfall

From engineering geological point of view, variations in rainfall brings fluctuations of the groundwater table, there by producing variations in the moisture content or degree of saturation of the underlying earth materials. The moisture content variation has a greater impact on the engineering properties of earth materials as strength of foundation materials decreases with increase in moisture content. Hence, prior knowledge of rainfall variation of an area helps to understand its impact on ground water table fluctuations and to pass the right decision on the design and long term safety of engineering structure.

In Addis Ababa, rainfall intensity variation is attributed to differences in Topography. The high elevated areas such as the Entoto receive relatively greater precipitation than lowland areas around Bole and Akaki. The mean monthly and annual mean rainfall of National Meteorological Services Agency (NMSA) stations in Addis Ababa located at Addis Ababa Observatory (1998 to 2018), were used.

According to National Meteorological Services Agency data from the mean monthly rainfall the months from June to September receives highest rainfall. (Table 3.1)

Table 3-1: Mean Monthly Rainfall (Source: National Meteorological Services Agency)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean Monthly Rainfall, mm	14.8	19.0	55.4	71.6	86.3	142.6	275.9	295.8	183.0	37.6	11.3	9.7

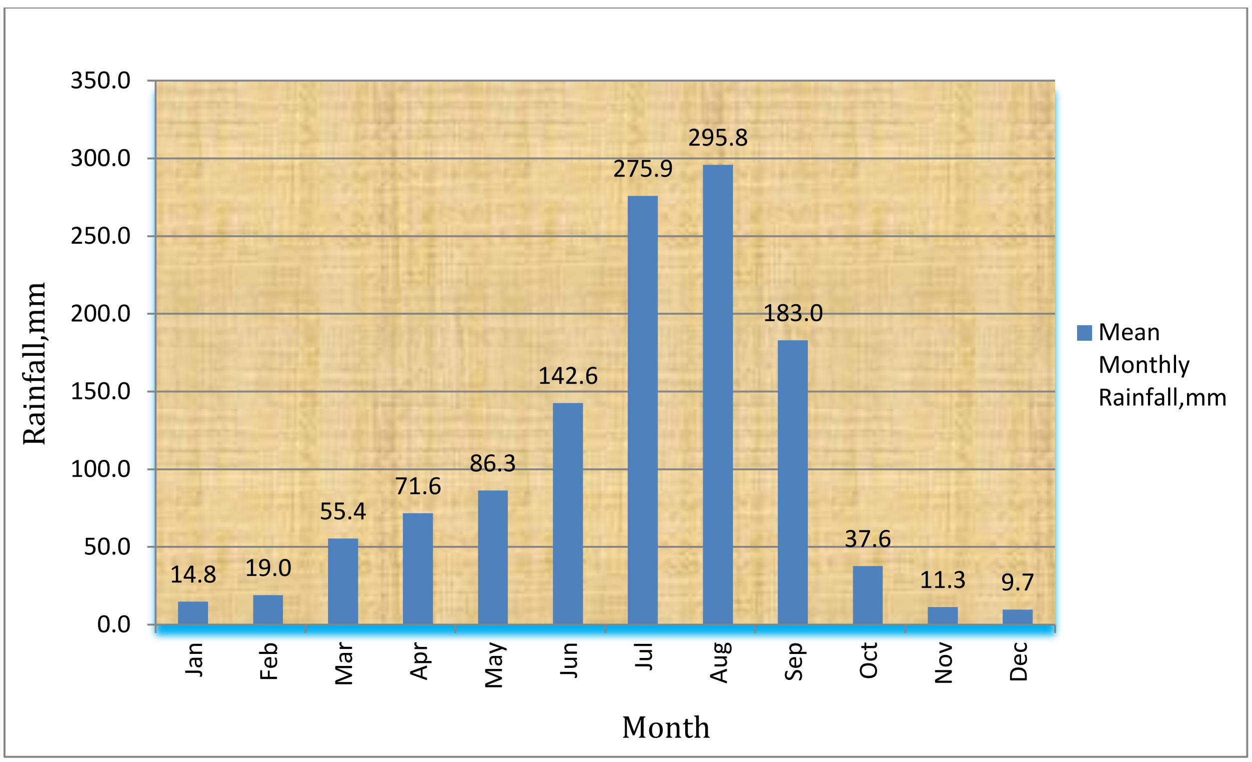


Figure 3-5: Mean Monthly rainfall

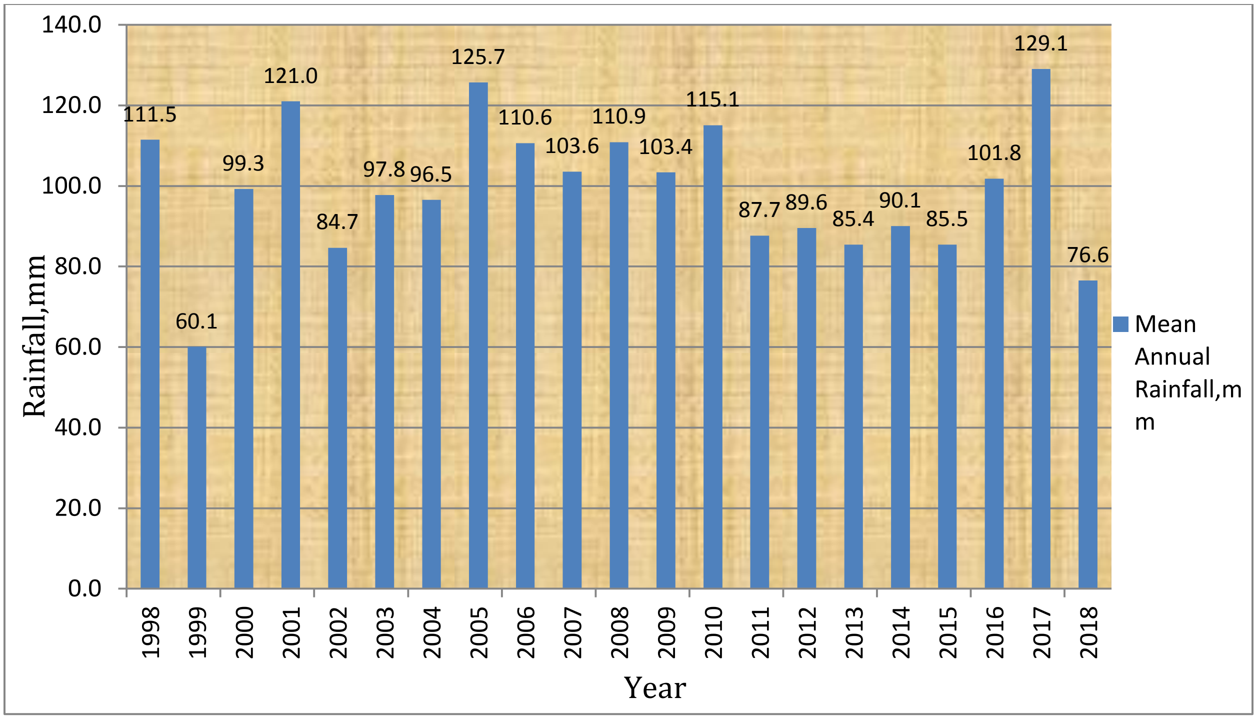


Figure 3-6: Mean Annual Rainfall

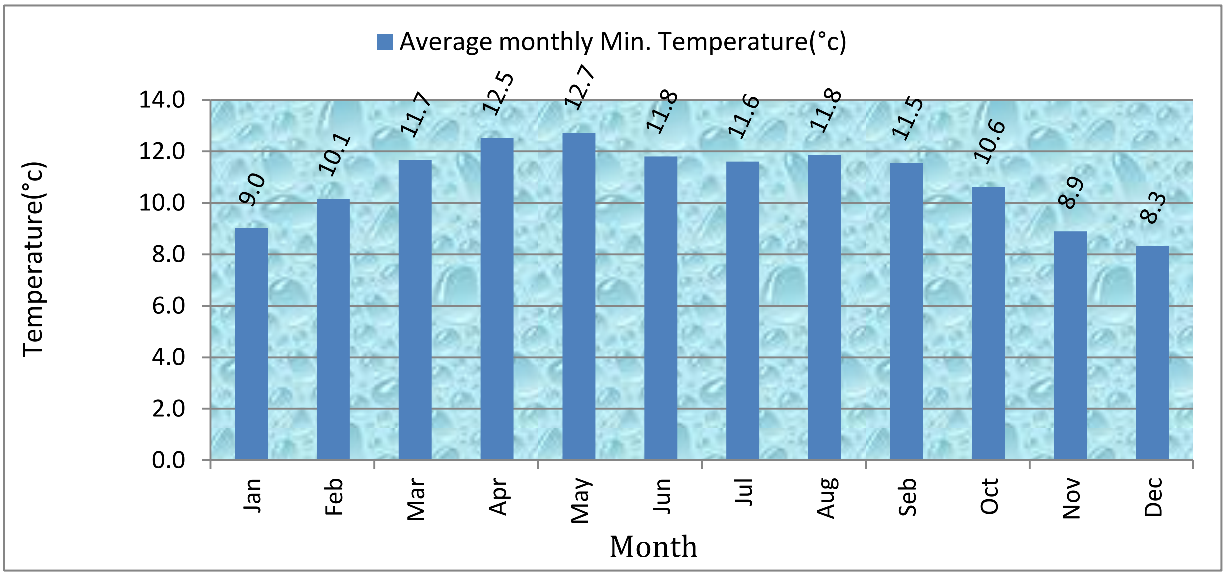
3.5.2 Temperature

The average temperatures of Ethiopia are typically tropical to sub-tropical and fluctuate by 5°C between the coldest and warmest months [24]. Fluctuating temperatures help break down mineral grains in rocks. Warmer temperatures increase chemical weathering. As a result, and being a tropical region, Addis Ababa has thick weathered profile in most of its areas, especially in gentle and flat lands. Although temperature has no direct influence on the engineering properties of foundation materials, its long term effect of accelerating weathering of near surface rocks cannot be denied. Weathering weakens the strength of earth materials through altering the mineralogy as well as their physical properties.

The mean monthly maximum and minimum temperature records of National Meteorological Services Agency (NMSA) for the last twenty-one years between 1998 and 2018 were utilized to calculate annual average temperature. The computed average maximum and minimum temperature is presented (Table3-2).

Table 3-2: Maximum and Minimum Monthly Temperature (Source: National Meteorological Services Agency)

Average Monthly Temperature(°c)	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Seb**	**Oct**	**Nov**	**Dec**
Minimum	9.0	10.1	11.7	12.5	12.7	11.8	11.6	11.8	11.5	10.6	8.9	8.3
Maximum	24.4	25.7	25.9	25.6	25.3	23.8	21.5	20.9	22.1	23.3	23.6	23.6



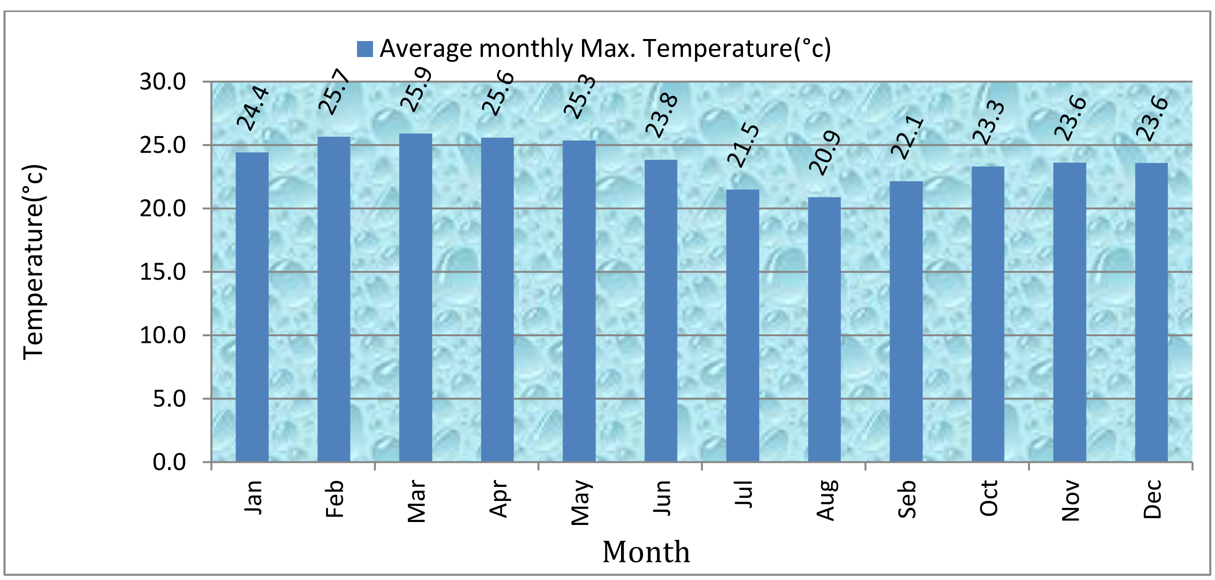
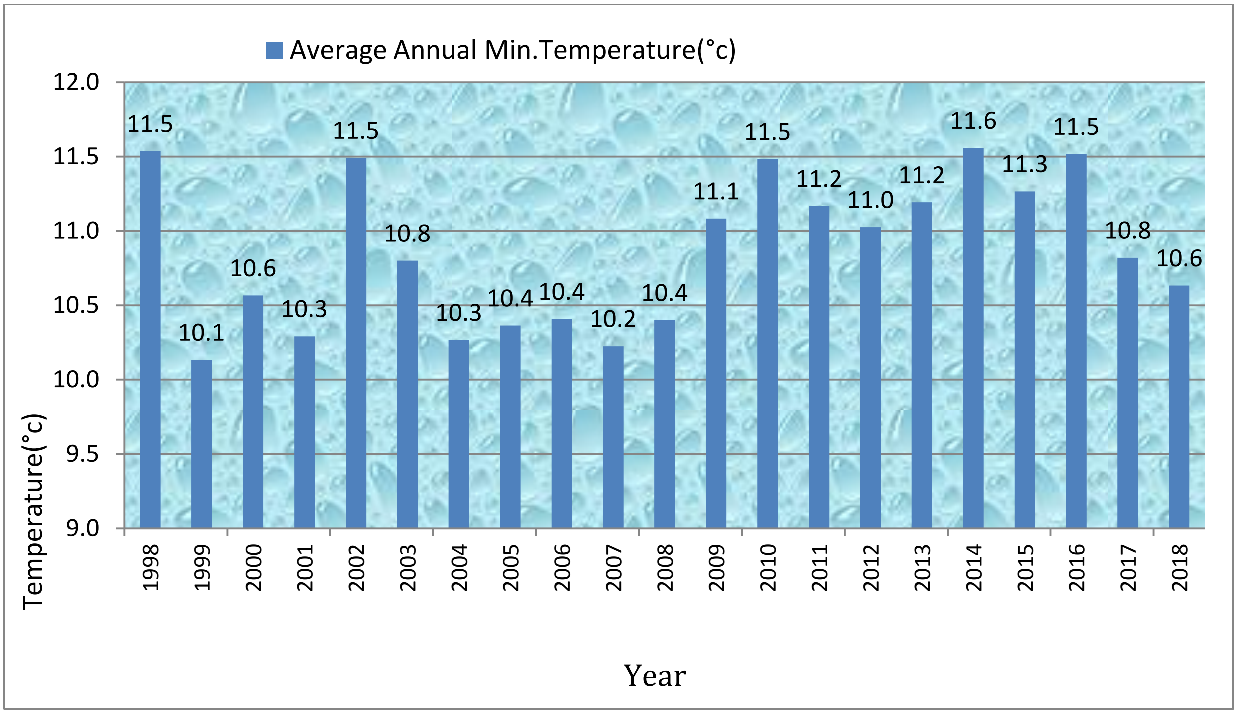
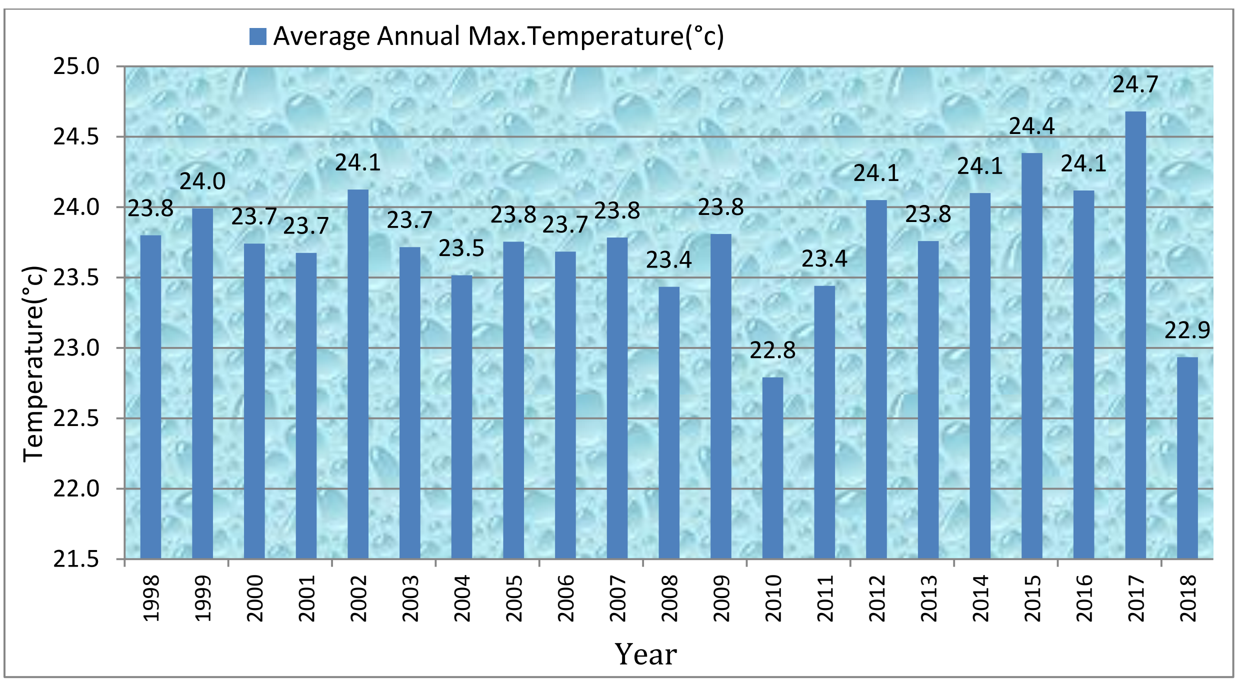


Figure 3-7: Minimum and Maximum Annual Temperature



A). Minimum Annual Temperature



B). Maximum Annual Temperature

Figure 3-8: Minimum and Maximum Annual Temperature

CHAPTER 4 MATERIALS AND METHODS

4.1 General

In the present study laboratory tests were conducted on natural untreated representative samples to characterize the soil. To assist the laboratory testing and subsequent identification of soil, field investigation was under taken before pitting and sampling. The field investigation included identification of soil based on observation of color and soil texture on the site where the sample was collected. The laboratory tests conducted include: - natural moisture content, grain size analysis, free swell, specific gravity, Atterberg limits, moisture density relation, unconfined compressive strength, CBR. These tests were deemed enough to characterize the soil for the present research work.

For proper improvement of soils, it is important to adequately identify and understand its characteristics. Therefore, the investigation that should be conducted on soils is a determining factor to select appropriate improvement methods in a technically and economically feasible manner.

4.2 Materials

4.2.1 Soil sample

The soil sample used for this research work is collected from Addis Ababa, Gulele Sub City Kechene-Ras Desta road construction project. The soil is red in color. Disturbed soil samples were collected at a depth of 1m below NGL.

Figure 4-1: In-situ condition of red clay soil sample

4.2.2 Plastic strip

Plastic strip was obtained from Huayang Recycled Plastic Manufacturing PLC, which is plastic recycling company located in Oromiya Regional State around Kenteri.

Figure 4-2: Plastic Strip sample

Figure 4-3: Soil plastic Strip mix

4.2.3 Water

According to the standard test, it is recommended to use distilled water to conduct certain laboratory tests like Atterberg limits and specific gravity. Distilled and tap water is used to conduct the laboratory tests.

4.3 Methods

4.3.1 Sample Preparation

After the collection of disturbed soil, moist sample was transported to the laboratory in plastic bags. Sample preparation was done in accordance with the method stated in AASHTO T87-86. Soil samples were air dried by spreading the material out in trays in the laboratory and leaving it open in the air.

4.3.2 Moisture Content

The test is conducted by taking representative sample of the natural soil and oven-dried to 50°C at RH 30. The sample was then reweighed, and the difference in weight was assumed to be the weight of the water driven off during drying. The difference in weight was divided by the weight of the dry soil, giving the water content of the soil a dry weight basis.

4.3.3 Atterberg Limits Testing

Soils containing clay exhibit a property called plasticity. Plasticity is the ability of a material to be moulded (irreversibly deformed) without fracturing. This behavior is unique to clay and arises due to the electrochemical behavior of clay minerals.

The stiffness or consistency of fine grained soils depends on their moisture content, and varies with variations in the amount of moisture present. Atterberg limits define the moisture contents at which the soil changes from one state to another. These limits are determined by tests carried out on the fine soil fraction passing the 425µm (No. 40) sieve.

The nature and response of soil upon change to moisture content is determined by Atterberg limit tests. This parameter is basic in the AASHTO and USCS soil classification systems. Atterberg limits are carried out to determine the consistency of fine-grained soils. The Atterberg limit depends on the type of predominant clay mineral available in the soil mass. If the predominant clay is montmorillonite the liquid limit can reach or even exceed 100% because the bond between the layers in montmorillonite is weak and large amounts of water can easily infiltrate the spaces between the layers. However, in the presence of kaolinite, the layers are held relatively tighter and water cannot easily infiltrate between the layers compared to montmorillonite. Therefore, liquid limit value will be much lower. It is also expected that the Atterberg limit is less for illite dominated soil and even less for kaolinite dominated soils. In general, soils that exhibit plastic behavior over wide ranges of moisture content and that have high liquid limits have greater potential for swelling and shrinking [26].

The test includes the determination of the liquid limits, plastic limits and the plasticity index for the natural soil and the plastic strip mixtures (plastic strip is sieved in accordance with the atterberg limit test required). The tests are conducted in accordance with AASHTO T89-90 and T90-96 testing procedures.

A) Liquid Limit

The soil sample for liquid limit is air dried and 200 g of the material passing No. 40 sieve (425µm aperture) was obtained and thoroughly mixed with water to form a homogeneous paste on a flat glass plate. A portion of the soil water mixture is then placed in the cup of the Casagrande apparatus, leveled off parallel to the base and divided by drawing the grooving tool along the diameter through the centre of the hinge. The cup is then lifted up and dropped by turning the crank until the two parts of the soil come into contact at the bottom of the groove. The number of blows at which that occurred was recorded and a little quantity of the soil was taken and its moisture content determined. The test is performed for well–spaced out moisture content from the drier to the wetter states. The values of the moisture content (determined) and the corresponding number of blows is then plotted on a semi–logarithmic graph and the liquid limit is determined as the moisture content corresponding to 25 blows. The same procedure is also carried out for the treated soil with increment of plastic strip content.

B) Plastic Limit.

A portion of the natural soil and the soil– plastic strip mixture used for the liquid limit test is retained for the determination of plastic limit. The ball of the natural soil and the soil– plastic strip mixture is moulded between the fingers and rolled between the palms of the hand until it dried sufficiently, even though the soil is already relatively drier than the ones used for liquid limit. The sample is then divided into approximately two equal parts. Each of the parts is rolled into a thread between the first finger and the thumb. The thread is then rolled between the tip of the fingers of one hand and the glass. This continued until the diameter of the thread is reduced to about 3mm. The movement continued until the thread shears both longitudinally and transversely. The crumbled natural soil and soil– plastic strip mixture is then put in the moisture container and the moisture content determined. The same procedure is also carried out for the treated soil with increment of plastic strip content.

C) Plasticity Index

The plasticity index of the natural soil and the soil– plastic strip mixture is the difference between the liquid limits and their corresponding plastic limits. The plasticity indexes of the samples are calculated as:

$$PI = LL - PL \qquad (4.1)$$

4.3.4 Particle Size Distribution

The aim of the test is to determine the relative properties of different grain sizes which make up a soil mass. The test includes the determination of the particle size distribution for the natural soil and used in the classification. Accordingly, Wet sieve analysis was employed to determine the grain size distribution of the soil samples in accordance with AASHTO T88-93 testing procedures. Approximately, 50gm of dry soil passing No. 200sieve is treated with a dispersing agent for 18 hours. A hydrometer analysis is then performed to measure the amount of silt and clay size particles. The sample is then washed through a series of sieves with progressively smaller screen sizes to determine the percentage of sand-sized particles in the specimens.

4.3.5 Free Swell Test

The test includes the determination of the free swell for the natural soil. The free swell test may be considered as a measurement of volume change in clay upon saturation and is one of the most commonly used simple tests. This test has not yet been standardized by AASHTO and ASTM. The method was suggested by Holtz and Gibbs, [25] to measure the expansive potential of cohesive soils. The test gives a fair approximation of the degree of expansiveness of the soil sample. The procedure consists of pouring very slowly of 10 cubic centimeters of that part of the dry soil passing No. 40 sieve in to a 100 cubic centimeters graduated measuring cylinder and letting the content stand for approximately 24 hours until all the soil completely settles on the bottom of the graduating cylinder. Then the final volume of the soil is noted. Finally, free swell value is calculated using Equation (4.2).

$$FS=\left(\frac{V_f-V_i}{V_i}\right)*100 \tag{4.2}$$

Where: FS = free swell, V_i =initial volume & V_f =final volume

Soils having a free swell value as low as 100 percent can cause considerable damage to lightly loaded structures, and soils having a free swell value below 50 percent seldom exhibit appreciable volume change even under very light loadings.

4.3.6 Specific Gravity

Specific gravity which is the measure of heaviness of the soil particles are determined by the method of pychnometer method using a soil sample passing No. 10 sieve and oven dried at 105 degree centigrade. The test includes the determination of the specific gravity for the natural soil. The test is conducted in accordance with AASHTO T100-93 testing procedure.

4.3.7 Compaction

The test includes the determination of the maximum dry density and the optimum moisture content for the natural soil and the soil-plastic strip mixture. Knowledge of the optimum moisture content and the maximum dry unit weight of soils is very important for construction specifications of soil improvement by compaction [37]. Compaction increases the strength, lowers the compressibility, and reduces the flow rate of water of a soil by rearranging its fabrics. The tests are conducted in accordance with AASHTO T99-94 testing procedures.

A) Maximum Dry Density

The maximum dry density is conducted for both the natural and soil- plastic strip mixture of about 2.5 kg, by varying the moisture content. The sample is then compacted into the 944 cubic centimeters (of mass m1); in three layers of approximately equal mass with each layer receiving 25 blows. The blows are uniformly distributed over the surface of each layer. The collar is then removed and the compacted sample leveled off at the top of the mould with a straight edge. The mould containing the leveled sample is then weighed to the nearest g/cm3. One small representative sample is then taken from the compacted soil for the determination of moisture content. The same procedure is repeated until minimum of five sets of samples are taken for moisture content determination. The bulk density is then calculated for each compacted specimen using:

$$\gamma_b = \frac{(m_1 - m_2)}{944} \qquad (4.3)$$

Where:

m_1 = mass after compacted the soil with mould

m_2 = mass of the mould.

γ_b = Bulk unit weight

The dry density is also calculated using the following equation:

$$\gamma_d = \frac{(\gamma_b)}{(1+\frac{\omega}{100})} \qquad (4.4)$$

Where:

ω = is the moisture content of each compacted specimen

γ_d =Dry unit weight

γ_b =Bulk unit weight

The values of the dry densities as obtained from equation above are plotted against their respective moisture contents and the dry densities.

B) Optimum Moisture Content

The corresponding value of moisture contents at maximum dry densities, which is deduced from the graph of dry density against moisture content, gives the optimum moisture content.

4.3.8 Unconfined Compressive Strength (UCS)

The unconfined compression test is a special case of a triaxial compression test in which the all-round pressure is equal to zero. The test is applicable only in cohesive soils which can stand without any lateral support. The test is an un-drained test and is based on the assumption that there is no moisture loss during the test. The unconfined compression test is one of the simplest and quickest tests used for the determination of the shear strength of cohesive soils. The primary purpose of this test is to determine the unconfined compressive strength, which is then used to calculate the unconsolidated un-drained shear strength of the clay under unconfined conditions. According to the ASTM standard, the unconfined compressive strength (qu) is defined as the compressive stress at which an unconfined cylindrical specimen of soil will fail in a simple compression test. In addition, in this test method, the unconfined compressive strength is taken as the maximum load attained per unit area, or the load per unit area at 15% axial strain, whichever occurs first during the performance of a test. Specimens of height to diameter ratio of 2 are normally used for the tests. The sample fails either by shearing on an inclined plane (if the soil is of brittle type) or by bulging. The test is carried out in cylindrical specimen with dimensions of 38mm diameter and 76mm in length. In this test the soil goes to failure by axial load only with no confining stresses. The UCS values are determined in accordance to AASHTO T-208. The unconfined compressive strength tests were conducted for both natural and soil-plastic mixed samples.

4.3.9 California Bearing Ratio (CBR)

The CBR test is conducted in accordance with AASHTO T193-93 for the natural soils and soil-plastic strip mixture. The CBR is expressed by the force exerted by the plunger and the depth of its penetration into the specimen; it is aimed at determining the relationship between force and penetration. The CBR values are used to determine the thickness of various layers. As it is evident, the required thickness of construction above a material decreases as the CBR value increases [4].

The CBR test indirectly measures the shearing resistance of a soil under controlled moisture and density conditions. The CBR is obtained as the ratio of load required to affect a certain depth of penetration of a standard penetration piston into a compacted specimen of the soil at some water content and density to the standard load required to obtain the same depth of penetration on a standard sample of crushed stone.

In equation form, this is:

$$CBR = (\text{test load on the sample/ standard load on the crushed stone}) * 100\ \% \qquad (4.5)$$

CBR tests were conducted on the compacted specimens at the optimum moisture content using standard compaction test. The compacted soil samples of the CBR mold are soaked for 96 hours in a water bath to get the soaked CBR value. The one-point CBR test was used for both soaked and unsoaked procedures were used for the stabilized and unstabilized soil specimen. Soil samples were mixed with respective percentage of plastic strip.

CHAPTER 5 LABORATORY TEST RESULTS AND DISCUSSIONS

5.1 General

This chapter presents the results of laboratory tests and discussion of the test results. Soil samples were collected from Gulele at kechene-Ras Desta road. Test pit was excavated at the site at 1m depth and disturbed samples were taken. The moisture content was determined immediately after sampling and transporting it to laboratory by warping with a plastic bag to avoid moisture loss. Disturbed samples were air dried to constant moisture and sieved with different sieve sizes after pulverizing depending on the requirement of specific test procedure.

Different laboratory tests were conducted both for natural and stabilized soil samples separately according to the need. Among these are natural moisture content, specific gravity, Atterberg limits, free swell, particle size analysis, moisture density relationship (compaction) and California bearing ratio (CBR) both soaked and unsoaked CBR tests are conducted.

5.2 Properties of material used for the Study

5.2.1 Natural soil

According to the laboratory test results of the natural soil sample obtained during the present study, as shown in Figure 5-1 on the particle size distribution curve almost 91 % of the soil is passing through No. 200 sieve, liquid limit of 50.49 %, plastic limit of 30.06 % and plasticity index of 20.43 %. Liquid limit less than 30 % indicates low plasticity, between 30 % and 50 % intermediate plasticity, between 50 % and 70 % high plasticity and between 70 % and 90 % very high plasticity [26], Hence, these values indicate that the soil is highly plastic clay. Accordingly, the soil falls under the A-7-5 soil class based on AASHTO soil classification system, CH (INORGANIC CLAYS OF HIGH PLASTICITY) based on USCS soil classification system and Silty Clay based on textural classification system. According to AASHTO classification system soils under this class are generally classified as a material of fair to poor engineering property to be used as a sub-grade material. Results that are related to swelling characteristics of the soil have a free swell of about 40 % this indicate that the soil is not expansive since the value is less than 50 %. The soil has a maximum dry density of 1.4 g/cm3, optimum moisture content of 28.04 %, unsoaked CBR value of 80.3 % and soaked CBR value of 3.5 %.

Hence, the soil was found to be highly plastic clay with low bearing capacity when it is soaked and low swelling potential. Therefore, the soil requires initial modification and/or stabilization to improve its strength and engineering property. The results of the tests conducted for identification and determination of properties of the natural soil before mixed with plastic strip are presented in Table 5-1. Details of the test results are shown in Appendix A.

Table 5-1: Geotechnical properties of the natural soil

Type of test		Test Results
Percentage passing No.200 sieve, %		91.1
Atterberg limits, %	Liquid Limit	50.49
	Plastic Limit	30.06
	Plasticity Index	20.43
Moisture-Density Relation	MDD, g/cc	1.4
	OMC, %	28.04
Specific Gravity		2.75
Free swell (%)		40
CBR (%)	Soaked CBR (%)	3.5
	Unsoaked CBR (%)	80.3
UCS (kPa)	q_u (kPa)	75.01
	c (kPa)	37.5
AASHTO Classification		A-7-5
USCS Classification		CH
Textural Classification		Silty Clay
Color		Red clay

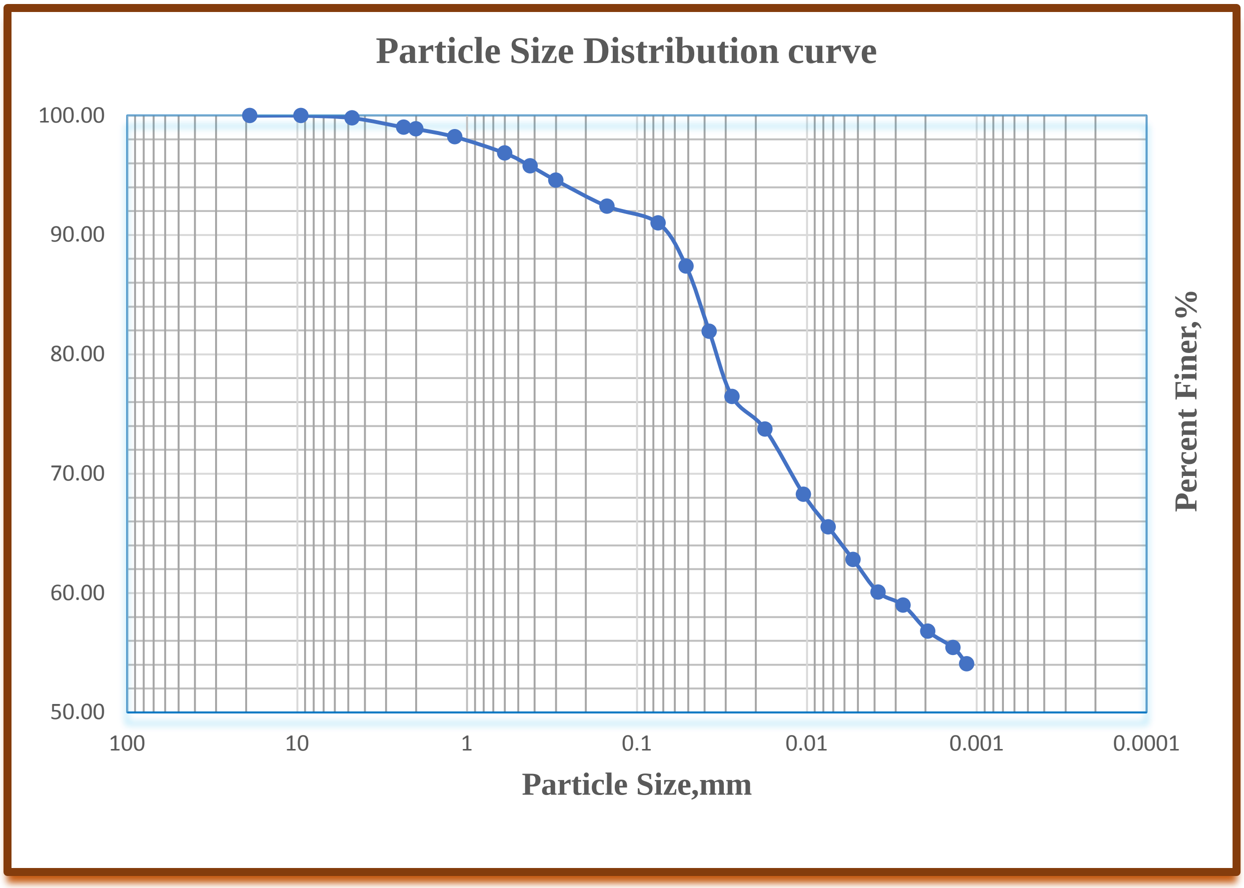


Figure 5-1: Particle size distribution curve of the natural soil

5.3 Laboratory Test Results of red clay soil mixed with plastic strip.

5.3.1 Effect of plastic strip on soil classification

The basis for USCS (Unified Soil Classification System) is Liquid Limit and Plasticity Index of a soil. An “A-line” which is defined by an equation (i.e. 0.73*(LL-20)) separates the ‘MH or OH’ and the ‘CH or OH’ designation. In USCS MH means elastic silt, CH means inorganic clay of high plasticity and OH means organic clay or silt.

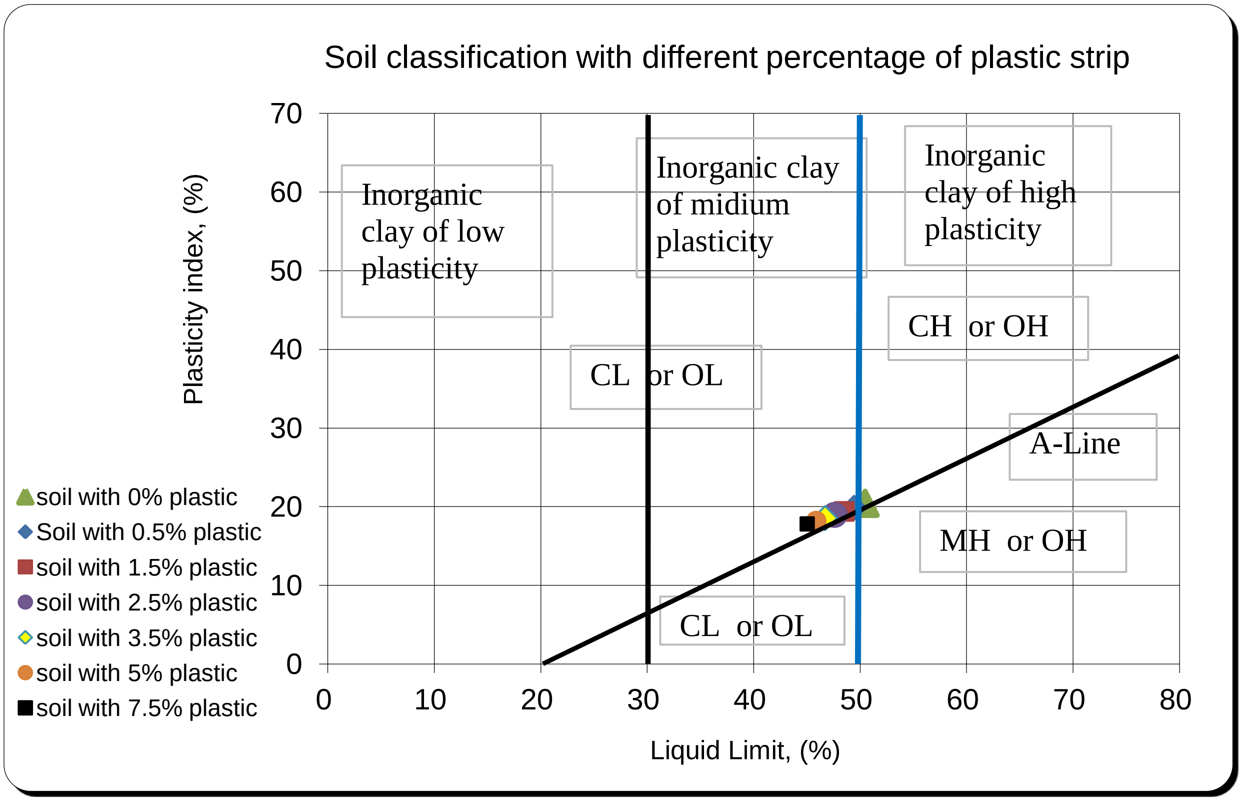


Figure 5-2: Plasticity chart indicating soil with different percentage of plastic strip

As shown in Fig 5-2, the stars indicate where the relation between the soil's plasticity index and liquid limit lies on the graph and above the A line graph for each step of plastic strip increment. The graph shows that plastic strip has slight effect on the plasticity index and liquid limit of the soil but it changes the classification from inorganic clay of highly plasticity (CH) to inorganic clay of medium plasticity (CL).

5.3.2 Effect of plastic strip on Atterberg limits.

Plasticity index (PI) is the difference between Liquid limit (LL) and Plastic limit (PL). Plasticity index is important in classifying fine-grained soils and is fundamental to the Casagrande plasticity chart. The larger the plasticity index, the greater will be the engineering problems associated with using the soil as an engineering material, such as foundation support for residential building and road sub-grades [8]. The effect of plastic strip on the plasticity index of the soil is shown in Figure 5-3. As shown in the figure plasticity index slightly decreased with increment in plastic strip content. The decrease in plasticity index is directly proportional to the quantity of plastic strip.

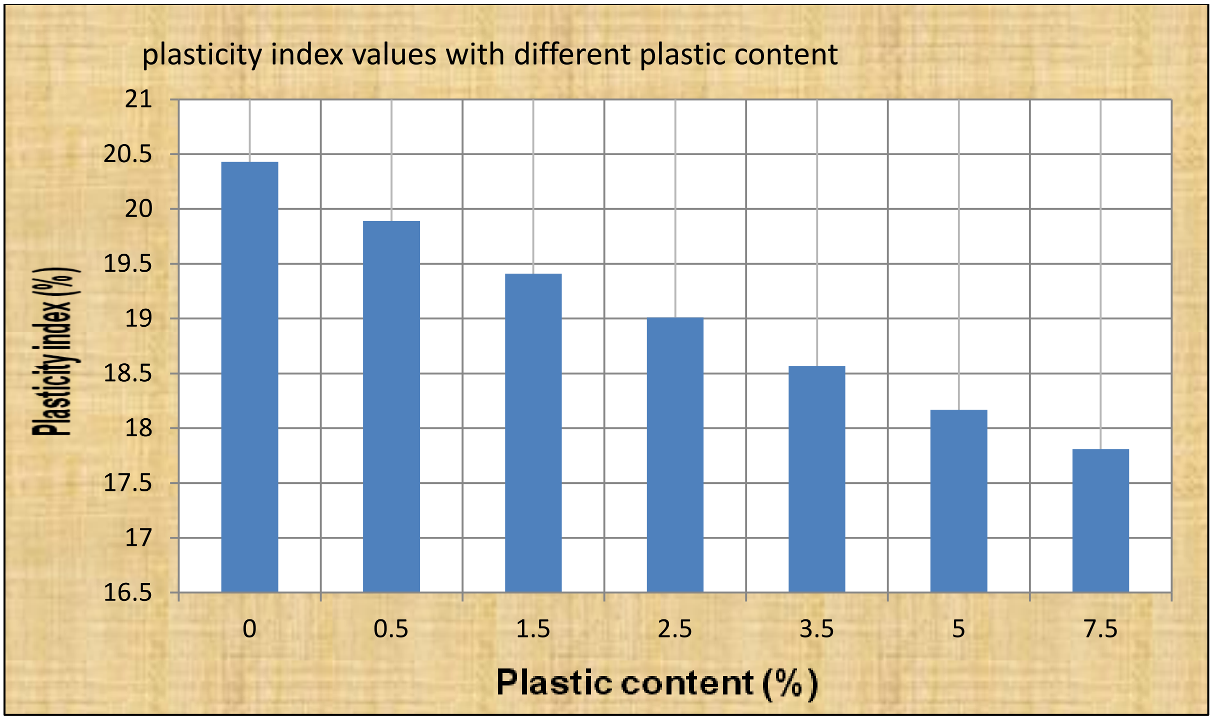


Figure 5-3: Variation of plasticity index with addition of different percentage of plastic strip contents

As one can see from the figure 5-3, the plasticity of the soil is decreased by the addition of plastic strip content. This is clearly shown by the fact that plasticity index of treated soil decreased with increasing plastic strip quantity. These effects are due to the partial replacement of plastic soil particles with plastic strips which is non plastic material and it doesn't absorb water. Details of the Atterberg limit test results are shown in Appendix B.

5.3.3 Effect of waste plastic strip on compaction characteristics

A) Maximum dry density

The effect of plastic strip on the maximum dry density of the red clay soil is shown in Figure 5-4. As one can see from the figure, maximum dry density increases from 1.4 g/cm3 to 1.53 g/cm3 of soil samples with increased plastic strip content from 0 % to 2.5 % beyond that limit the result decreases with the increase in plastic strip content.

The compaction of soil, that is to place it in a dense state, is desirable for three reasons:

(a) to decrease future settlements

(b) to decrease permeability and

(c) to increase shear strength

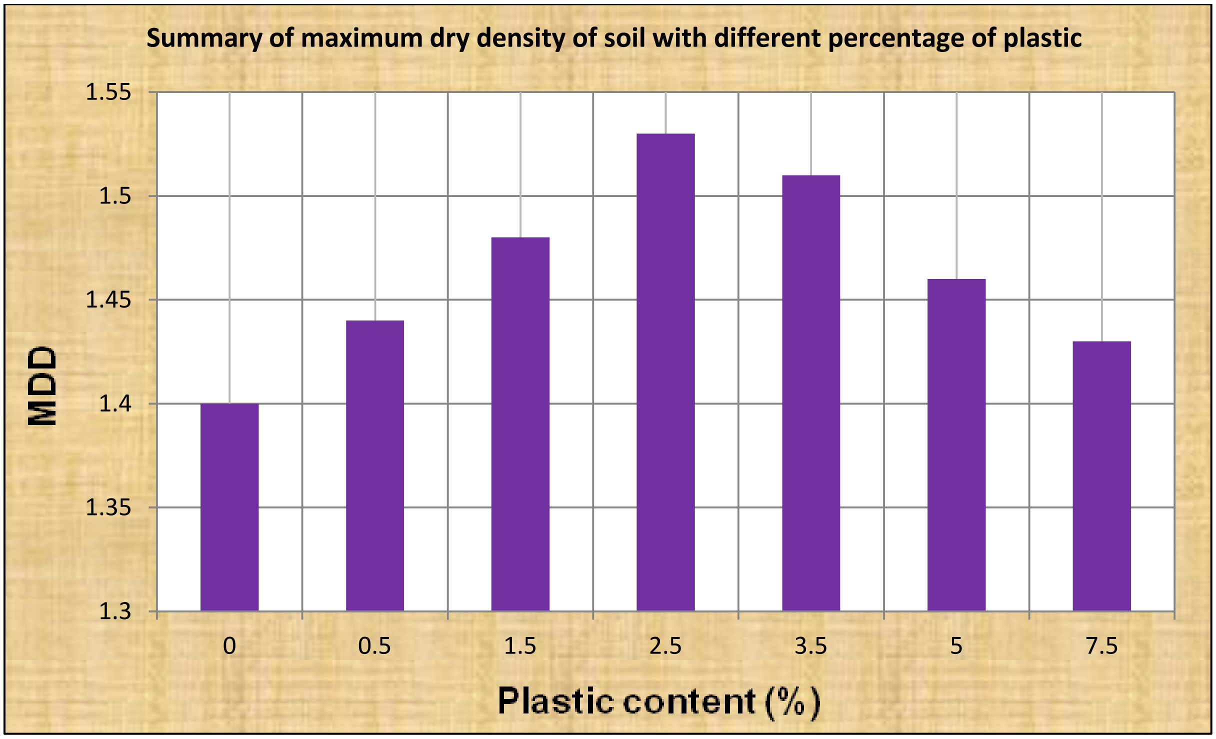


Figure 5-4: Variation of MDD with application of different percentage of plastic strip contents

As it can be seen from the figure 5-4, maximum dry density increase as plastic strip content increase up to 2.5% beyond that it decreases. The increase in the maximum dry density is mainly due to the interlocking between soil and plastic strip, as clay material gets their strength by adhesion, they stick to the plastic material and form bond this decrease the void space between particles this will enhance compaction which in turns reduce the optimum moisture content and increase the Maximum Dry Density. Also, the plastic strips can bend and roll into even smaller shapes under different compactive efforts. This helps in further packing of soil grains with plastic strips together. In this way, compaction test on soil with plastic strips yields increase in maximum dry density and lower optimum moisture content.

The decrease in dry density beyond 2.5% plastic content is due to plastic strip occupying larger spaces, volume of solid fraction of soil does not make a very good bonding with the plastic pieces. This phenomenon is also attributed to the fact that void spaces between soil grains get completely filled up by the plastic strips for higher percent of plastic content. Also, plastic strip is light material as compared to soil leading to corresponding decrease in dry density after further increase in plastic strip content. The soil and plastic grains have a closer packing during compaction up to 2.5% plastic content. If the plastic content is increased further, then soil grains and plastic strips start to segregate even with further compactive efforts as the finer soil grains are replaced by relatively coarser plastic strips. That is why, the soil mixed with plastic strips beyond 2.5% show decrement in maximum dry density during compaction test.

B) Optimum moisture content

The effect of plastic strip on the optimum moisture content for the soil plastic strip mixtures are shown in Figure 5-5. The optimum moisture content decrease with the increase in plastic strip content. The decrease in optimum moisture content is directly proportional to the quantity of plastic strip. The optimum moisture content decreases from 28.04% to 25.96 % of soil samples with increased plastic strip content from 0% to 7.5%.

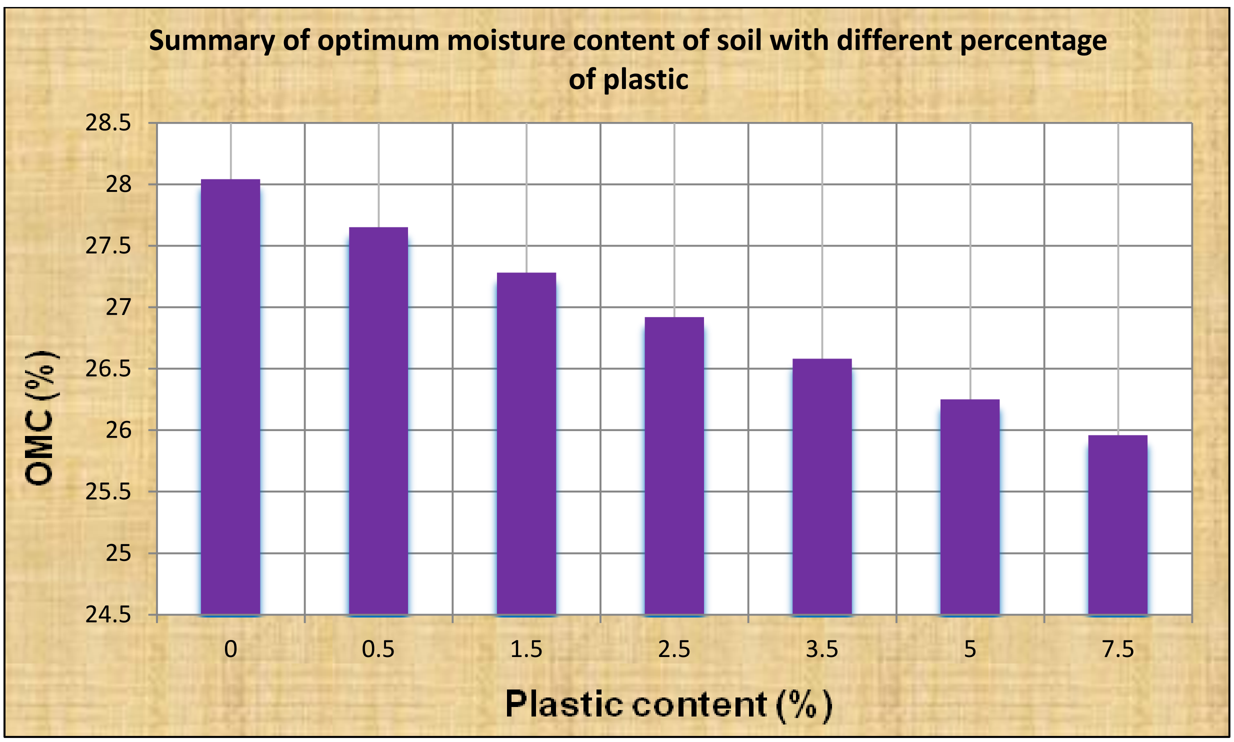


Figure 5-5: Variation of OMC with application of different percentage of plastic strip contents

As one can see from the figure 5-5, the optimum moisture content of soil decreases with an increase plastic strip content, because plastic strip is impermeable material and the plastic pieces does not absorb water. This implies that less water is needed in order to compact the soil with plastic strip mixture. Therefore, soil can be compacted to its maximum dry density at lower addition of water.

So plastic strip effectively decreases optimum moisture content of soil, which is useful during construction in dry area.

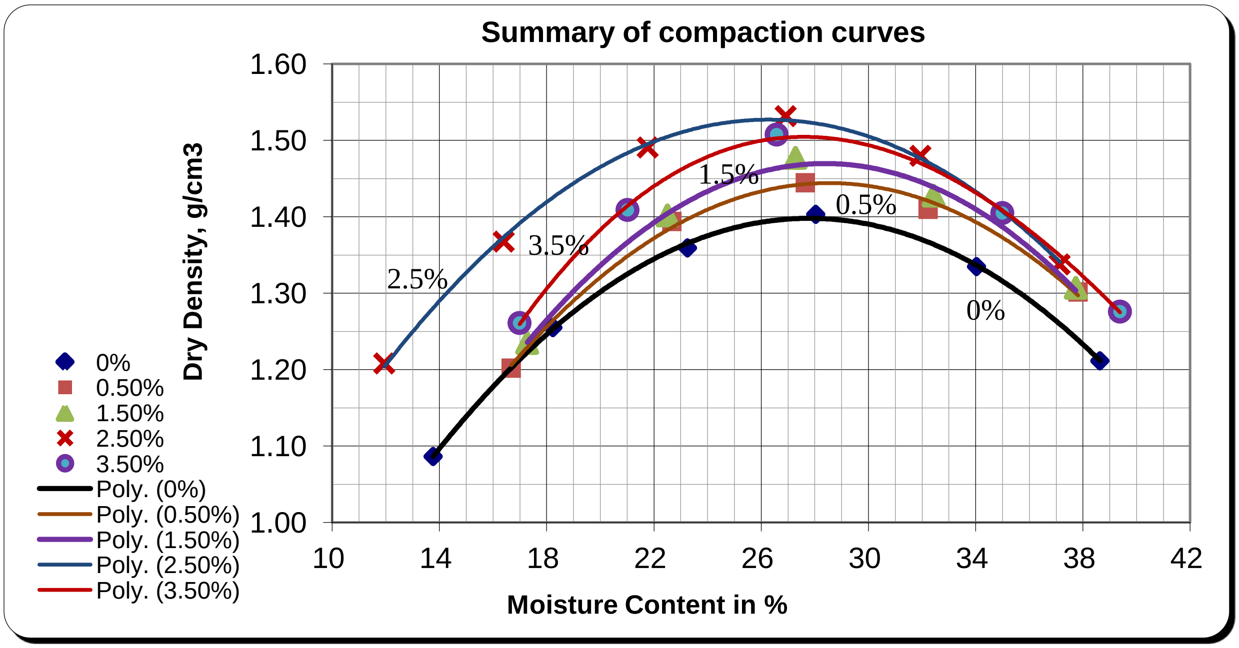


Figure 5-6: Summary of compaction curves with application of different plastic strip contents.

The summaries of compaction curves show in the Figure 5-6, treating soil with plastic strip give the bell shaped compaction curves for soil samples. The curve shifted to the left and upward in the case of treating the soil with plastic strip, which means addition of plastic strip increase the maximum dry density up to 2.5% of plastic strip content and decrease the optimum moisture content up to 7.5% of plastic strip content further addition of plastic strip content also decreases optimum moisture content as it does not absorb water. The increase in maximum dry density and decrease corresponding optimum moisture content of all treated soils is related to the additive quantities. Details of the maximum dry density and optimum moisture content results are shown in the Appendix C.

5.3.4 Effect of waste plastic strip on CBR

A) Soaked CBR

CBR test is used to evaluate the potential strength of sub-grade, sub-base and base-course material. The effect of plastic strip on the CBR values of the soil plastic strip mixtures are shown in Figure 5-7. When treating the soil at 2.5% plastic strip content the soil plastic strip sample gives a soaked CBR value of 5% from a value of 3.5% for the natural soil. The CBR of the soil increased with the increment of plastic strip contents up to 2.5% beyond that the result decreases. This shows that the load bearing capacity of the sample increased with plastic strip treatment. Hence, the plastic strip treated red clay soil meet the minimum criteria as specified by Ethiopian Roads Authority pavement design manual [17] specification for materials suitable for use as sub grade material of not less than 3% CBR determined at MDD and OMC. It also used as fill material as it meets the criteria as specified by Ethiopian Road Authority pavement design manual (2002) specification the fill material shall have a minimum soaked Californian Bearing Ratio (CBR) of not less than 4% when determined in accordance with AASHTO T-193. The plastic strip could be used as stabilizer and reduce the cost of stabilization as it is found everywhere (wastes that is abundantly available).

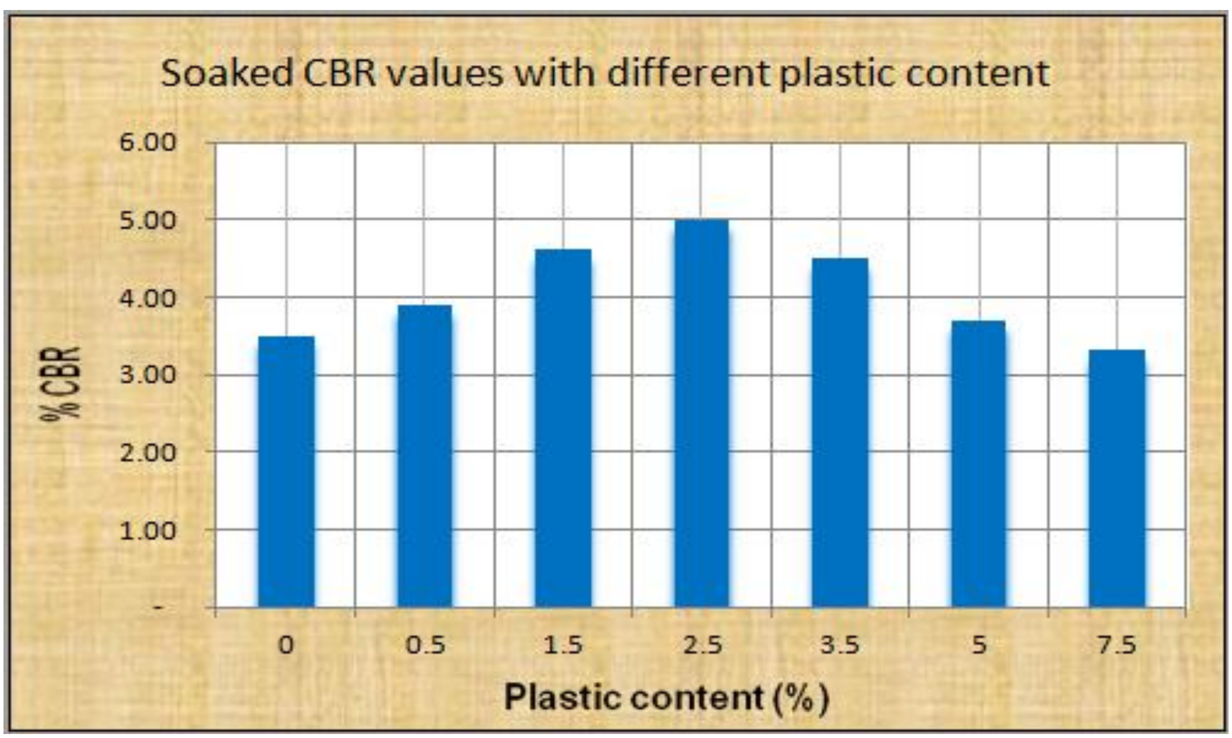


Figure 5-7: Variation of soaked CBR with application of different plastic strip contents.

CBR values can be considered as indirect measure of strength of a soil sample. As one can see from the results, it is evident that waste plastic increases the CBR value with the increment of plastic strip content up to 2.5% beyond that limit the result decreases. There is an increase in CBR value when the soil is incorporated with Plastic strips and compared to that of soil with no plastic. The penetration resistance of soil increases on addition of plastic strips. From this, it can be inferred that, 2.5% plastic content is the optimum content of utilization of plastic strip in the soil.

The result indicates that plastic strip stabilization is effective in improving the strength of soil by increasing the resistance to penetration. The resisting action of the strips can be visualized in Figure 5-8 (a) and (b). In situation (a) the plunger pushes down particle ‘C’ to occupy position in between particle ‘A’ and ‘B’. The strip resists the downward movement of particle ‘C’ until slippage between soil and strip occurs resulting into a development of situation (b). Thus, it is the interaction between soil and strips which causes the resistance to penetration of the plunger resulting into increase in CBR values. Detailed test results are given in Appendix E.

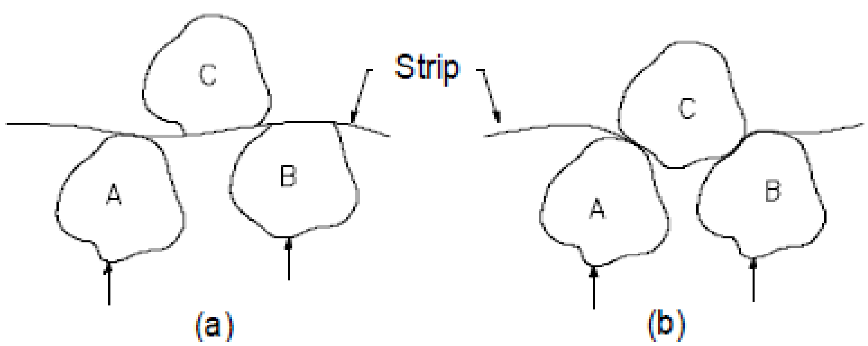


Figure 5-8: Schematic diagram showing position of strip (a) before and (b) after slippage between soil and strip

Further increase in plastic strip beyond 2.5% results in decline of CBR value. Such behavior of soil is probably exhibited, because soil-plastic strip interaction is more slippery than soil-soil interaction. As the numbers of plastic strip in the soil are increased large number of plastic strips may lead to segregation of soil– plastic strip mixes during compaction.

B) UnSoaked CBR

The effect of plastic strip on the unsoaked CBR values of the soil plastic strip mixtures are shown in Figure 5-9. The unsoaked CBR value of soil with plastic strip content increases up to 2.5% plastic strip inclusion in the soil sample gives a peak CBR value of 108.7% from a value of 80.3% for the natural soil. The unsoaked CBR of the soil increased with the increment of plastic strip contents up to 2.5% beyond that it decreases. As it can be observed from the results there is a big difference between soaked and unsoaked CBR values this show that water has significant effect on the strength of soil plastic strip mixture.

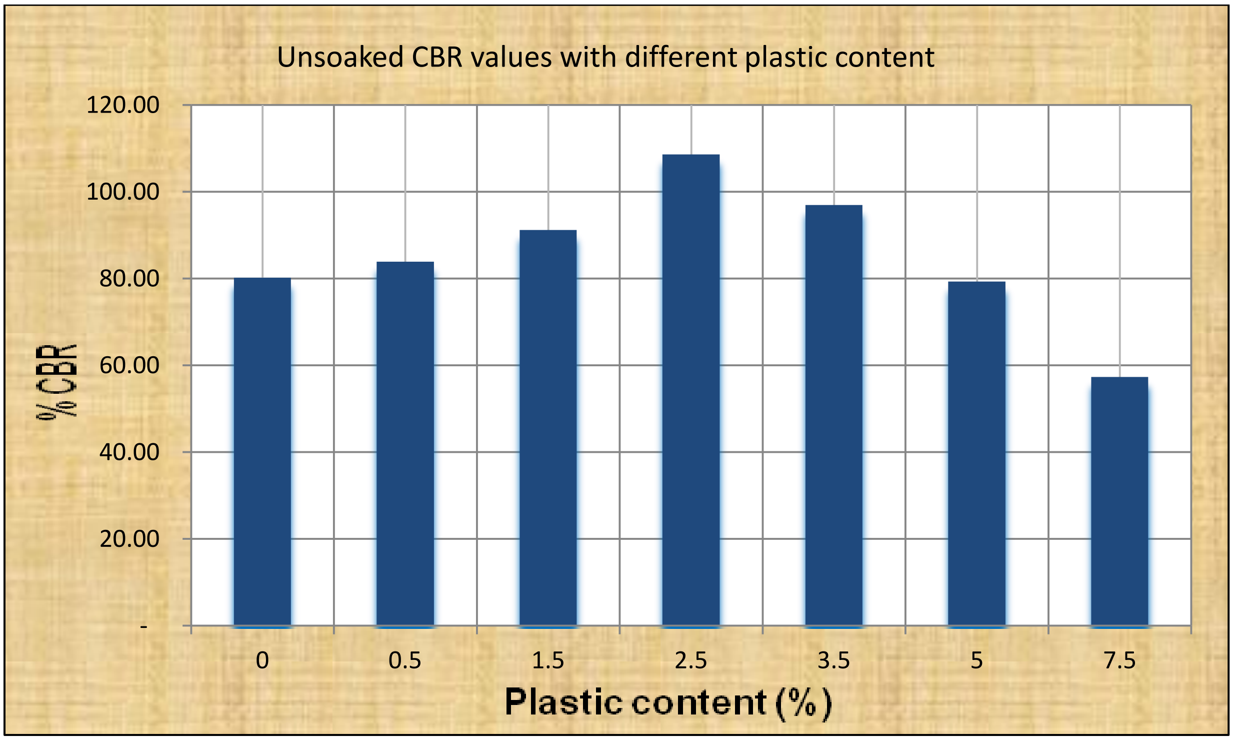


Figure 5-9: Variation of unsoaked CBR with application of different plastic strip contents.

As one can see from the figure 5-9, the unsoaked CBR increases due to the increment of plastic strip content up to 2.5% beyond that limit the result decreases. The 2.5% plastic strip which gave the maximum unsoaked CBR value is taken here as the optimum amount.

Comparatively the unsoaked CBR value was greater than soaked CBR value. The decrease in CBR value for the soaked samples may be due to the effect of the soaking water on the soil plastic strip mix. This is mainly due to the fact that, the absorption of water which weakened the soil and water could still percolate into the interstitial spaces of the soil plastic strip mix thereby weakening the bond between them. Therefore, it is recommended to use plastic strip as stabilizer where the ground water table is found at deeper depth. Detailed test results are given in Appendix F.

5.3.5 Effect of waste plastic strip on Unconfined Compressive Strength (UCS)

The unconfined compression test is a special case of the unconsolidated un-drained triaxial test. In this simple test, a cylindrical cohesive specimen without any lateral support is subjected to axial loading, till the sample falls either due to shear along a diagonal plane or by the lateral bulging. The test is undrained test and is based on the assumption that there is no moisture loss during the test. The UC test is one of the easiest and simplest tests for determining a quick estimate of the shear strength of cohesive soils. The test provides an immediate approximate value of the compressive strength of the soil, either in the undisturbed or the remolded condition. It is also widely used to determine the consistency of saturated clays and other cohesive soils [14].

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. Due to interlocking, particulate material may expand or contract in volume as it is subject to shear strains.

The effect of plastic strip on the unconfined compressive strength of the red clay soil is shown in Figure 5-10. The unconfined compressive strength increases from 75.01 kPa to 196.14 kPa of soil samples with increased plastic strip content from 0% to 5% beyond that limit the result decreases with the increase in plastic strip content.

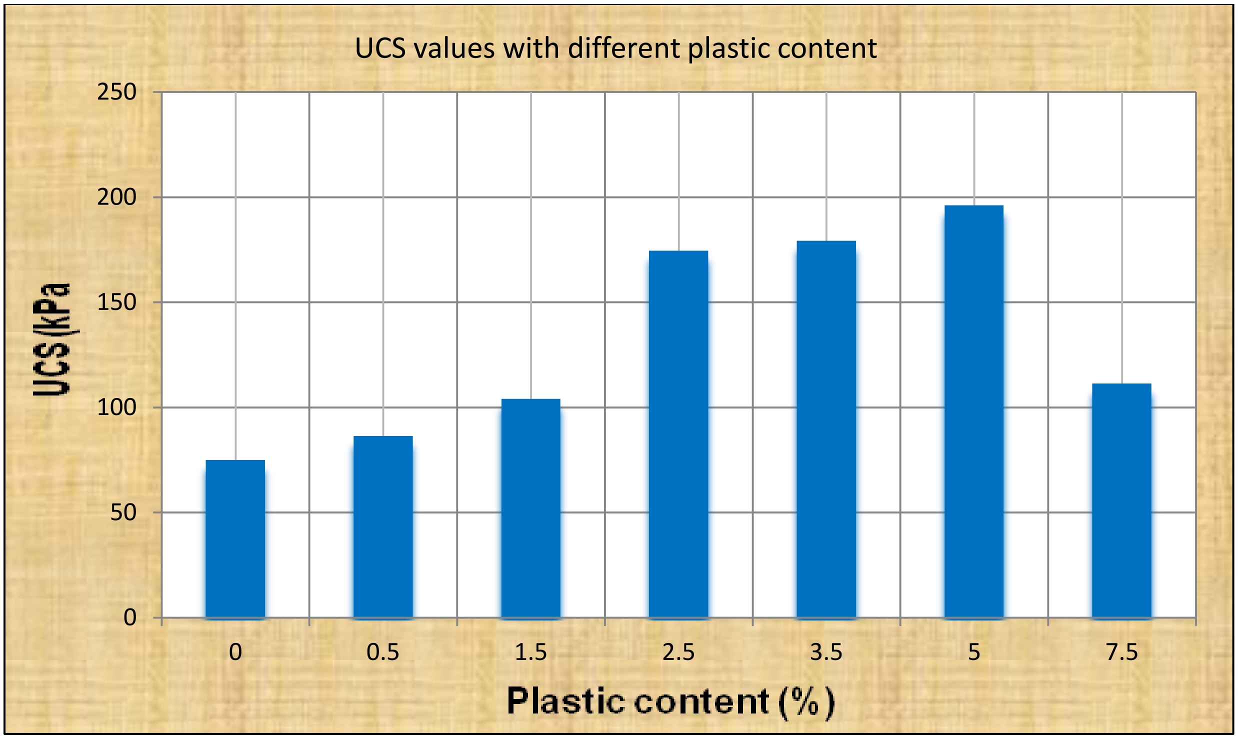


Figure 5-10: Variation of UCS with application of different plastic strip contents.

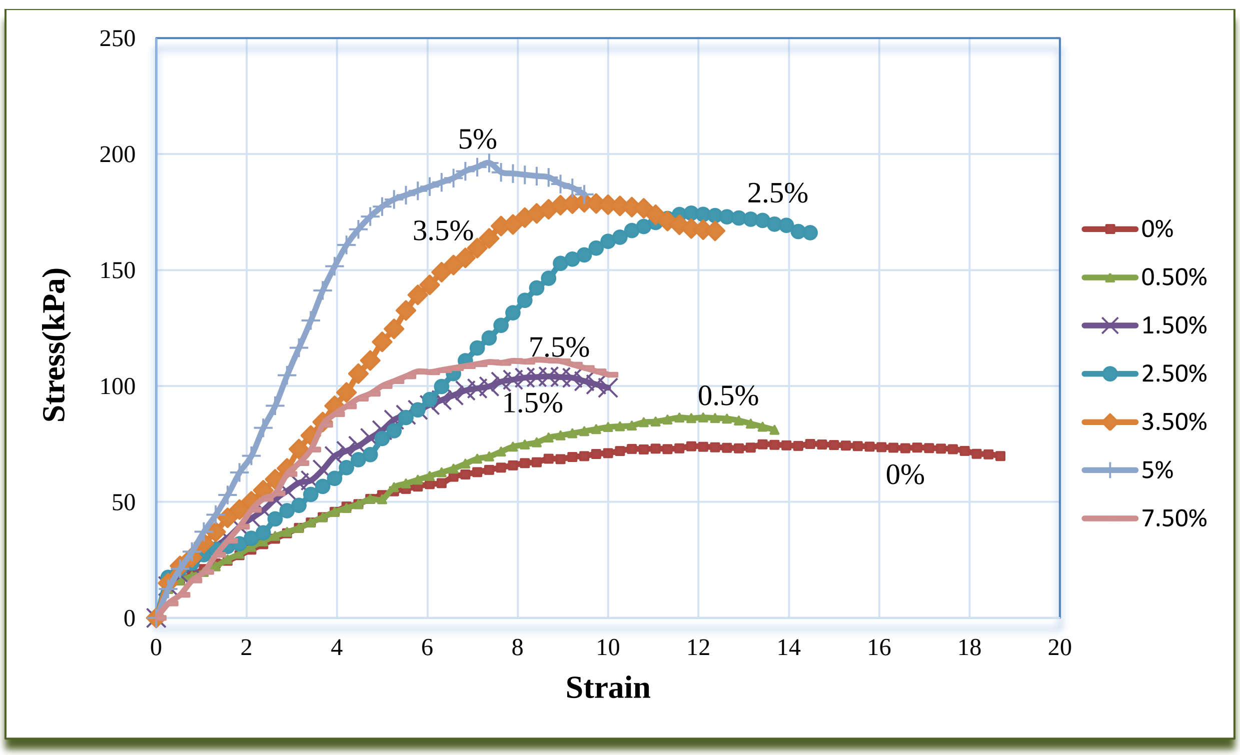


Figure 5-11: Stress relationship with different plastic strip contents

As one can see from figure 5-10, it has been observed that the UCS increased significantly with increase in the plastic strip content up to 5% plastic strip content. This is due to the adhesion between the soil sample and the plastic strip. Thus, the addition of plastics will enhance good cohesion to soil which in turn increases the shear strength of the soil. But further increase in the plastic content leads to decrease in the cohesion and thereby decrease in the strength.

Shear strength increases due to distribution of plastic pieces in different directions along surface. This phenomenon is attributed to the properties of combined soil and plastic mass which may be different from the type of behavior depicted by exclusively soil material during shearing this phenomenon increases the resistance to shearing. With further increase in plastic content, the shear parameter values are observed to show a decreasing trend. Increase in shear strength parameters is achieved because there is increase in frictional surface between soil particles and plastic strips that result in the development of tensile stress in the plastic strips.

Plastic strip also increases shear strength of soil because shear strength of clay related to its consistency and plastic strip decrease liquid limit of soil due to that reason shear strength increase. Shear strength is a property which enables soil to resist sliding along internal surfaces within a mass. It is well known that the shearing strength of cohesive clay varies with its consistency. A clay which is at liquid limit has very little shearing strength, whereas the same clay at lower moisture content may have considerable shearing strength [3].

The reason for the decrease for the unconfined compressive strength of the soil plastic strip mix is due to the fact that the addition of more cohesion less material to the clay soil reduces its natural cohesive force between the particles of clay soil. The other reason for the decrease in shear strength parameter at higher content of plastic strip may be attributed to slippage between the soil particles and the smooth plastic surfaces; this may cause separation of soil particles on addition of plastic strip. Detailed test results are given in Appendix D.

The optimum amount of plastic strip that increase the UCS of soil is 5% but for CBR the optimum amount of plastic strip to be added is 2.5% by weight of soil. This difference in optimum amount of plastic strip is due to different reasons. UCS test measures shear strength of soil and CBR measures the bearing capacity of soil. Plastic strip is used as reinforcement of soil as it is strip. The reinforcements in soil are used to intersect potential failure surfaces in the soil mass, such that strains in the soil mass generate strains in the reinforcements, which in turn, generate tensile loads in the reinforcements. These tensile loads act to restrict soil movements and thus impart additional shear strength. This results in the composite soil-plastic strip mix system having significantly greater shear strength than the soil mass alone. This difference in strengths achieved is mainly due to the difference in mechanism of failure in the soil reinforced with plastic strip material in different forms. The reinforcements are mostly provided in three forms: (i) planer (ii) randomly oriented and (iii) cellular. Horizontal plastic strip layers improve the strength mainly by friction, and interlocking between soil and the reinforcement, whereas the randomly oriented plastic strip improve strength by friction and coiling around soil particles, and the cellular strip layers improve strength by friction and all-round confinement of soil. From this one can see that addition of plastic strip increases the shear strength of soil.

Shear strength increases due to distribution of plastic pieces in different directions along surface of shear. This phenomenon is attributed to the properties of combined soil and plastic strip mass which may be different from the type of behavior depicted by exclusively soil material during shearing. The Increase may also be due to the fact that the interlocking capacity between the particles has been increased. Increase in shear strength parameters is achieved because there is increase in frictional surface between soil particles and plastic pieces where the surface area of plastic pieces is greater than of that of the soil particles that results in the development of tensile stress in the plastic waste.

The optimum amount of plastic strip that gives maximum value of UCS is 5% but for CBR the optimum amount of plastic strip that gives maximum value is 2.5% by weight of soil. The optimum amount of plastic to be added to the soil is decided based on the optimization method. Optimization involves selecting the level of certain activities that compete for scarce resources that are necessary to perform those activities. The choice of activity levels then dictates how much of each resource will be consumed by each activity. However, the one common ingredient in each of these situations is the necessity for allocating resources to activities by choosing the levels of those activities. The optimum value is the value that has intersection between them or the union of the two values that is 2.5%.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

Based on the test results obtained from the investigation of the selected soil treated with plastic strips the following conclusions can be drawn.

- The plasticity index of red clay soil slightly reduced with the addition of plastic strip content in the soil.
- The optimum moisture content decreased with the increase in plastic strip content.
- The maximum dry density values increased with increment of plastic strip content up to 2.5% by weight of the soil. Beyond that limit dry density decreases.
- The addition of plastic strip improved the CBR of the soil. The improvement is more significant at a 2.5% of plastic strip content.
- Based on the difference shown between soaked and unsoaked CBR values, soaking has a reducing effect on the strength of soil stabilized by plastic strip.
- There is an increase in UCS of the soil when the plastic strip is added to the soil in increasing percentage from 0 to 5% plastic strip content. The improvement is more significant at a 5% of plastic strip content. Further increase in the plastic strip showed decrease in the Unconfined Compressive Strength of the soil.
- Plastic strip can be used to stabilize red clay soil as it increases the strength of the soil.
- From this study, the optimum amount of plastic strip content that can be added to the red clay is 2.5% by weight of the soil.
- Plastics strips can be used as alternative stabilization materials in place of conventionally used stabilizing materials.

6.2 Recommendation

Based on the findings of this research, the following recommendations are forwarded

- Further researches need to be conducted with increased number of samples from same areas and additional areas that were not included in this research of Addis Ababa where red clay soil is found and also for other types of soil in order to show the effect of plastic strip on the local soil.
- Large scale test is also needed to determine the boundary effects influence on test results like X-ray diffraction.
- Further tests are needed to quantify the cost reduction due to use of waste plastic bottle strips as stabilizing materials in soil improvement.

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APPENDIX

APPENDIX A: TEST RESULTS OF NATURAL SOIL

Appendix A1: Determination of Natural Moisture Content Determination

Table A-1: Natural Moisture Content of natural soil

Test type	Natural Moisture Content		
Project	Msc Thesis		
Sample source	Kechene-Rasdesta Road		
Material	Red Clay Soil		
Depth, m	1m		
Specimen no.	1	2	3
Moisture can number	C4	C6	C8
Mc =Mass of empty , clean can(grams)	15.2	15.5	10.8
Mcms=Mass of can, moist soil(gram)	65.3	74.8	67.1
Mcds=mass of can, dry soil(grams)	54.5	61.9	54.9
Ms=mass of soils (grams)	39.3	46.4	44.1
Mw=mass of pore water(grams)	10.8	12.9	12.2
w=water content, w%	27%	28%	28%
Average Water Content (%)	27.65%		

Appendix A2: Determination of specific gravity

Table A-2: Specific gravity of natural soil

Test type	Specific Gravity		
Sample source	Kechene-Rasdesta Road		
Material	Red Clay Soil		
Sample date	13/03/19		
Test date	12/4/2019		
Trial	**A**	**B**	
Pycnometer #	1	2	
A. Mass of Pycnometer (empty, clean)	58	58	
B. Mass of empty pycno + Dry soil	83	83	
C. Mass of Dry Soil (No. 10 sieve)	25	25	
D. Mass of Pyknometer full of water	158.4	158.3	
E. Mass of pycno + Soil +full of water (boiled)	174.3	174.2	
F. Specific Gravity=C/(C+(D-E))	2.75	2.75	
Average Specific Gravity ((1+2)/2)	2.75		At 21°C temperature

Corrected Average Specific Gravity =2.75*0.9998 =2.74945

Appendix A3: Determination of Sieve Analysis (wet preparation method)

Table A-3: Sieve Analysis of natural soil

Test type		Sieve analysis			Depth		1m	
Weight of Dry Sample (g)		500.0			Material		Red Clay Soil	
Sieve Number	**Diameter (mm)**	**Mass of Empty Sieve (g)**	**Mass of Sieve & Soil (g)**	**Soil Retained (g)**	**Soil Retained (%)**	**Soil Passing (%)**	**Cumulative percent retained**	**Percent Passing**
3/4 in	19	443.50	443.50	0.00	0.00	100.00	0.0	100.00
1 1/2 in	9.5	454.30	454.30	0.00	0.00	100.00	0.00	100.00
4	4.75	431.50	432.48	0.98	0.20	99.80	0.20	99.80
8	2.36	387.30	391.20	3.90	0.78	99.02	0.98	99.02
10	2	377.60	378.30	0.70	0.14	98.88	1.12	98.88
16	1.18	372.00	375.30	3.30	0.66	98.22	1.78	98.22
30	0.6	324.20	331.00	6.80	1.36	96.86	3.14	96.86
40	0.425	295.20	300.60	5.40	1.08	95.78	4.22	95.78
50	0.3	302.70	308.70	6.00	1.20	94.58	5.42	94.58
100	0.15	282.70	293.60	10.90	2.18	92.40	7.60	92.40
200	0.075	294.40	301.40	7.00	1.40	91.00	9.00	91.00
Pan		240.30	240.30	0.00	0.00	0.00		
			TOTAL:	**44.98**	**9.0**			

Appendix A4: Determination of Hydrometer analysis

Table A-4: Hydrometer analysis of natural soil

Test type		Hydrometer analysis			Weight of Sample (g)		50.0	
GS		2.75			Material		Red Clay Soil	
T (min)	Temp (°C)	Ra	L Table 2, D422	Dynamic Viscosity of water	Diameter, D(mm)	Reading in control cylinder	Percent finer, %	Adjusted Percent Finer
0.5	19	1.0340	7.3	0.010340	0.051362221	1.0020	96.03	87.39
1	19	1.0320	7.8	0.010340	0.037541764	1.0020	90.02	81.93
2	19	1.0300	8.4	0.010340	0.027548123	1.0020	84.02	76.46
5	19	1.0290	8.6	0.010340	0.017629159	1.0020	81.02	73.73
15	19.5	1.0270	9.2	0.010215	0.010463442	1.0020	75.02	68.27
30	19.5	1.0260	9.4	0.010215	0.00747876	1.0020	72.02	65.54
60	20	1.0250	9.7	0.010090	0.0053390	1.0020	69.02	62.81
120	21	1.0235	10.1	0.009840	0.0038043	1.0015	66.02	60.08
240	21	1.0228	10.26	0.009840	0.00271127	1.0012	64.82	58.99
480	21	1.0220	10.5	0.009840	0.00193945	1.0012	62.42	56.80
960	21	1.0215	10.6	0.009840	0.001377914	1.0012	60.92	55.44
1440	20	1.0210	10.7	0.010090	0.001144625	1.0012	59.42	54.07

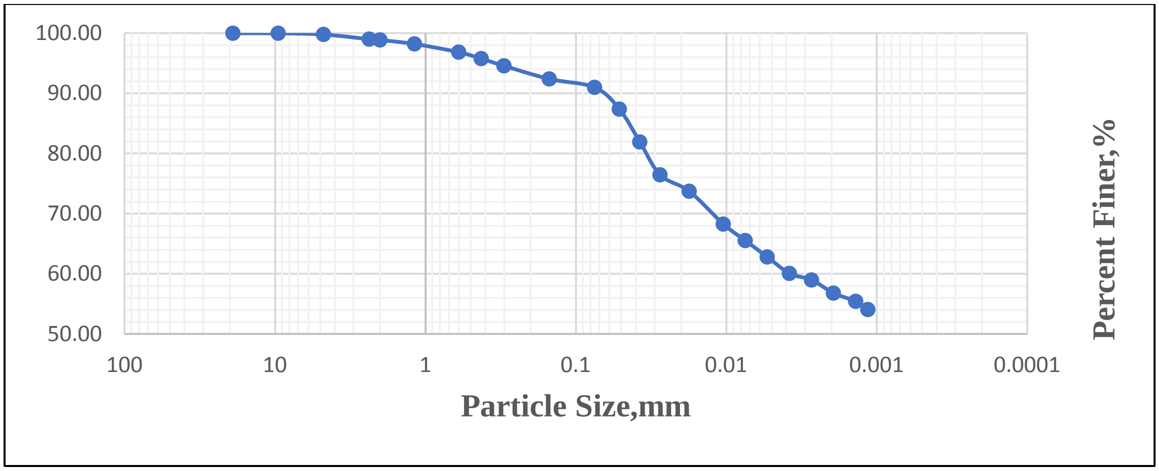


Figure A-1: Combined particle size distribution curve for natural soil

Appendix A5: Determination of free swell

Table A-5: Determination of free swell for natural soil

Test type		Free swell	Sample date	13/03/19	
Material		Red Clay Soil	Test date	1/4/2019	
Sample Depth (m)	Cylinder #	Initial volume of sample in the cylinder (CC)	Final volume of sample in the cylinder (after 24hr) (CC)	Difference in Height	% Swell
1	1	10	14	4	40%

Appendix A6: Determination of Atterberg Limits

Table A-6: Atterberg Limits of natural Soil

Test type	Atterberg limit		Sample date		13/03/19	
Material	Red Clay Soil		Test date		18/03/19	
Sample of	Soil with 0% Stabilizer		Depth		1m	
	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	16	20	26	33		
Wt. of wet Soil+can ,(g)	54.10	48.20	42.70	34.50	24.20	25.2
Wt.of dry + can ,(g)	45.50	37.00	33.60	26.80	22.17	22.98
Wt. of water ,(g)	8.60	11.20	9.10	7.70	2.03	2.22
Wt. of can , (g)	29.10	15.20	15.50	11.20	15.50	15.5
Wt. of dry soil ,(g)	16.40	21.80	18.10	15.60	6.67	7.48
Moisture content (%)	52.44	51.38	50.28	49.36	30.43	29.68
	Average PL (%) =				**30.06**	

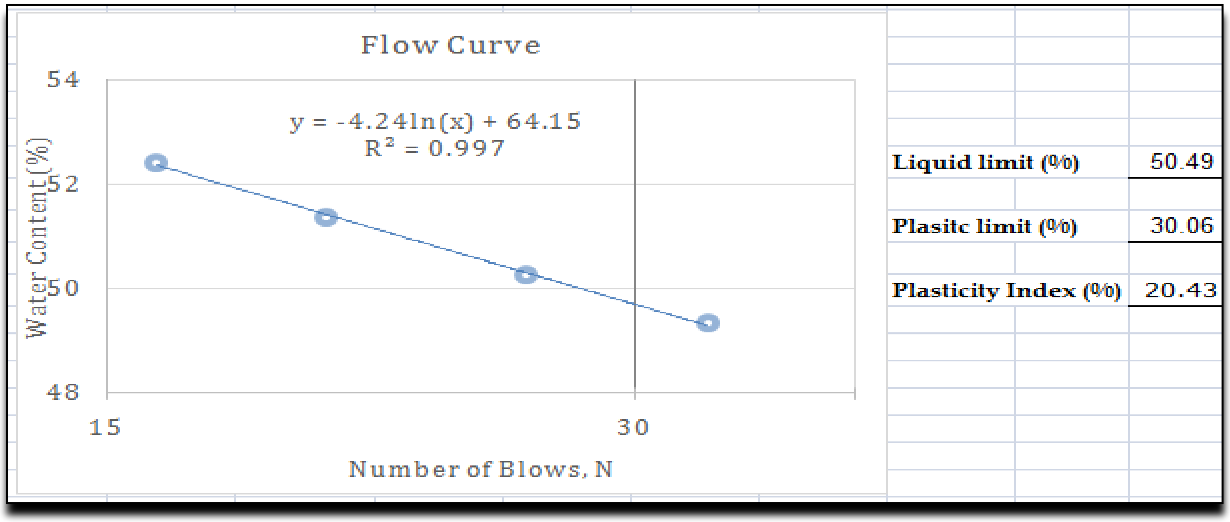


Figure A-2: Flow curve for natural Soil

Appendix A7: Determination of Moisture Density Relationship

Table A-7: Moisture-Density relations of natural Soils

A	Mold	No.	1		2		3		4		5		6	
B	Wt. of Mold + Wet Soil	grams	5796		6029		6209		6323		6316		6213	
C	Wt. of Mold	grams	4634		4634		4634		4634		4634		4634	
D	Wt. Wet Soil	grams	1162		1395		1575		1689		1682		1579	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.24		1.48		1.68		1.80		1.79		1.68	
G	Compacted Soil - Sample	No.	1		2		3		4		5		6	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B
I	Container	No.	1	2	3	4	5	6	7	8	9	10	11	12
J	Weight of Container	grams	15.50	15.80	15.40	15.60	29.10	10.80	142.10	115.10	15.80	15.80	15.70	14.40
K	Wt. Cont + Wet soil	grams	59.70	62.20	63.00	70.50	81.10	64.80	192.80	167.60	69.10	81.40	93.30	121.20
L	Wt. Cont + Dry soil	grams	53.79	57.19	55.60	62.10	71.30	54.60	181.70	156.10	55.60	64.70	71.70	91.40
M	Weight of Dry Soil	grams	38.29	41.39	40.20	46.50	42.20	43.80	39.60	41.00	39.80	48.90	56.00	77.00
N	Weight of Water	grams	5.91	5.01	7.40	8.40	9.80	10.20	11.10	11.50	13.50	16.70	21.60	29.80
O	Moisture Content	%	15.43	12.10	18.41	18.06	23.22	23.29	28.03	28.05	33.92	34.15	38.57	38.70
P	Moisture Content	%	13.77	18.24	23.26	28.04	34.04	38.64						
Q	Dry Density	gr/cu.cm.	1.09	1.26	1.36	1.40	1.34	1.21						

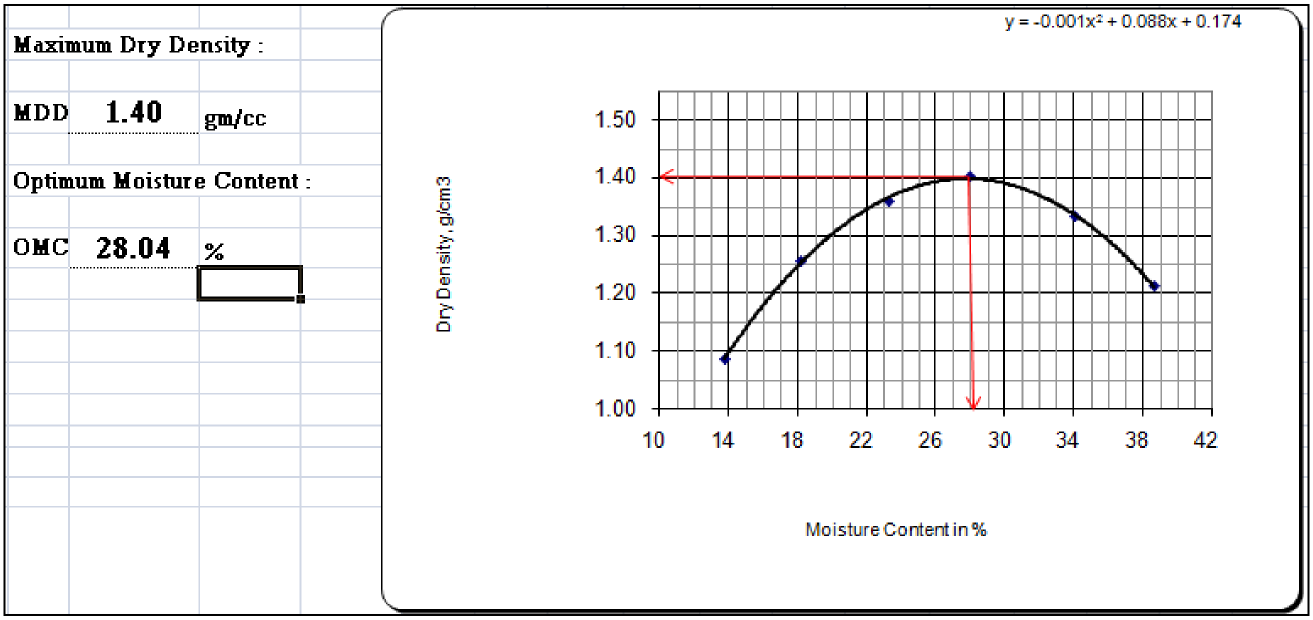


Figure A -3: Moisture-Dry Density curve for natural soil

Appendix A8: Determination of Unconfined Compressive Strength (UCS)

Table A -8: Unconfined Compressive Strength value of natural Soils

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Natural soil			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		20/06/19
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0	0.000
20	0.2	0.00263	0.0011363	10	0.0142	12.496
40	0.4	0.00526	0.0011394	13	0.01846	16.202
60	0.6	0.00789	0.0011424	15	0.0213	18.645
80	0.8	0.01053	0.0011454	17	0.02414	21.075
100	1	0.01316	0.0011485	19	0.02698	23.492
120	1.2	0.01579	0.0011515	20	0.0284	24.663
140	1.4	0.01842	0.0011546	22	0.03124	27.056
160	1.6	0.02105	0.0011577	24	0.03408	29.437
180	1.8	0.02368	0.0011608	26	0.03692	31.804
200	2	0.02632	0.0011640	28	0.03976	34.159
220	2.2	0.02895	0.0011671	30	0.0426	36.499

240	2.4	0.03158	0.0011703	32	0.04544	38.827
260	2.6	0.03421	0.0011735	34	0.04828	41.142
280	2.8	0.03684	0.0011767	36	0.05112	43.443
300	3	0.03947	0.0011799	38	0.05396	45.732
320	3.2	0.04211	0.0011832	40	0.0568	48.007
340	3.4	0.04474	0.0011864	41	0.05822	49.072
360	3.6	0.04737	0.0011897	43	0.06106	51.323
380	3.8	0.05000	0.0011930	44.5	0.06319	52.967
400	4	0.05263	0.0011963	46	0.06532	54.601
420	4.2	0.055263	0.0011997	47	0.06674	55.633
440	4.4	0.05789	0.0012030	48	0.06816	56.658
460	4.6	0.06053	0.0012064	49	0.06958	57.677
480	4.8	0.06316	0.0012098	49.5	0.07029	58.102
500	5	0.06579	0.0012132	52	0.07384	60.865
520	5.2	0.06842	0.0012166	53	0.07526	61.861
540	5.4	0.07105	0.0012200	54	0.07668	62.850
560	5.6	0.07368	0.0012235	55	0.0781	63.833
580	5.8	0.07632	0.0012270	56	0.07952	64.809
600	6	0.07895	0.0012305	57	0.08094	65.778
620	6.2	0.08158	0.0012340	58	0.08236	66.741
640	6.4	0.08421	0.0012376	58.5	0.08307	67.123
660	6.6	0.08684	0.0012411	60	0.0852	68.647
680	6.8	0.08947	0.0012447	60	0.0852	68.449
700	7	0.09211	0.0012483	61	0.08662	69.389
720	7.2	0.09474	0.0012520	61.5	0.08733	69.755
740	7.4	0.09737	0.0012556	62.5	0.08875	70.683
760	7.6	0.10000	0.0012593	63	0.08946	71.040
780	7.8	0.10263	0.0012630	64	0.09088	71.957
800	8	0.10526	0.0012667	65	0.0923	72.867
820	8.2	0.10789	0.0012704	65	0.0923	72.653
840	8.4	0.11053	0.0012742	65.5	0.09301	72.996
860	8.6	0.11316	0.0012780	65.5	0.09301	72.780
880	8.8	0.11579	0.0012818	66	0.09372	73.118
900	9	0.11842	0.0012856	67	0.09514	74.005
920	9.2	0.12105	0.0012894	67	0.09514	73.784
940	9.4	0.12368	0.0012933	67	0.09514	73.563
960	9.6	0.12632	0.0012972	67	0.09514	73.342
980	9.8	0.12895	0.0013011	67	0.09514	73.121
1000	10	0.13158	0.0013051	67.5	0.09585	73.444

1020	10.2	0.13421	0.0013090	69	0.09798	74.849
1040	10.4	0.13684	0.0013130	69	0.09798	74.621
1060	10.6	0.13947	0.0013170	69	0.09798	74.394
1080	10.8	0.14211	0.0013211	69	0.09798	74.166
1100	11	0.14474	0.0013252	70	0.0994	75.010
1120	11.2	0.14737	0.0013292	70	0.0994	74.779
1140	11.4	0.15000	0.0013334	70	0.0994	74.549
1160	11.6	0.15263	0.0013375	70	0.0994	74.318
1180	11.8	0.15526	0.0013417	70	0.0994	74.087
1200	12	0.15789	0.0013459	70	0.0994	73.856
1220	12.2	0.16053	0.0013501	70	0.0994	73.625
1240	12.4	0.16316	0.0013543	70	0.0994	73.395
1260	12.6	0.16579	0.0013586	70	0.0994	73.164
1280	12.8	0.16842	0.0013629	70.5	0.10011	73.454
1300	13	0.17105	0.0013672	70.5	0.10011	73.222
1320	13.2	0.17368	0.0013716	70.5	0.10011	72.989
1340	13.4	0.17632	0.0013760	70.5	0.10011	72.757
1360	13.6	0.17895	0.0013804	70	0.0994	72.010
1380	13.8	0.18158	0.0013848	69	0.09798	70.754
1400	14	0.18421	0.0013893	69	0.09798	70.526
1420	14.2	0.18684	0.0013938	68.5	0.09727	69.789

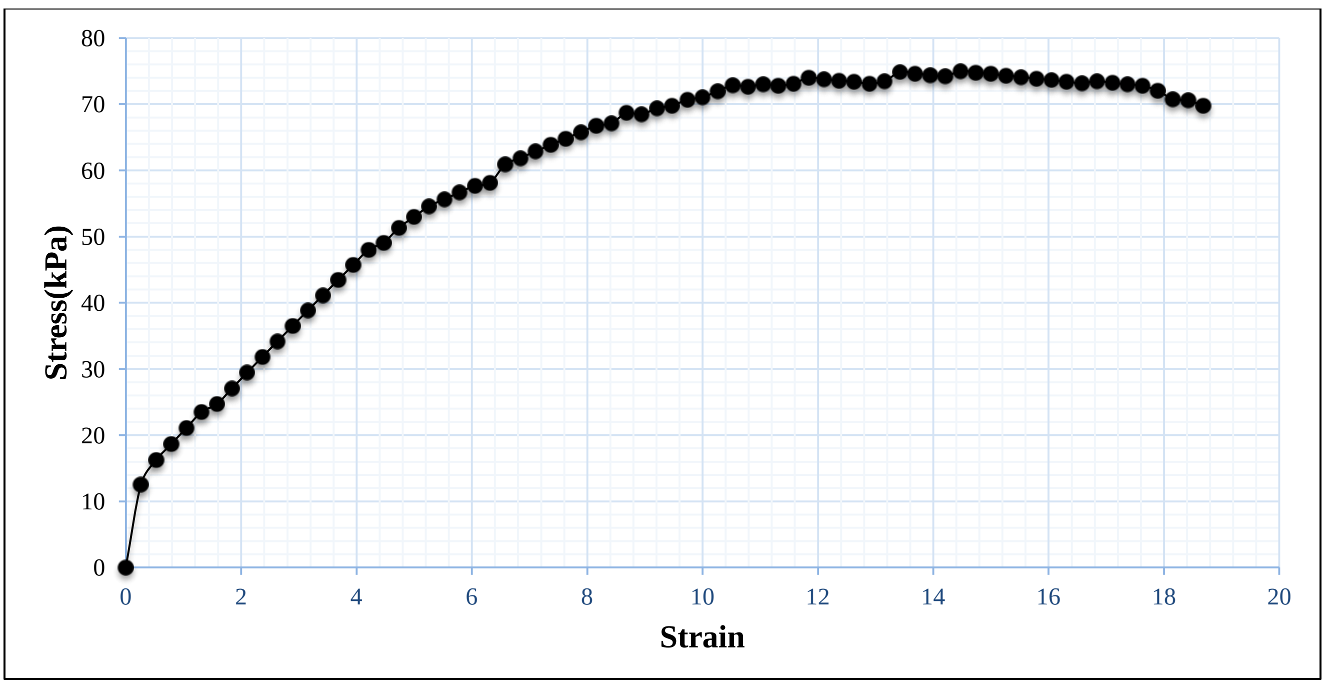


Figure A -4: Unconfined Compressive Strength curve for natural soil

Appendix A9: Determination of California Bearing Ratio (CBR) (Soaked)

Table A-9: Penetration Test result of natural soil (Soaked CBR)

CBR Data for natural soil (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		5	0.12		
1.27		11	0.27		
1.91		15	0.36		
2.54	13	19	0.46	0.46	**3.5**
5.08	20	27	0.65	0.65	**3.3**
6.35		30	0.72		
7.62		32	0.77		

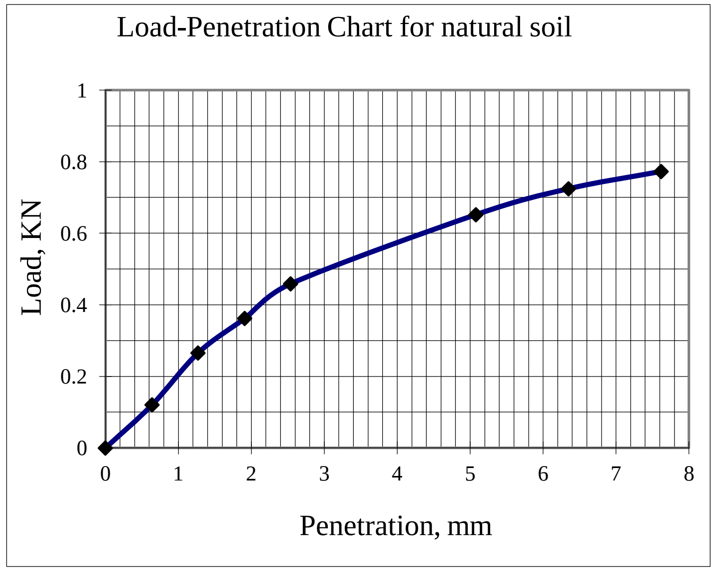


Figure A-5: Load-penetration curves of natural soil (Soaked CBR)

Appendix A10: Determination of California Bearing Ratio (CBR) (Unsoaked)

Table A-10: Penetration Test result of natural soil (Unsoaked CBR)

Unsoaked CBR Data for natural soil (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		131	3.16		
1.27		282	6.81		
1.91		373	9.01		
2.54	13	432	10.43	10.43	**80.3**
5.08	20	544	13.14	13.14	**65.7**
6.35		568	13.72		
7.62		584	14.10		

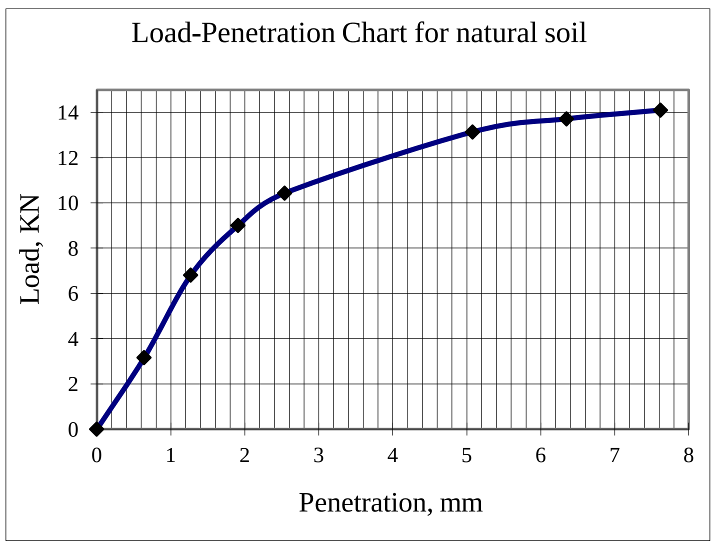


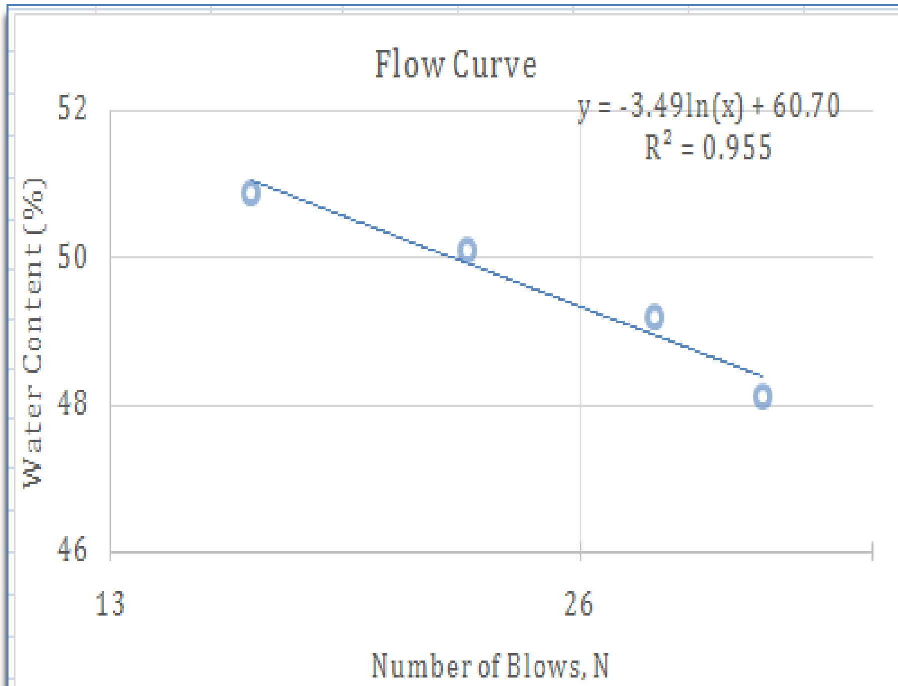
Figure A-6: Load-penetration curves of natural soil (Unsoaked CBR)

APPENDIX B: ATTERBERG LIMITS WITH VARYING PERCENTAGE OF PLASTIC STRIPS.

Appendix B1: Determination of Atterberg Limits of Soil with 0.5% plastic strips

Table B-1: Atterberg Limits of Soil with 0.5% plastic strips

0.5% plastic strip						
Description	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	16	22	29	34		
Wt. of wet Soil+can , (g)	50.21	43.37	37.56	42.01	28.52	26.34
Wt.of dry + can ,(g)	38.63	34.22	30.34	33.52	25.53	23.87
Wt. of water ,(g)	11.58	9.15	7.22	8.49	2.99	2.48
Wt. of can , (g)	15.87	15.94	15.67	15.88	15.42	15.50
Wt. of dry soil ,(g)	22.76	18.28	14.67	17.64	10.11	8.37
Moisture content (%)	50.88	50.09	49.21	48.13	29.57	29.59
	Average PL (%) =				29.58	



Liquid limit (%)	49.47
Plasitc limit (%)	29.58
Plasticity Index (%)	19.89

Figure B -1: Flow curve for Soil with 0.5% plastic strip

Appendix B2: Determination of Atterberg Limits of Soil with 1.5% plastic strips

Table B-2: Atterberg Limits of Soil with 1.5% plastic strip

1.5% plastic strip						
Description	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	17	21	28	35		
Wt. of wet Soil+can , (g)	43.29	45.37	47.67	41.85	23.82	22.73
Wt.of dry + can , (g)	34.05	35.56	37.34	33.46	21.98	21.15
Wt. of water , (g)	9.24	9.81	10.33	8.39	1.84	1.58
Wt. of can , (g)	15.85	15.60	15.85	15.50	15.71	15.67
Wt. of dry soil , (g)	18.20	19.96	21.49	17.96	6.27	5.48
Moisture content (%)	50.77	49.15	48.07	46.71	29.35	28.93
	Average PL (%) =				29.14	

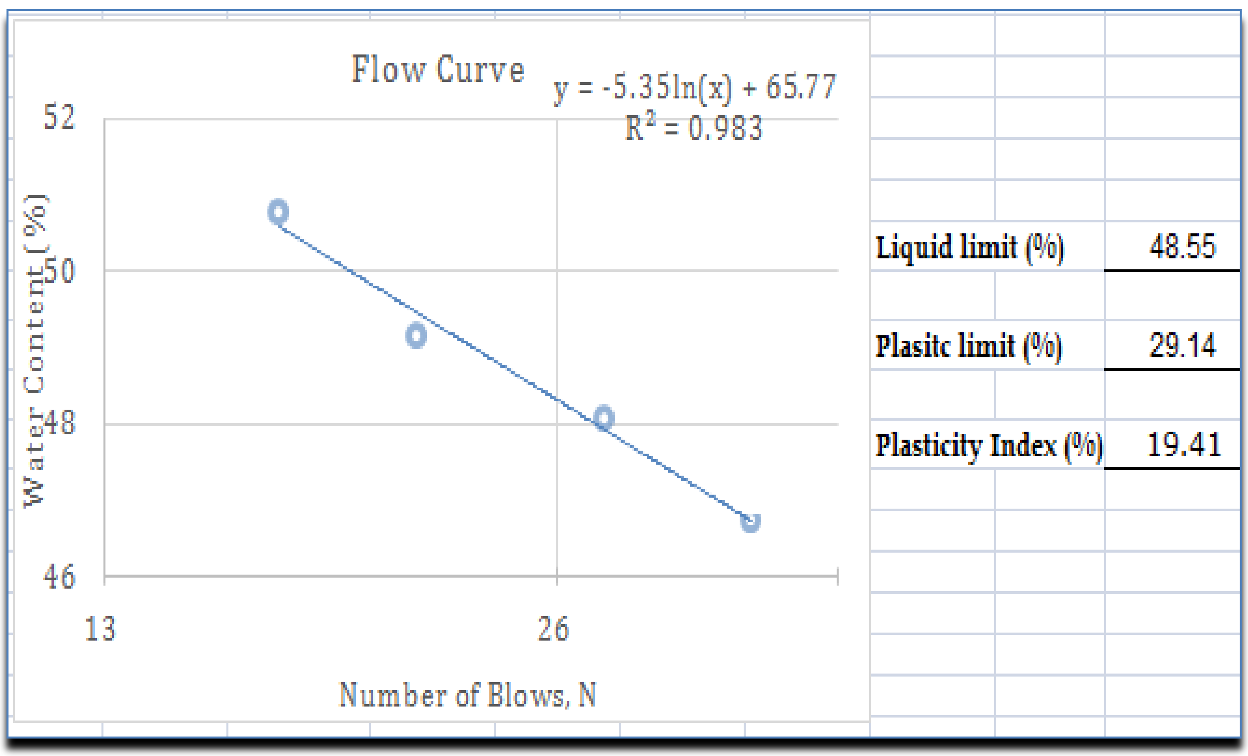
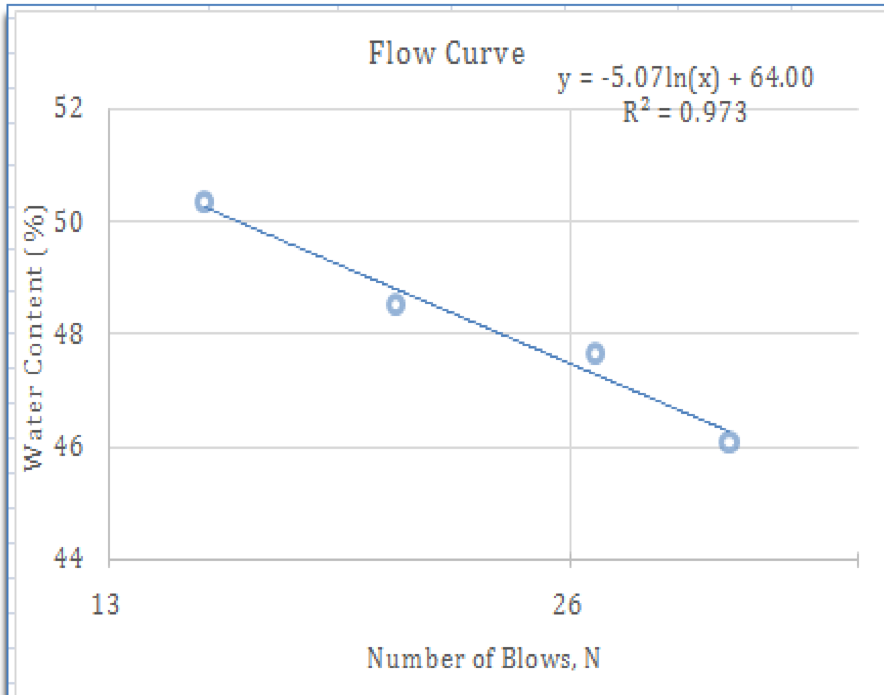


Figure B -2: Flow curve for Soil with 1.5% plastic strips

Appendix B3: Determination of Atterberg Limits of Soil with 2.5% plastic strips

Table B -3: Atterberg Limits of Soil with 2.5% plastic strip

2.5% plastic strip						
Description	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	15	20	27	33		
Wt. of wet Soil+can , (g)	37.42	35.53	32.63	30.75	24.82	27.31
Wt.of dry + can , (g)	29.98	29.02	27.20	26.05	22.79	24.72
Wt. of water , (g)	7.44	6.51	5.43	4.70	2.03	2.59
Wt. of can , (g)	15.20	15.60	15.80	15.85	15.67	15.74
Wt. of dry soil ,(g)	14.78	13.42	11.40	10.20	7.12	8.98
Moisture content (%)	50.34	48.51	47.63	46.08	28.51	28.83
	Average PL (%) =				28.67	



Liquid limit (%)	47.68
Plasitc limit (%)	28.67
Plasticity Index (%)	19.01

Figure B-3: Flow curve for Soil with 2.5% plastic strip

Appendix B4: Determination of Atterberg Limits of Soil with 3.5% plastic strips

Table B -4: Atterberg Limits of Soil with 3.5% plastic strip

3.5% plastic strip						
Description	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	17	22	29	35		
Wt. of wet Soil+can , (g)	43.36	54.04	50.62	47.17	24.53	21.71
Wt.of dry + can , (g)	34.27	41.80	39.12	37.32	22.58	20.42
Wt. of water , (g)	9.09	12.24	11.50	9.85	1.95	1.29
Wt. of can , (g)	15.50	15.85	14.30	15.50	15.60	15.87
Wt. of dry soil ,(g)	18.77	25.95	24.82	21.82	6.98	4.55
Moisture content (%)	48.42	47.17	46.33	45.14	27.97	28.37
	Average PL (%) =				28.17	

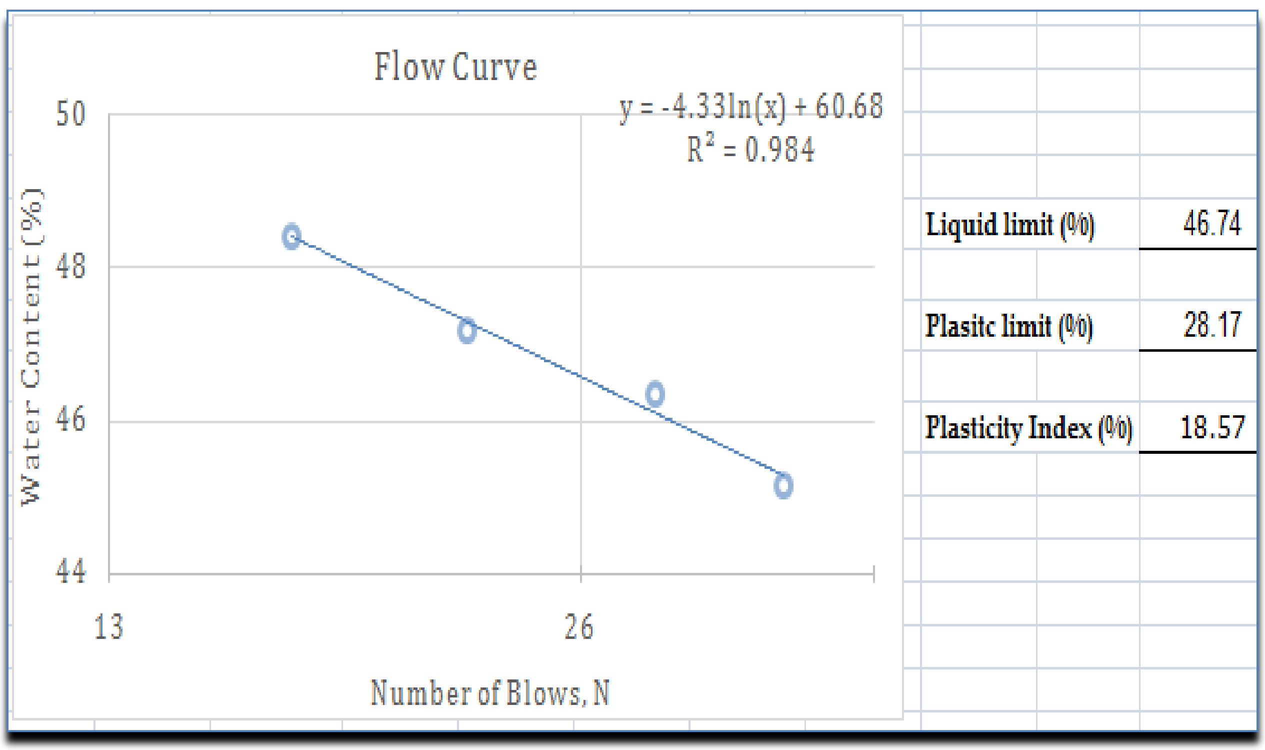


Figure B-4: Flow curve for Soil with 3.5% plastic strip

Appendix B5: Determination of Atterberg Limits of Soil with 5% plastic strips

Table B -5: Atterberg Limits of Soil with 5% plastic strip

5% plastic strip						
Description	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	16	21	27	35		
Wt. of wet Soil+can , (g)	42.56	45.78	40.92	43.44	24.63	20.78
Wt.of dry + can , (g)	33.87	34.83	33.01	34.99	22.69	19.69
Wt. of water , (g)	8.69	10.95	7.91	8.45	1.94	1.09
Wt. of can , (g)	16.00	11.20	15.60	15.88	15.50	15.85
Wt. of dry soil , (g)	17.87	23.63	17.41	19.11	7.19	3.84
Moisture content (%)	48.63	46.34	45.43	44.22	27.05	28.39
	Average PL (%) =				27.72	

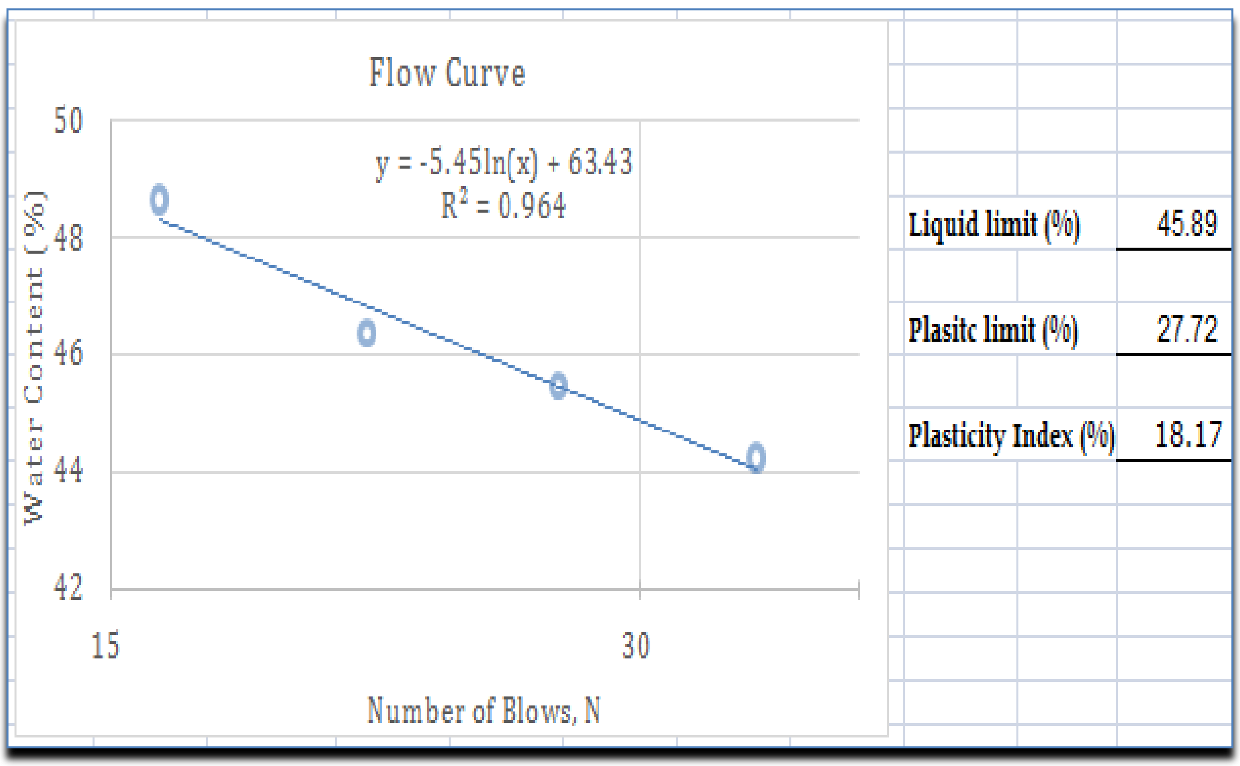
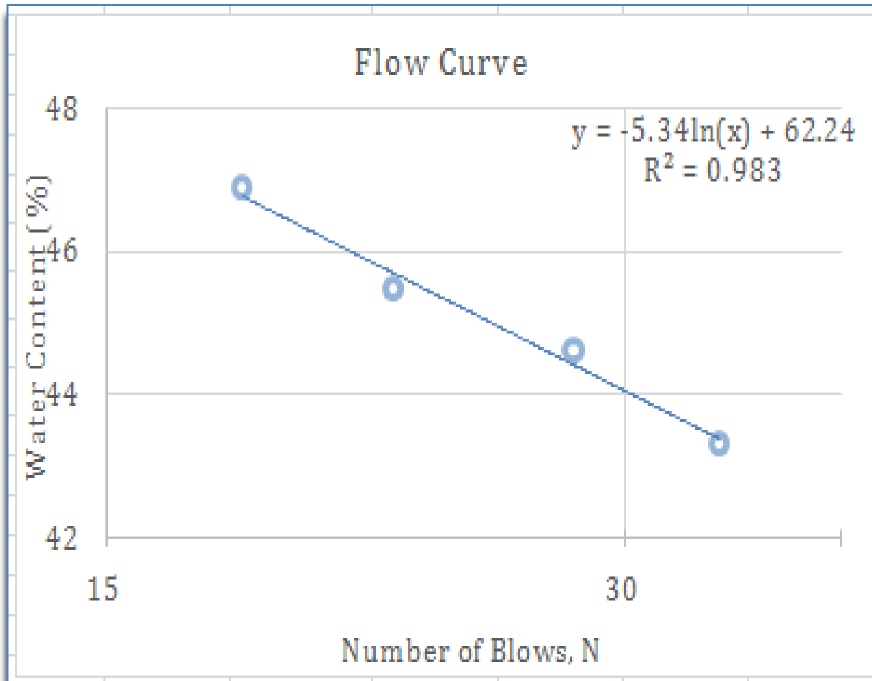


Figure B -5: Flow curve for Soil with 5% plastic strip

Appendix B6: Determination of Atterberg Limits of Soil with 7.5% plastic strips

Table B -6: Atterberg Limits of Soil with 7.5% plastic strip

7.5% plastic strip						
Description	Liquid Limit				Plastic Limit	
Can No.	1	2	3	4	5	6
No. blows	18	22	28	34		
Wt. of wet Soil+can , (g)	36.52	40.95	43.27	45.86	25.34	21.89
Wt.of dry + can , (g)	29.81	33.06	34.81	36.32	22.96	20.54
Wt. of water , (g)	6.71	7.89	8.46	9.54	2.38	1.35
Wt. of can , (g)	15.50	15.71	15.85	14.30	14.30	15.53
Wt. of dry soil , (g)	14.31	17.35	18.96	22.02	8.66	5.01
Moisture content (%)	46.89	45.48	44.62	43.32	27.48	27.00
	Average PL (%) =				27.24	



Liquid limit (%)	45.05
Plasitc limit (%)	27.24
Plasticity Index (%)	17.81

Figure B -6: **Flow curve for Soil with 7.5% plastic strip**

APPENDIX C: MOISTURE DENSITY RELATIONSHIP WITH VARYING PERCENTAGE OF PLASTIC STRIPS.

Appendix C1: Determination of Moisture Density Relationship of Soil with 0.5% plastic strips

Table C-1: **Moisture-Density relations of Soil with 0.5% plastic strip**

A	Mold	No.	1		2		3		4		5	
B	Wt. of Mold + Wet Soil	grams	4418		4695		4840		4865		4794	
C	Wt. of Mold	grams	3117.5		3117.5		3117.5		3117.5		3117.5	
D	Wt. Wet Soil	grams	1300.5		1577.5		1722.5		1747.5		1676.5	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.38		1.68		1.83		1.86		1.78	
G	Compacted Soil - Sample	No.	1		2		3		4		5	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
I	Container	No.	C11	C12	W1	W2	W3	W4	W5	W6	W7	W8
J	Weight of Container	grams	15.63	15.50	15.50	15.50	15.60	15.21	14.30	15.85	15.50	15.80
K	Wt. Cont + Wet soil	grams	63.72	68.29	75.94	68.36	70.35	72.92	65.83	69.24	76.42	74.60
L	Wt. Cont + Dry soil	grams	56.91	60.71	64.83	58.65	58.44	60.47	53.22	56.09	59.83	58.36
M	Weight of Dry Soil	grams	41.28	45.21	49.33	43.15	42.84	45.26	38.92	40.24	44.33	42.56
N	Weight of Water	grams	6.81	7.58	11.11	9.71	11.91	12.45	12.61	13.15	16.59	16.24
O	Moisture Content	%	16.50	16.77	22.52	22.50	27.80	27.51	32.40	32.68	37.42	38.16
P	Moisture Content	%	16.63	22.51	27.65	32.54	37.79					
Q	Dry Density	gr/cu.cm.	1.19	1.37	1.44	1.40	1.29					

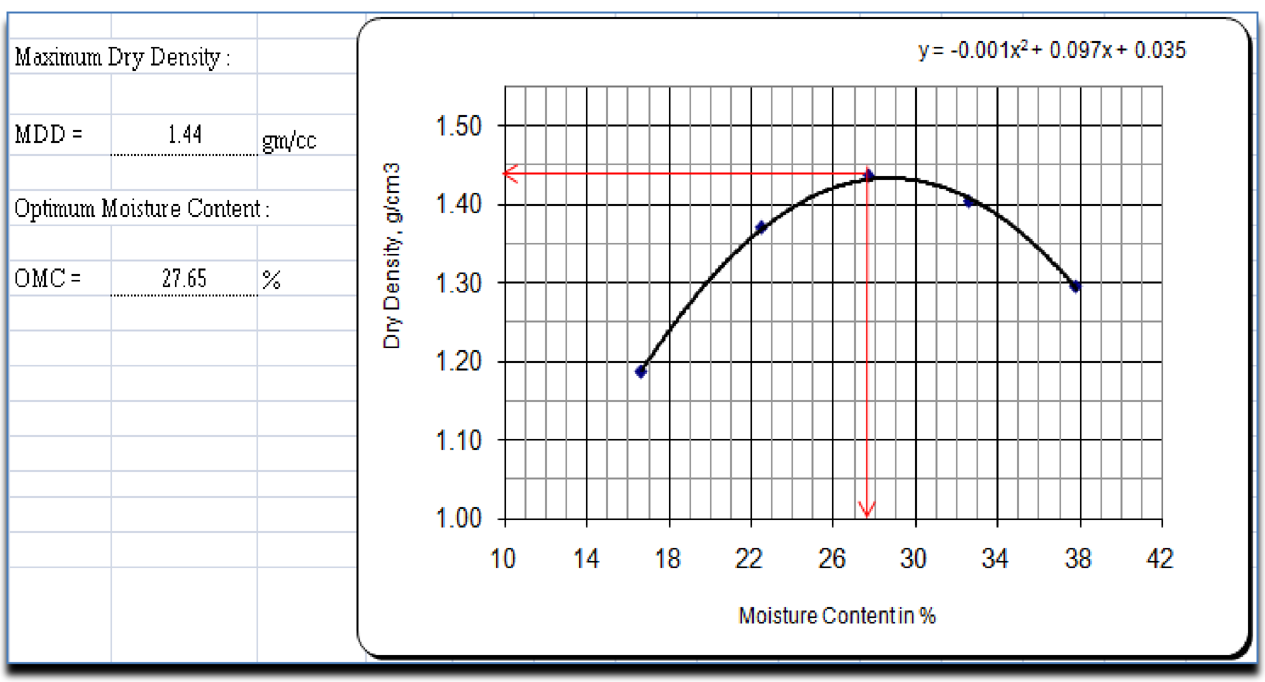


Figure C -1: **Moisture-Dry Density curve for Soil with 0.5% plastic strip**

Appendix C2: Determination of Moisture Density Relationship of Soil with 1.5% plastic strips

Table C -2: **Moisture-Density relations of Soil with 1.5% plastic strips**

A	Mold	No.	1		2		3		4		5	
B	Wt. of Mold + Wet Soil	grams	4479		4732		4885		4895		4810	
C	Wt. of Mold	grams	3117.5		3117.5		3117.5		3117.5		3117.5	
D	Wt. Wet Soil	grams	1361.5		1614.5		1767.5		1777.5		1692.5	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.45		1.72		1.88		1.89		1.80	
G	Compacted Soil - Sample	No.	1		2		3		4		5	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
I	Container	No.	6	1	C1	13	81	23	33	88	89	52
J	Weight of Container	grams	11.10	15.80	124.60	15.80	15.60	18.80	15.40	18.60	19.00	19.00
K	Wt. Cont + Wet soil	grams	62.30	63.00	173.90	68.80	75.20	104.60	82.20	143.90	148.50	166.80
L	Wt. Cont + Dry soil	grams	54.70	56.10	164.90	59.00	62.50	86.10	65.90	113.10	113.20	126.10
M	Weight of Dry Soil	grams	43.60	40.30	40.30	43.20	46.90	67.30	50.50	94.50	94.20	107.10
N	Weight of Water	grams	7.60	6.90	9.00	9.80	12.70	18.50	16.30	30.80	35.30	40.70
O	Moisture Content	%	17.43	17.12	22.33	22.69	27.08	27.49	32.28	32.59	37.47	38.00
P	Moisture Content	%	17.28	22.51	27.28	32.43	37.74					
Q	Dry Density	gr/cu.cm.	1.24	1.40	1.48	1.43	1.31					

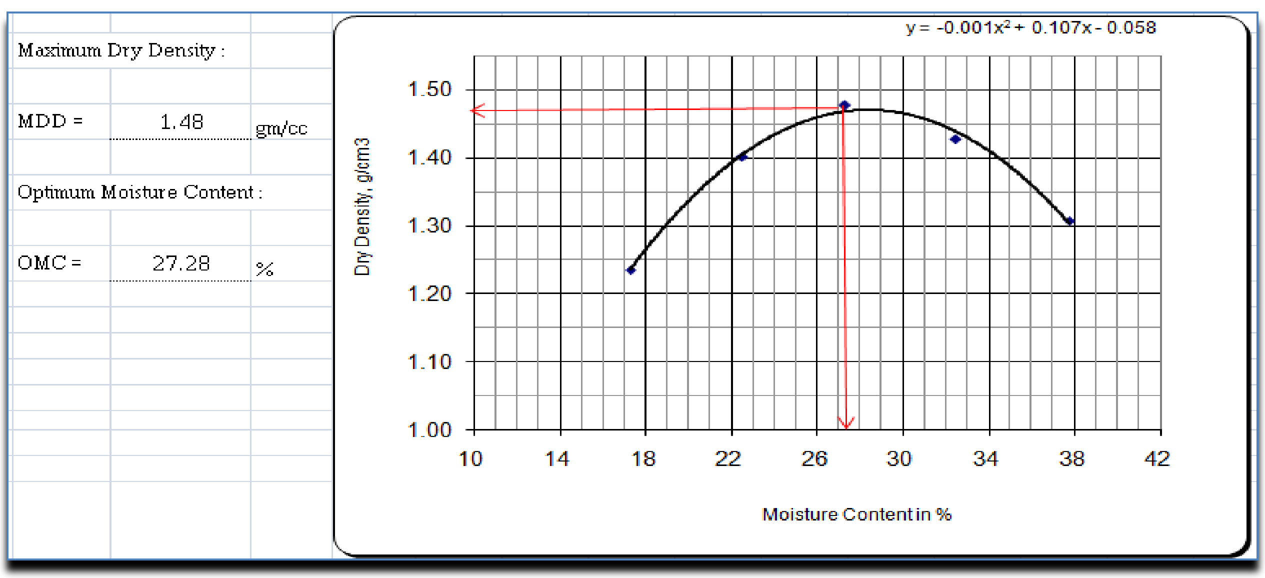


Figure C -2: **Moisture-Dry Density curve for Soil with 1.5% plastic strips**

Appendix C3: Determination of Moisture Density Relationship of Soil with 2.5% plastic strips

Table C -3: Moisture-Density relations of Soil with 2.5% plastic strips

A	Mold	No.	1		2		3		4		5		6	
B	Wt. of Mold + Wet Soil	grams	4389		4614		4824		4945		4953		4842	
C	Wt. of Mold	grams	3117.5		3117.5		3117.5		3117.5		3117.5		3117.5	
D	Wt. Wet Soil	grams	1271.5		1496.5		1706.5		1827.5		1835.5		1724.5	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.35		1.59		1.82		1.94		1.95		1.83	
G	Compacted Soil - Sample	No.	1		2		3		4		5		6	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B	6A	6B
I	Container	No.	L1	C1	L2	111	W9	W8	W5	W6	W7	W1	W3	W4
J	Weight of Container	grams	15.60	124.60	15.90	16.10	15.50	15.80	15.50	14.40	15.50	15.60	14.70	14.90
K	Wt. Cont + Wet soil	grams	68.20	177.00	60.60	66.50	64.50	59.00	66.37	63.54	67.30	75.30	85.70	84.60
L	Wt. Cont + Dry soil	grams	62.20	171.80	54.30	59.40	55.60	51.40	55.60	53.10	54.80	60.80	66.40	65.80
M	Weight of Dry Soil	grams	46.60	47.20	38.40	43.30	40.10	35.60	40.10	38.70	39.30	45.20	51.70	50.90
N	Weight of Water	grams	6.00	5.20	6.30	7.10	8.90	7.60	10.77	10.44	12.50	14.50	19.30	18.80
O	Moisture Content	%	12.88	11.02	16.41	16.40	22.19	21.35	26.86	26.98	31.81	32.08	37.33	36.94
P	Moisture Content	%	11.95	16.40	21.77	26.92	31.94	37.13						
Q	Dry Density	gr/cu.cm.	1.21	1.37	1.49	1.53	1.48	1.34						

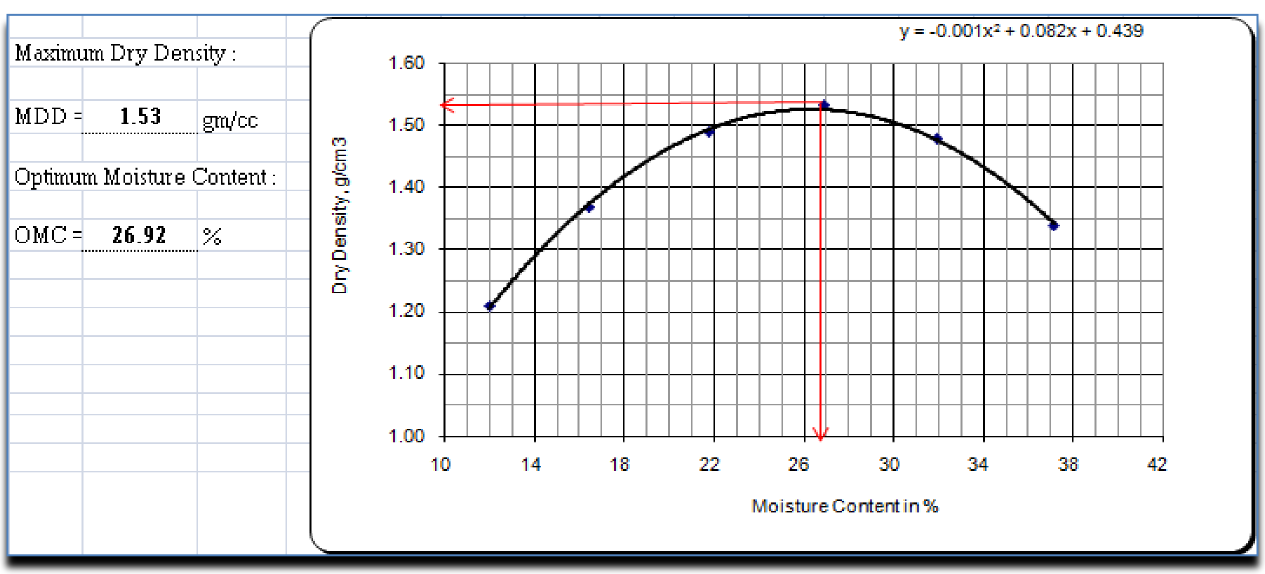


Figure C -3: **Moisture-Dry Density curve for Soil with 2.5% plastic strip**

Appendix C4: Determination of Moisture Density Relationship of Soil with 3.5% plastic strips

Table C -4: **Moisture-Density relations of Soil with 3.5% plastic strips**

A	Mold	No.	1		2		3		4		5	
B	Wt. of Mold + Wet Soil	grams	5753		5969		6160		6149		6038	
C	Wt. of Mold	grams	4366		4366		4366		4366		4366	
D	Wt. Wet Soil	grams	1387		1603		1794		1783		1672	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.48		1.71		1.91		1.90		1.78	
G	Compacted Soil - Sample	No.	1		2		3		4		5	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
I	Container	No.	P3	P8	P1	P4	22	W9	W1	P5	P7	W7
J	Weight of Container	grams	15.60	15.80	15.70	15.80	15.60	15.50	15.60	15.70	14.80	15.50
K	Wt. Cont + Wet soil	grams	70.20	69.50	79.10	65.20	96.70	77.63	89.00	98.30	102.90	105.20
L	Wt. Cont + Dry soil	grams	62.58	61.40	68.27	56.48	79.61	64.63	70.54	76.26	78.04	79.82
M	Weight of Dry Soil	grams	46.98	45.60	52.57	40.68	64.01	49.13	54.94	60.56	63.24	64.32
N	Weight of Water	grams	7.62	8.10	10.83	8.72	17.09	13.00	18.46	22.04	24.86	25.38
O	Moisture Content	%	16.22	17.76	20.60	21.44	26.70	26.46	33.60	36.39	39.31	39.46
P	Moisture Content	%	16.99	21.02	26.58	35.00	39.38					
Q	Dry Density	gr/cu.cm.	1.26	1.41	1.51	1.41	1.28					

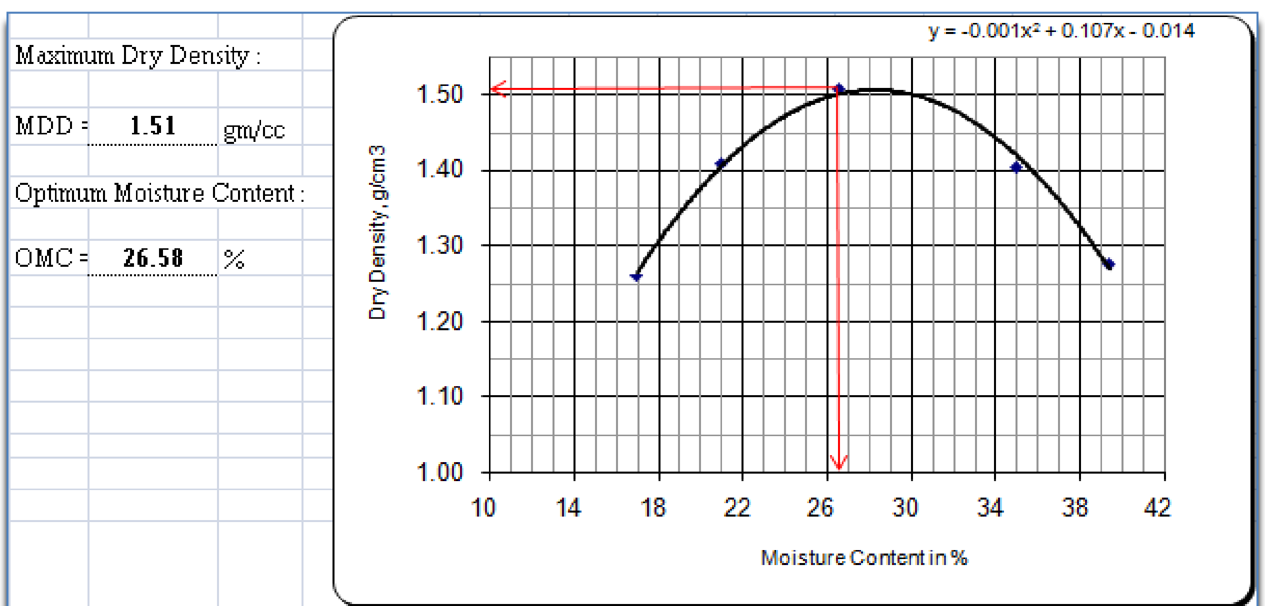


Figure C -4: Moisture-Dry Density curve for Soil with 3.5% plastic strip

Appendix C5: Determination of Moisture Density Relationship of Soil with 5% plastic strips

Table C -5: **Moisture-Density relations of Soil with 5% plastic strips**

A	Mold	No.	1		2		3		4		5	
B	Wt. of Mold + Wet Soil	grams	5949		6165		6367		6394		6310	
C	Wt. of Mold	grams	4634		4634		4634		4634		4634	
D	Wt. Wet Soil	grams	1315		1531		1733		1760		1676	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.40		1.63		1.84		1.87		1.78	
G	Compacted Soil - Sample	No.	1		2		3		4		5	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
I	Container	No.	W1	W2	22	15	W7	W6	W9	W4	Co-4	Co-9
J	Weight of Container	grams	15.60	15.30	15.60	15.70	15.50	14.40	15.50	15.10	15.70	15.80
K	Wt. Cont + Wet soil	grams	66.30	68.40	73.60	72.50	60.30	62.40	82.40	88.70	122.50	95.70
L	Wt. Cont + Dry soil	grams	59.70	61.40	64.00	63.00	51.10	52.30	66.10	70.50	92.80	73.50
M	Weight of Dry Soil	grams	44.10	46.10	48.40	47.30	35.60	37.90	50.60	55.40	77.10	57.70
N	Weight of Water	grams	6.60	7.00	9.60	9.50	9.20	10.10	16.30	18.20	29.70	22.20
O	Moisture Content	%	14.97	15.18	19.83	20.08	25.84	26.65	32.21	32.85	38.52	38.47
P	Moisture Content	%	15.08	19.96	26.25	32.53	38.50					
Q	Dry Density	gr/cu.cm.	1.22	1.36	1.46	1.41	1.29					

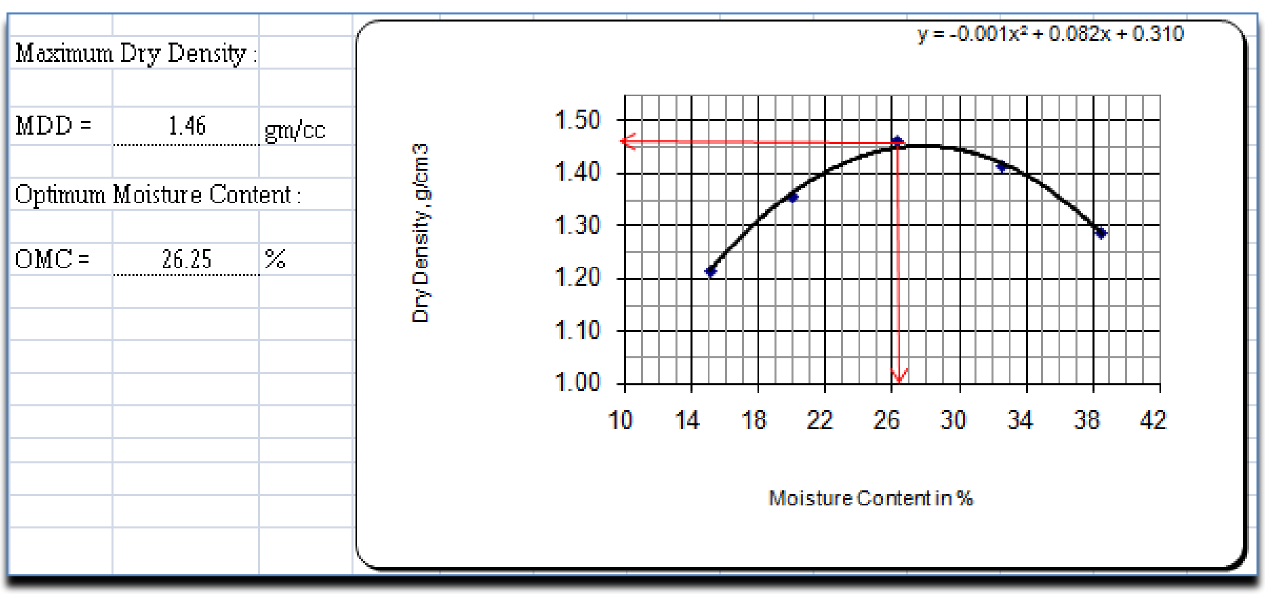


Figure C -5: **Moisture-Dry Density curve for Soil with 5% plastic strip**

Appendix C6: Determination of Moisture Density Relationship of Soil with 7.5% plastic strips

Table C -6: **Moisture-Density relations of Soil with 7.5% plastic strips**

A	Mold	No.	1		2		3		4		5	
B	Wt. of Mold + Wet Soil	grams	4412		4617		4809		4851		4736	
C	Wt. of Mold	grams	3117.5		3117.5		3117.5		3117.5		3117.5	
D	Wt. Wet Soil	grams	1294.5		1499.5		1691.5		1733.5		1618.5	
E	Volume of Mold	cu.cm.	939.98		939.98		939.98		939.98		939.98	
F	Wet Density	gr/cu.cm.	1.38		1.60		1.80		1.84		1.72	
G	Compacted Soil - Sample	No.	1		2		3		4		5	
H	Water content - Sample	No.	1A	1B	2A	2B	3A	3B	4A	4B	5A	5B
I	Container	No.	C7	C11	W3	W5	W1	C3	C12	C9	W7	C1
J	Weight of Container	grams	19.00	124.60	16.00	15.50	15.50	15.87	15.50	15.87	14.30	15.21
K	Wt. Cont + Wet soil	grams	84.76	183.45	57.23	62.48	67.92	73.45	55.91	69.27	75.22	64.43
L	Wt. Cont + Dry soil	grams	76.09	175.78	50.01	54.16	57.21	61.49	45.72	56.00	58.46	50.84
M	Weight of Dry Soil	grams	57.09	51.18	34.01	38.66	41.71	45.62	30.22	40.13	44.16	35.63
N	Weight of Water	grams	8.67	7.67	7.22	8.32	10.71	11.96	10.19	13.27	16.76	13.59
O	Moisture Content	%	15.19	14.99	21.23	21.52	25.68	26.22	33.72	33.07	37.95	38.14
P	Moisture Content	%	15.09	21.38	25.95	33.39	38.05					
Q	Dry Density	gr/cu.cm.	1.20	1.31	1.43	1.38	1.25					

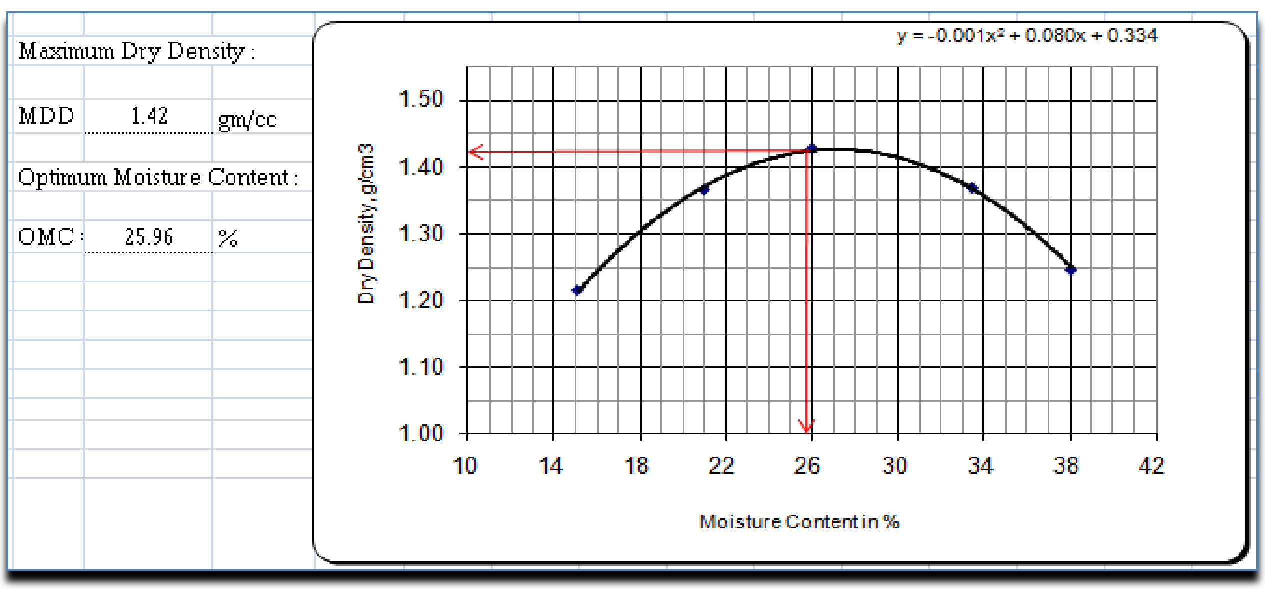


Figure C -6: **Moisture-Dry Density curve for Soil with 7.5% plastic strip**

APPENDIX D: UNCONFINED COMPRESSIVE STRENGTH (UCS) WITH VARYING PERCENTAGE OF PLASTIC STRIPS.

Appendix D1: Determination of Unconfined Compressive Strength of Soil with 0.5% plastic strips

Table D -1: **Unconfined Compressive Strength value of Soil with 0.5% plastic strips**

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Soil with 0.5 % plastic strip			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		20/06/19
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0	0.000
20	0.2	0.00263	0.0011363	10	0.0142	12.496
40	0.4	0.00526	0.0011394	13	0.01846	16.202
60	0.6	0.00789	0.0011424	14.5	0.02059	18.024
80	0.8	0.01053	0.0011454	16	0.02272	19.836
100	1	0.01316	0.0011485	18	0.02556	22.256
120	1.2	0.01579	0.0011515	20.5	0.02911	25.279
140	1.4	0.01842	0.0011546	22.5	0.03195	27.671
160	1.6	0.02105	0.0011577	25	0.0355	30.664
180	1.8	0.02368	0.0011608	27	0.03834	33.028
200	2	0.02632	0.0011640	29	0.04118	35.378
220	2.2	0.02895	0.0011671	30.5	0.04331	37.108
240	2.4	0.03158	0.0011703	32	0.04544	38.827
260	2.6	0.03421	0.0011735	34	0.04828	41.142
280	2.8	0.03684	0.0011767	36	0.05112	43.443
300	3	0.03947	0.0011799	38	0.05396	45.732
320	3.2	0.04211	0.0011832	39.5	0.05609	47.406
340	3.4	0.04474	0.0011864	41	0.05822	49.072
360	3.6	0.04737	0.0011897	43	0.06106	51.323
380	3.8	0.05000	0.0011930	43	0.06106	51.182
400	4	0.05263	0.0011963	47.5	0.06745	56.381
420	4.2	0.05526	0.0011997	49	0.06958	58.000
440	4.4	0.05789	0.0012030	50.5	0.07171	59.609
460	4.6	0.06053	0.0012064	52	0.07384	61.208
480	4.8	0.06316	0.0012098	53.5	0.07597	62.798
500	5	0.06579	0.0012132	55	0.0781	64.377
520	5.2	0.06842	0.0012166	57	0.08094	66.530

540	5.4	0.07105	0.0012200	59	0.08378	68.670
560	5.6	0.07368	0.0012235	60	0.0852	69.636
580	5.8	0.07632	0.0012270	62	0.08804	71.753
600	6	0.07895	0.0012305	64	0.09088	73.856
620	6.2	0.08158	0.0012340	65	0.0923	74.796
640	6.4	0.08421	0.0012376	66	0.09372	75.729
660	6.6	0.08684	0.0012411	68	0.09656	77.800
680	6.8	0.08947	0.0012447	69	0.09798	78.716
700	7	0.09211	0.0012483	70	0.0994	79.626
720	7.2	0.09474	0.0012520	71	0.10082	80.530
740	7.4	0.09737	0.0012556	72	0.10224	81.427
760	7.6	0.10000	0.0012593	73	0.10366	82.317
780	7.8	0.10263	0.0012630	73.5	0.10437	82.638
800	8	0.10526	0.0012667	74	0.10508	82.956
820	8.2	0.10789	0.0012704	75.5	0.10721	84.389
840	8.4	0.11053	0.0012742	76	0.10792	84.697
860	8.6	0.11316	0.0012780	77	0.10934	85.558
880	8.8	0.11579	0.0012818	78	0.11076	86.412
900	9	0.11842	0.0012856	78	0.11076	86.155
920	9.2	0.12105	0.0012894	78.5	0.11147	86.448
940	9.4	0.12368	0.0012933	78.5	0.11147	86.189
960	9.6	0.12632	0.0012972	78.5	0.11147	85.930
980	9.8	0.12895	0.0013011	78	0.11076	85.126
1000	10	0.13158	0.0013051	77	0.10934	83.781
1020	10.2	0.13421	0.0013090	76	0.10792	82.442
1040	10.4	0.13684	0.0013130	75	0.1065	81.110

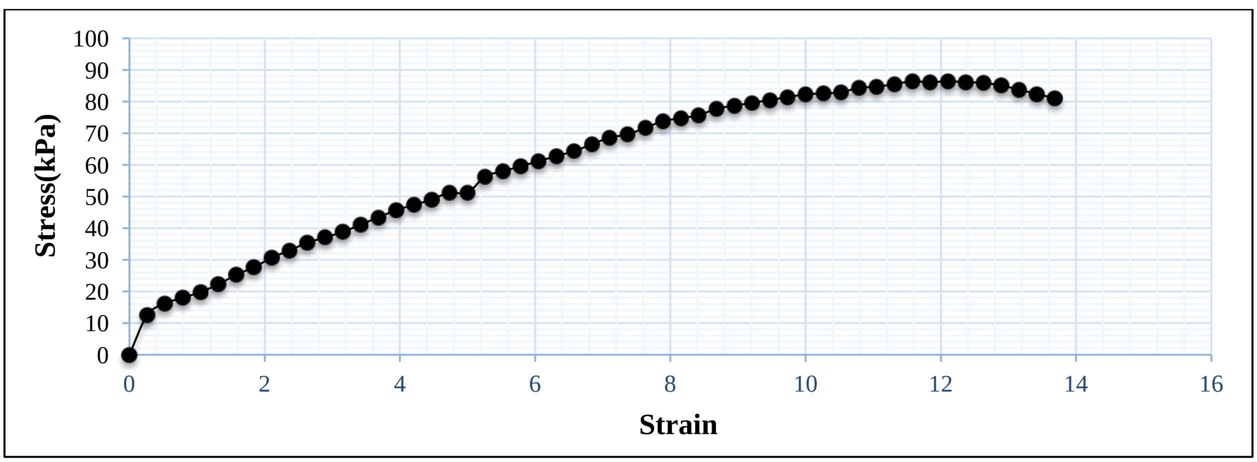


Figure D -1: **Unconfined Compressive Strength curve for Soil with 0.5% plastic strip**

Appendix D2: Determination of Unconfined Compressive Strength of Soil with 1.5% plastic strips

Table D -2: **Unconfined Compressive Strength value of Soil with 1.5% plastic strips**

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Soil with 1.5 % Stabilizer			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		20/06/19
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0	0.000
20	0.2	0.00263	0.0011363	11	0.01562	13.746
40	0.4	0.00526	0.0011394	15	0.0213	18.695
60	0.6	0.00789	0.0011424	18	0.02556	22.374
80	0.8	0.01053	0.0011454	22	0.03124	27.274
100	1	0.01316	0.0011485	25	0.0355	30.911
120	1.2	0.01579	0.0011515	28	0.03976	34.528
140	1.4	0.01842	0.0011546	32	0.04544	39.355
160	1.6	0.02105	0.0011577	35	0.0497	42.929
180	1.8	0.02368	0.0011608	38	0.05396	46.483
200	2	0.02632	0.0011640	42	0.05964	51.238
220	2.2	0.02895	0.0011671	45	0.0639	54.749
240	2.4	0.03158	0.0011703	48	0.06816	58.241
260	2.6	0.03421	0.0011735	49	0.06958	59.293
280	2.8	0.03684	0.0011767	53	0.07526	63.958
300	3	0.03947	0.0011799	58	0.08236	69.801
320	3.2	0.04211	0.0011832	60	0.0852	72.010
340	3.4	0.04474	0.0011864	62	0.08804	74.206
360	3.6	0.04737	0.0011897	65	0.0923	77.582
380	3.8	0.05000	0.0011930	68	0.09656	80.939
400	4	0.05263	0.0011963	72	0.10224	85.462
420	4.2	0.055263	0.0011997	74	0.10508	87.592
440	4.4	0.05789	0.0012030	76	0.10792	89.709
460	4.6	0.06053	0.0012064	78	0.11076	91.813
480	4.8	0.06316	0.0012098	80	0.1136	93.903
500	5	0.06579	0.0012132	82	0.11644	95.980
520	5.2	0.06842	0.0012166	84	0.11928	98.044

540	5.4	0.07105	0.0012200	85	0.1207	98.931
560	5.6	0.07368	0.0012235	86	0.12212	99.811
580	5.8	0.07632	0.0012270	88	0.12496	101.842
600	6	0.07895	0.0012305	89	0.12638	102.706
620	6.2	0.08158	0.0012340	90	0.1278	103.564
640	6.4	0.08421	0.0012376	90.5	0.12851	103.841
660	6.6	0.08684	0.0012411	91	0.12922	104.114
680	6.8	0.08947	0.0012447	91	0.12922	103.814
700	7	0.09211	0.0012483	91	0.12922	103.514
720	7.2	0.09474	0.0012520	90	0.1278	102.080
740	7.4	0.09737	0.0012556	89	0.12638	100.652
760	7.6	0.10000	0.0012593	88	0.12496	99.231

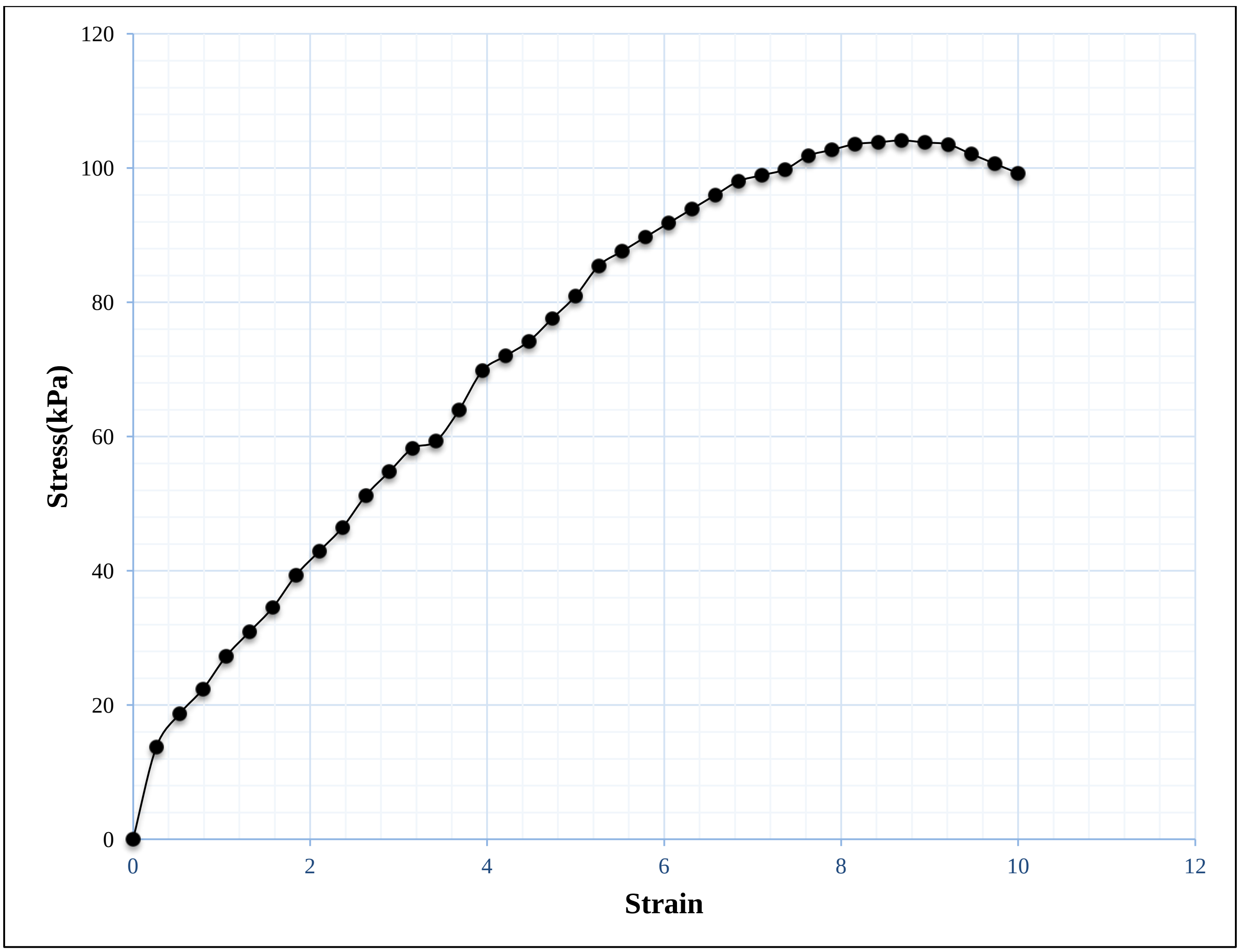


Figure D -2: **Unconfined Compressive Strength curve for Soil with 1.5% plastic strip**

Appendix D3: Determination of Unconfined Compressive Strength of Soil with 2.5% plastic strips

Table D -3: **Unconfined Compressive Strength value of Soil with 2.5% plastic strips**

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Soil with 2.5 % Plastic strip			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		20/06/19
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0	0.000
20	0.2	0.00263	0.0011363	14	0.01988	17.495
40	0.4	0.00526	0.0011394	17	0.02414	21.188
60	0.6	0.00789	0.0011424	19	0.02698	23.618
80	0.8	0.01053	0.0011454	22	0.03124	27.274
100	1	0.01316	0.0011485	24	0.03408	29.674
120	1.2	0.01579	0.0011515	25	0.0355	30.828
140	1.4	0.01842	0.0011546	26	0.03692	31.976
160	1.6	0.02105	0.0011577	28	0.03976	34.343
180	1.8	0.02368	0.0011608	30	0.0426	36.697
200	2	0.02632	0.0011640	35	0.0497	42.698
220	2.2	0.02895	0.0011671	38	0.05396	46.233
240	2.4	0.03158	0.0011703	40	0.0568	48.534
260	2.6	0.03421	0.0011735	44	0.06248	53.242
280	2.8	0.03684	0.0011767	47	0.06674	56.718
300	3	0.03947	0.0011799	50	0.071	60.173
320	3.2	0.04211	0.0011832	54	0.07668	64.809
340	3.4	0.04474	0.0011864	57	0.08094	68.221
360	3.6	0.04737	0.0011897	59	0.08378	70.421
380	3.8	0.05000	0.0011930	65	0.0923	77.368
400	4	0.05263	0.0011963	68	0.09656	80.714
420	4.2	0.055263	0.0011997	73	0.10366	86.409
440	4.4	0.05789	0.0012030	76	0.10792	89.709
460	4.6	0.06053	0.0012064	80	0.1136	94.167
480	4.8	0.06316	0.0012098	85	0.1207	99.772
500	5	0.06579	0.0012132	90	0.1278	105.344
520	5.2	0.06842	0.0012166	95	0.1349	110.883

540	5.4	0.07105	0.0012200	100	0.142	116.390
560	5.6	0.07368	0.0012235	104	0.14768	120.702
580	5.8	0.07632	0.0012270	109	0.15478	126.146
600	6	0.07895	0.0012305	114	0.16188	131.556
620	6.2	0.08158	0.0012340	119	0.16898	136.934
640	6.4	0.08421	0.0012376	124	0.17608	142.279
660	6.6	0.08684	0.0012411	128	0.18176	146.446
680	6.8	0.08947	0.0012447	134	0.19028	152.869
700	7	0.09211	0.0012483	136	0.19312	154.702
720	7.2	0.09474	0.0012520	138	0.19596	156.522
740	7.4	0.09737	0.0012556	141	0.20022	159.460
760	7.6	0.10000	0.0012593	144	0.20448	162.378
780	7.8	0.10263	0.0012630	146	0.20732	164.152
800	8	0.10526	0.0012667	149	0.21158	167.034
820	8.2	0.10789	0.0012704	151	0.21442	168.778
840	8.4	0.11053	0.0012742	153	0.21726	170.509
860	8.6	0.11316	0.0012780	155	0.2201	172.227
880	8.8	0.11579	0.0012818	157	0.22294	173.931
900	9	0.11842	0.0012856	158	0.22436	174.518
940	9.4	0.12368	0.0012933	158	0.22436	173.476
980	9.8	0.12895	0.0013011	158	0.22436	172.435
1000	10	0.13158	0.0013051	158	0.22436	171.914
1040	10.4	0.13684	0.0013130	157	0.22294	169.790
1080	10.8	0.14211	0.0013211	155	0.2201	166.605

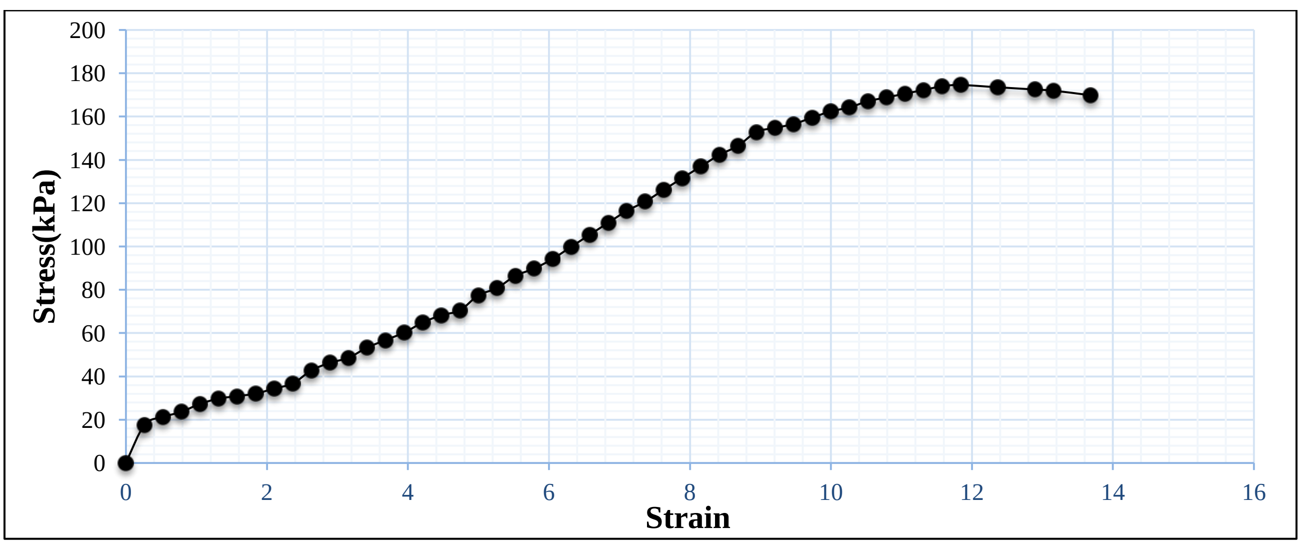


Figure D -3: **Unconfined Compressive Strength curve for Soil with 2.5% plastic strip**

Appendix D4: Determination of Unconfined Compressive Strength of Soil with 3.5% plastic strips

Table D -4: **Unconfined Compressive Strength value of Soil with 3.5% plastic strips**

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Soil with 3.5 % Plastic strip			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		2/7/2019
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0.00000	0.000
20	0.2	0.00263	0.0011363	12	0.01704	14.995
40	0.4	0.00526	0.0011394	18	0.02556	22.434
60	0.6	0.00789	0.0011424	21	0.02982	26.104
80	0.8	0.01053	0.0011454	26	0.03692	32.233
100	1	0.01316	0.0011485	30	0.04260	37.093
120	1.2	0.01579	0.0011515	35	0.04970	43.160
140	1.4	0.01842	0.0011546	38	0.05396	46.734
160	1.6	0.02105	0.0011577	41	0.05822	50.288
180	1.8	0.02368	0.0011608	45	0.06390	55.046
200	2	0.02632	0.0011640	49	0.06958	59.777
220	2.2	0.02895	0.0011671	53	0.07526	64.482
240	2.4	0.03158	0.0011703	60	0.08520	72.801
260	2.6	0.03421	0.0011735	65	0.09230	78.654
280	2.8	0.03684	0.0011767	70	0.09940	84.473
300	3	0.03947	0.0011799	76	0.10792	91.463
320	3.2	0.04211	0.0011832	81	0.11502	97.213
340	3.4	0.04474	0.0011864	88	0.12496	105.324
360	3.6	0.04737	0.0011897	93	0.13206	111.002
380	3.8	0.05000	0.0011930	100	0.14200	119.027
400	4	0.05263	0.0011963	105	0.14910	124.632
420	4.2	0.055263	0.0011997	112	0.15904	132.572
440	4.4	0.05789	0.0012030	118	0.16756	139.285
460	4.6	0.06053	0.0012064	122	0.17324	143.604
480	4.8	0.06316	0.0012098	127	0.18034	149.071
500	5	0.06579	0.0012132	130	0.18460	152.164
520	5.2	0.06842	0.0012166	133	0.18886	155.237
540	5.4	0.07105	0.0012200	137	0.19454	159.454
560	5.6	0.07368	0.0012235	141	0.20022	163.644
580	5.8	0.07632	0.0012270	146	0.20732	168.966

600	6	0.07895	0.0012305	147	0.20874	169.639
620	6.2	0.08158	0.0012340	150	0.21300	172.606
640	6.4	0.08421	0.0012376	152	0.21584	174.406
660	6.6	0.08684	0.0012411	154	0.21868	176.193
680	6.8	0.08947	0.0012447	156	0.22152	177.967
700	7	0.09211	0.0012483	157	0.22294	178.590
720	7.2	0.09474	0.0012520	158	0.22436	179.207
740	7.4	0.09737	0.0012556	158	0.22436	178.686
760	7.6	0.10000	0.0012593	158	0.22436	178.165
780	7.8	0.10263	0.0012630	158	0.22436	177.644
800	8	0.10526	0.0012667	158	0.22436	177.123
820	8.2	0.10789	0.0012704	158	0.22436	176.602
840	8.4	0.11053	0.0012742	156	0.22152	173.852
860	8.6	0.11316	0.0012780	154	0.21868	171.116
880	8.8	0.11579	0.0012818	153	0.21726	169.500
900	9	0.11842	0.0012856	152	0.21584	167.891
920	9.2	0.12105	0.0012894	152	0.21584	167.390
940	9.4	0.12368	0.0012933	152	0.21584	166.889

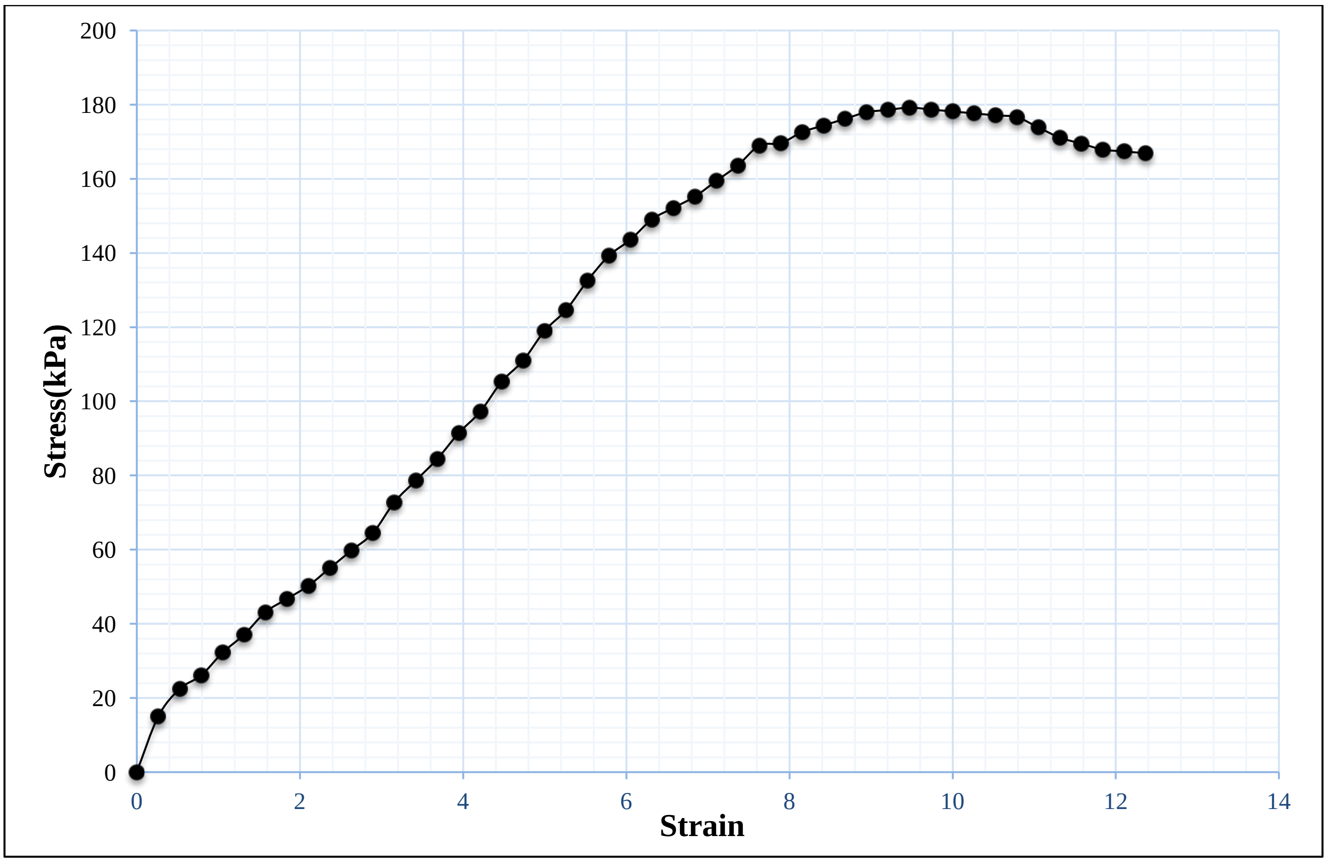


Figure D -4: **Unconfined Compressive Strength curve for Soil with 3.5% plastic strip**

Appendix D5: Determination of Unconfined Compressive Strength of Soil with 5% plastic strips

Table D -5: **Unconfined Compressive Strength value of Soil with 5% plastic strips**

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Soil with 5 % Plastic strip			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		2/7/2019
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0.00000	0.000
20	0.2	0.00263	0.0011363	10	0.01420	12.496
40	0.4	0.00526	0.0011394	17	0.02414	21.188
60	0.6	0.00789	0.0011424	23	0.03266	28.590
80	0.8	0.01053	0.0011454	30	0.04260	37.192
100	1	0.01316	0.0011485	36	0.05112	44.512
120	1.2	0.01579	0.0011515	43	0.06106	53.025
140	1.4	0.01842	0.0011546	51	0.07242	62.722
160	1.6	0.02105	0.0011577	57	0.08094	69.913
180	1.8	0.02368	0.0011608	67	0.09514	81.957
200	2	0.02632	0.0011640	75	0.10650	91.496
220	2.2	0.02895	0.0011671	86	0.12212	104.632
240	2.4	0.03158	0.0011703	96	0.13632	116.482
260	2.6	0.03421	0.0011735	106	0.15052	128.266
280	2.8	0.03684	0.0011767	117	0.16614	141.191
300	3	0.03947	0.0011799	126	0.17892	151.636
320	3.2	0.04211	0.0011832	134	0.19028	160.822
340	3.4	0.04474	0.0011864	140	0.19880	167.561
360	3.6	0.04737	0.0011897	145	0.20590	173.068
380	3.8	0.05000	0.0011930	149	0.21158	177.351
400	4	0.05263	0.0011963	152	0.21584	180.420
420	4.2	0.055263	0.0011997	154	0.21868	182.286
440	4.4	0.05789	0.0012030	156	0.22152	184.139
460	4.6	0.06053	0.0012064	158	0.22436	185.979

480	4.8	0.06316	0.0012098	160	0.22720	187.806
500	5	0.06579	0.0012132	162	0.23004	189.619
520	5.2	0.06842	0.0012166	165	0.23430	192.587
540	5.4	0.07105	0.0012200	167	0.23714	194.370
560	5.6	0.07368	0.0012235	169	0.23998	196.141
580	5.8	0.07632	0.0012270	166	0.23572	192.112
600	6	0.07895	0.0012305	166	0.23572	191.565
620	6.2	0.08158	0.0012340	166	0.23572	191.017
640	6.4	0.08421	0.0012376	166	0.23572	190.470
660	6.6	0.08684	0.0012411	166	0.23572	189.923
680	6.8	0.08947	0.0012447	164	0.23288	187.094
700	7	0.09211	0.0012483	163	0.23146	185.415
720	7.2	0.09474	0.0012520	161	0.22862	182.610

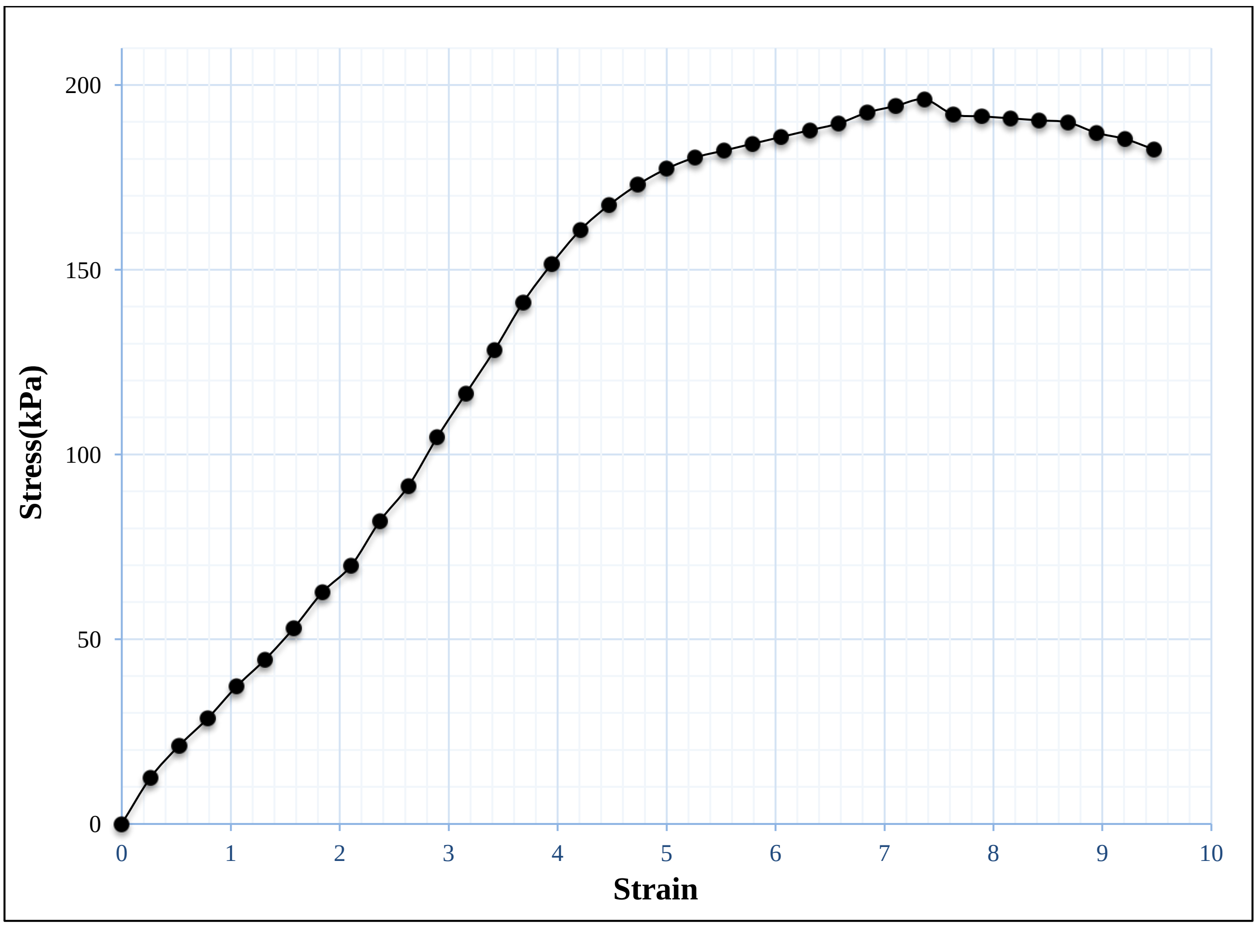


Figure D -5: **Unconfined Compressive Strength curve for Soil with 5% plastic strip**

Appendix D6: Determination of Unconfined Compressive Strength of Soil with 7.5% plastic strips

Table D -6: **Unconfined Compressive Strength value of Soil with 7.5% plastic strips**

Test type	UCS			Test Pit Depth (m)		1.00
Sample source	Kechene-Rasdesta Road			Diameter of sample (mm)		38
Sample of	Soil with 7.5 % Plastic strip			Length of sample (mm)		76
Material	Red Clay Soil			Ring Calibration Factor (kN/div)		0.00142
Sample date	13/03/19			Test date		2/7/2019
Deformation Dial Reading (Division)	Deformation (mm)	Strain (ε= ΔL/Lo)	Corrected Area (Ac=Ao/(1-ε))	Proving Ring Reading (Division)	Load (kN)	Stress (kPa)
0	0	0.00000	0.0011334	0	0.00000	0.000
20	0.2	0.00263	0.0011363	5	0.00710	6.248
40	0.4	0.00526	0.0011394	8	0.01136	9.971
60	0.6	0.00789	0.0011424	13	0.01846	16.159
80	0.8	0.01053	0.0011454	16	0.02272	19.836
100	1	0.01316	0.0011485	22	0.03124	27.202
120	1.2	0.01579	0.0011515	27	0.03834	33.295
140	1.4	0.01842	0.0011546	32	0.04544	39.355
160	1.6	0.02105	0.0011577	38	0.05396	46.609
180	1.8	0.02368	0.0011608	42	0.05964	51.376
200	2	0.02632	0.0011640	44	0.06248	53.678
220	2.2	0.02895	0.0011671	51	0.07242	62.049
240	2.4	0.03158	0.0011703	55	0.07810	66.734
260	2.6	0.03421	0.0011735	60	0.08520	72.603
280	2.8	0.03684	0.0011767	69	0.09798	83.266
300	3	0.03947	0.0011799	73	0.10366	87.853
320	3.2	0.04211	0.0011832	76	0.10792	91.212
340	3.4	0.04474	0.0011864	79	0.11218	94.552
360	3.6	0.04737	0.0011897	81	0.11502	96.679
380	3.8	0.05000	0.0011930	84	0.11928	99.983
400	4	0.05263	0.0011963	86	0.12212	102.080
420	4.2	0.055263	0.0011997	88	0.12496	104.164
440	4.4	0.05789	0.0012030	90	0.12780	106.234
460	4.6	0.06053	0.0012064	90	0.12780	105.938
480	4.8	0.06316	0.0012098	91	0.12922	106.815
500	5	0.06579	0.0012132	92	0.13064	107.685
520	5.2	0.06842	0.0012166	93	0.13206	108.549

540	5.4	0.07105	0.0012200	94	0.13348	109.406
560	5.6	0.07368	0.0012235	95	0.13490	110.257
580	5.8	0.07632	0.0012270	95	0.13490	109.944
600	6	0.07895	0.0012305	96	0.13632	110.784
620	6.2	0.08158	0.0012340	96	0.13632	110.468
640	6.4	0.08421	0.0012376	97	0.13774	111.299
660	6.6	0.08684	0.0012411	97	0.13774	110.979
680	6.8	0.08947	0.0012447	97	0.13774	110.659
700	7	0.09211	0.0012483	96	0.13632	109.202
720	7.2	0.09474	0.0012520	95	0.13490	107.751
740	7.4	0.09737	0.0012556	94	0.13348	106.307
760	7.6	0.10000	0.0012593	93	0.13206	104.869

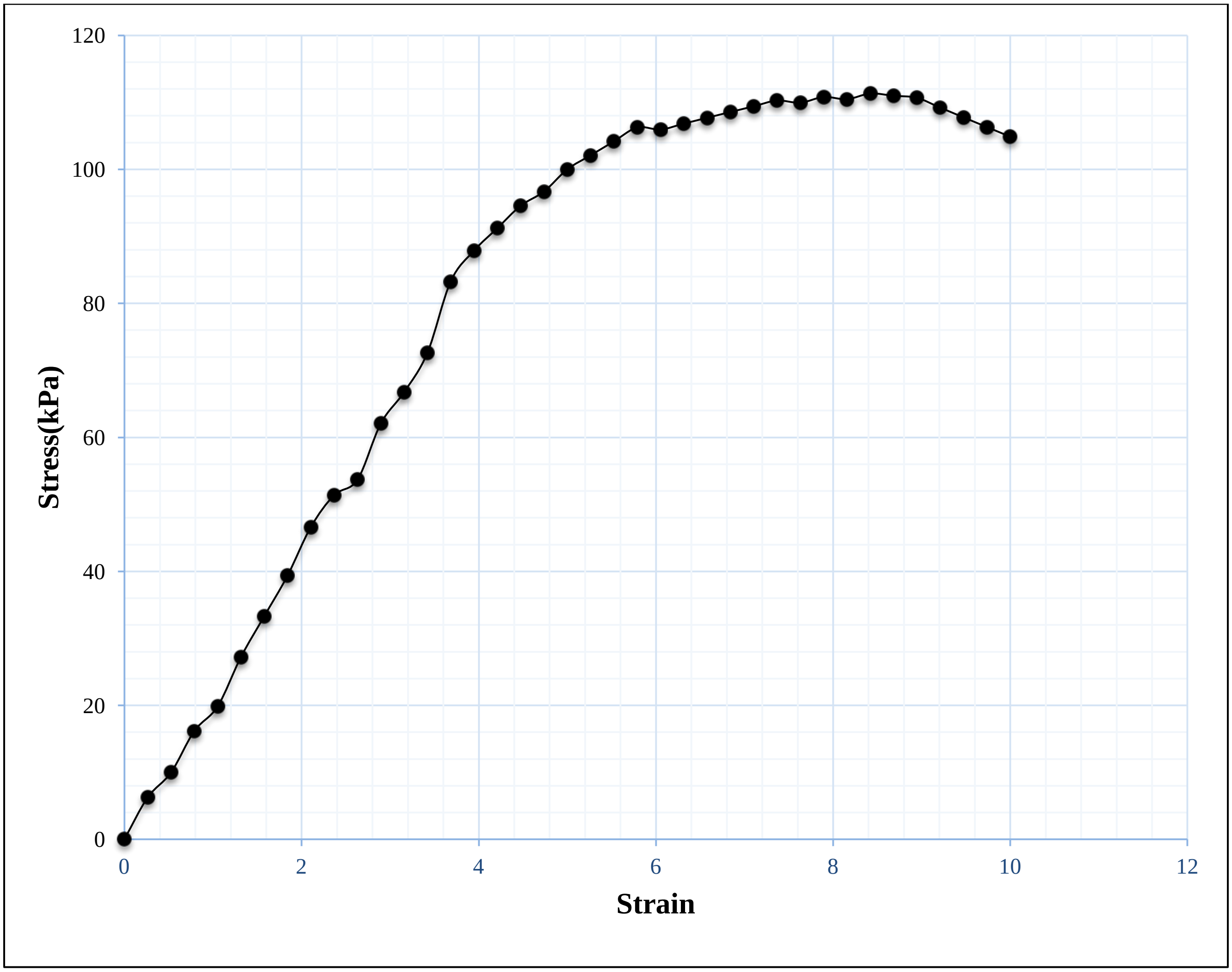


Figure D -6: **Unconfined Compressive Strength curve for Soil with 7.5% plastic strip**

APPENDIX E: CALIFORNIAN BEARING RATIO (CBR) WITH VARYING PERCENTAGE OF PLASTIC STRIPS.

Appendix E1: Determination of Soaked CBR for Soil with 0.5% plastic strips

Table E -1: **Soaked CBR penetration test result of Soil with 0.5% plastic strips**

CBR Data for soil with 0.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		6	0.14		
1.27		12	0.29		
1.91		17	0.41		
2.54	13	21	0.51	0.51	**3.9**
5.08	20	30	0.72	0.72	**3.6**
6.35		32	0.77		
7.62		33	0.80		

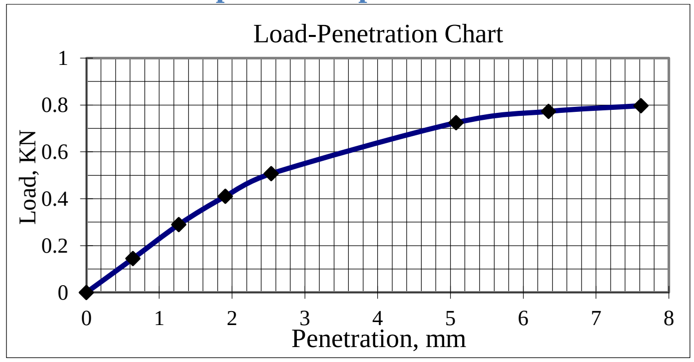


Figure E-1: **Load-penetration curves of Soil with 0.5% plastic strips (Soaked CBR)**

Appendix E2: Determination of Soaked CBR for Soil with 1.5% plastic strips

Table E -2: **Soaked CBR penetration test result of Soil with 1.5% plastic strips**

CBR Data for soil with 1.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		8	0.19		
1.27		15	0.36		
1.91		20	0.48		
2.54	13	25	0.60	0.60	**4.6**
5.08	20	33	0.80	0.80	**4.0**
6.35		35	0.85		
7.62		36	0.87		

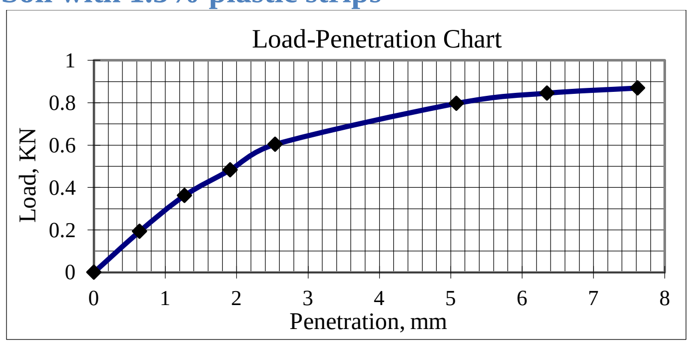


Figure E-2: **Load-penetration curves of Soil with 1.5% plastic strips (Soaked CBR)**

Appendix E3: Determination of Soaked CBR for Soil with 2.5% plastic strips

Table E-3: **Soaked CBR penetration test result of Soil with 2.5% plastic strips**

CBR Data for soil with 2.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		8	0.19		
1.27		15	0.36		
1.91		22	0.53		
2.54	13	27	0.65	0.65	**5.0**
5.08	20	35	0.85	0.85	**4.2**
6.35		37	0.89		
7.62		38	0.92		

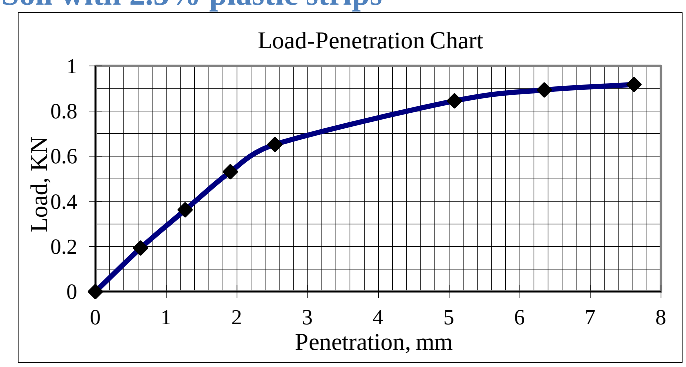


Figure E-3: **Load-penetration curves of Soil with 2.5% plastic strips (Soaked CBR)**

Appendix E4: Determination of Soaked CBR for Soil with 3.5% plastic strips

Table E-4: **Soaked CBR penetration test result of Soil with 3.5% plastic strips**

CBR Data for soil with 3.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		7	0.17		
1.27		14	0.34		
1.91		20	0.48		
2.54	13	24	0.58	0.58	**4.5**
5.08	20	32	0.77	0.77	**3.9**
6.35		34	0.82		
7.62		35	0.85		

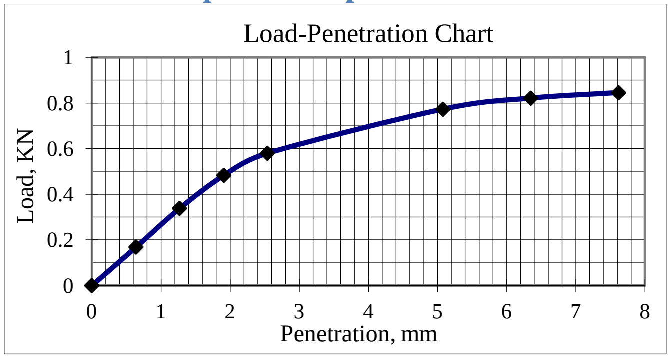


Figure E-4: **Load-penetration curves of Soil with 3.5% plastic strips (Soaked CBR)**

Appendix E5: Determination of Soaked CBR for Soil with 5% plastic strips

Table E -5: **Soaked CBR penetration test result of Soil with 5% plastic strips**

CBR Data for soil with 5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		5	0.12		
1.27		11	0.27		
1.91		16	0.39		
2.54	13	20	0.48	0.48	**3.7**
5.08	20	28	0.68	0.68	**3.4**
6.35		30	0.72		
7.62		31	0.75		

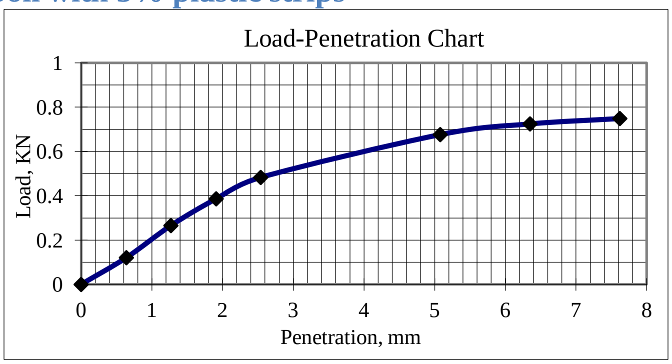


Figure E -5: **Load-penetration curves of Soil with 5% plastic strips (Soaked CBR)**

Appendix E6: Determination of Soaked CBR for Soil with 7.5% plastic strips

Table E -6: **Soaked CBR penetration test result of Soil with 7.5% plastic strips**

CBR Data for soil with 7.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		4	0.10		
1.27		9	0.22		
1.91		14	0.34		
2.54	13	18	0.43	0.43	**3.3**
5.08	20	25	0.60	0.60	**3.0**
6.35		27	0.65		
7.62		28	0.68		

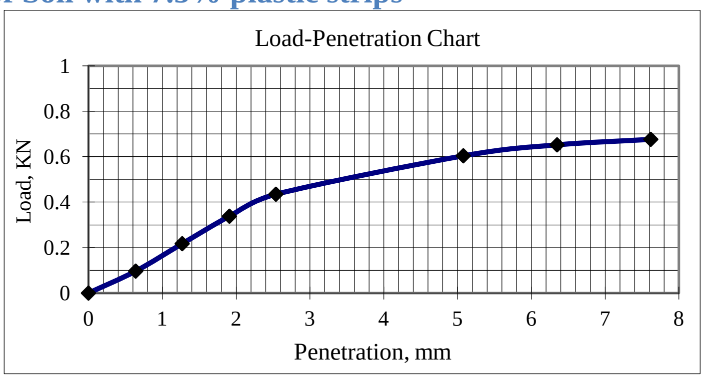


Figure E -6: **Load-penetration curves of Soil with 7.5% plastic strips (Soaked CBR)**

APPENDIX F: UNSOAKED CBR WITH VARYING PERCENTAGE OF PLASTIC STRIPS.

Appendix F1: Determination of unsoaked CBR for Soil with 0.5% plastic strips

Table F -1: **UnSoaked CBR penetration test result of Soil with 0.5% plastic strips**

CBR Data for soil with 0.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		183	4.42		
1.27		295	7.12		
1.91		375	9.06		
2.54	13	452	10.92	10.92	**84.0**
5.08	20	641	15.48	15.48	**77.4**
6.35		682	16.47		
7.62		690	16.66		

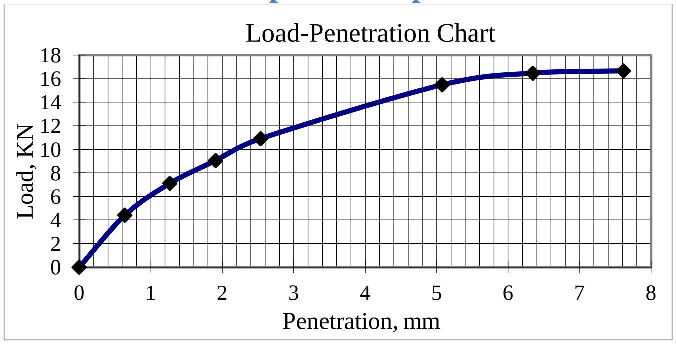


Figure F -1: **Load-penetration curves of Soil with 0.5% plastic strips (Unsoaked CBR)**

Appendix F2: Determination of unsoaked CBR for Soil with 1.5% plastic strips

Table F -2: **UnSoaked CBR penetration test result of Soil with 1.5% plastic strips**

CBR Data for soil with 1.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		199	4.81		
1.27		342	8.26		
1.91		429	10.36		
2.54	13	491	11.86	11.86	**91.2**
5.08	20	648	15.65	15.65	**78.2**
6.35		694	16.76		
7.62		715	17.27		

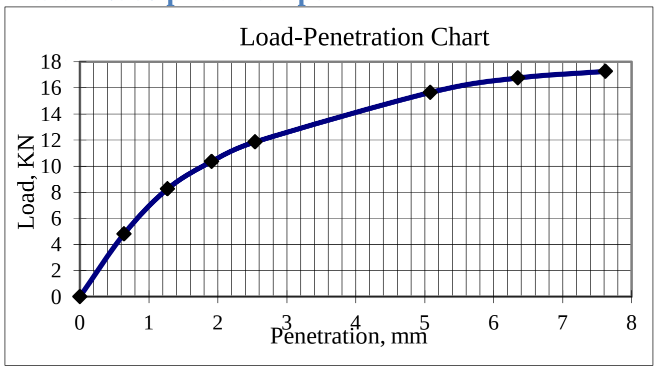


Figure F -2: **Load-penetration curves of Soil with 1.5% plastic strips (Unsoaked CBR)**

Appendix F3: Determination of unsoaked CBR for Soil with 2.5% plastic strips

Table F -3: **Unsoaked CBR penetration test result of Soil with 2.5% plastic strips**

CBR Data for soil with 2.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		238	5.75		
1.27		348	8.40		
1.91		473	11.42		
2.54	13	585	14.13	14.13	**108.7**
5.08	20	745	17.99	17.99	**90.0**
6.35		794	19.18		
7.62		820	19.80		

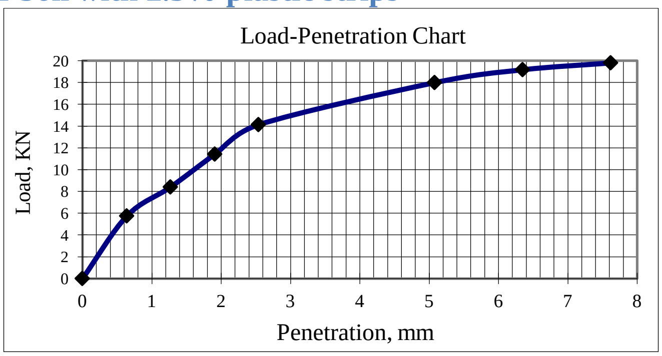


Figure F -3: **Load-penetration curves of Soil with 2.5% plastic strips (Unsoaked CBR)**

Appendix F4: Determination of unsoaked CBR for Soil with 3.5% plastic strips

Table F -4: **UnSoaked CBR penetration test result of Soil with 3.5% plastic strips**

CBR Data for soil with 3.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		273	6.59		
1.27		385	9.30		
1.91		463	11.18		
2.54	13	522	12.61	12.61	**97.0**
5.08	20	651	15.72	15.72	**78.6**
6.35		689	16.64		
7.62		705	17.03		

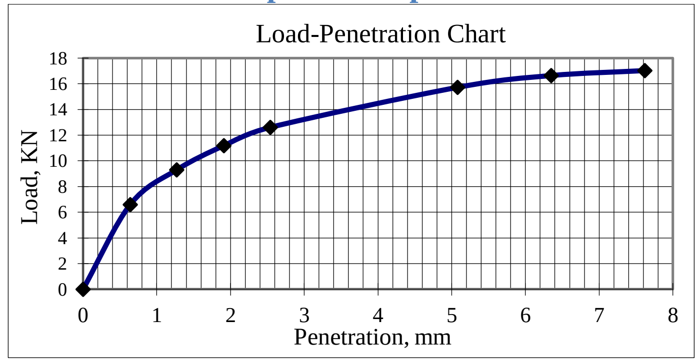


Figure F -4: **Load-penetration curves of Soil with 3.5% plastic strips (Unsoaked CBR)**

Appendix F5: Determination of unsoaked CBR for Soil with 5% plastic strips

Table F -5: **UnSoaked CBR penetration test result of Soil with 5% plastic strips**

CBR Data for soil with 5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		219	5.29		
1.27		309	7.46		
1.91		376	9.08		
2.54	13	427	10.31	10.31	**79.3**
5.08	20	560	13.52	13.52	**67.6**
6.35		600	14.49		
7.62		620	14.97		

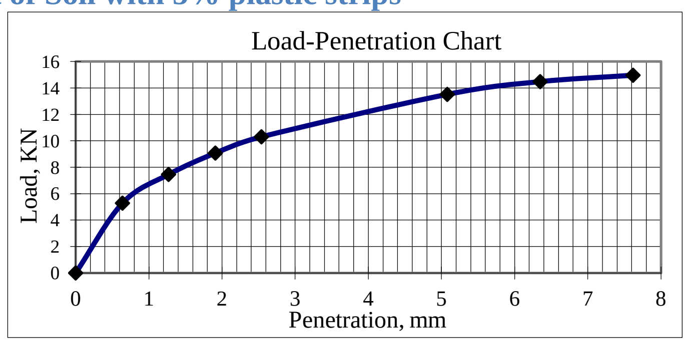


Figure F -5: **Load-penetration curves of Soil with 5% plastic strips (Unsoaked CBR)**

Appendix F6: Determination of unsoaked CBR for Soil with 7.5% plastic strips

Table F -6: **Unsoaked CBR penetration test result of Soil with 7.5% plastic strips**

CBR Data for soil with 7.5% plastic strip (56 Blows)					
Penetration (mm)	Std load (kN)	Gauge reading	Load	Corrected CBR	
			kN	kN	%
0		0	0		
0.64		90	2.17		
1.27		180	4.35		
1.91		255	6.16		
2.54	13	309	7.46	7.46	**57.4**
5.08	20	450	10.87	10.87	**54.3**
6.35		503	12.15		
7.62		550	13.28		

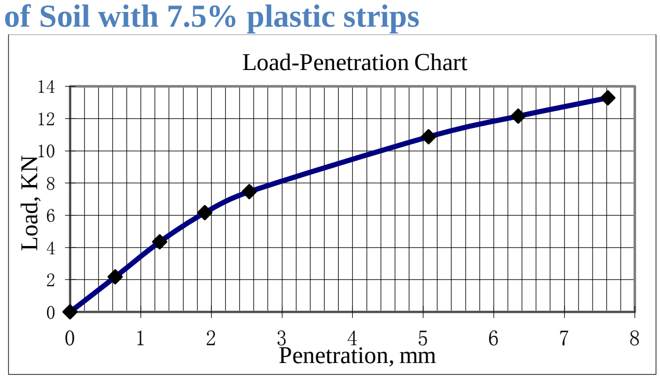


Figure F -6: Load-penetration curves of Soil with 7.5% plastic strips (Unsoaked CBR)