ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

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Soil Stabilization using plastic wastes

(Case Study on Addis Ababa)

A Thesis Submitted to the Graduate School of Civil Engineering and Architecture of Adama Science and Technology University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Civil Engineering [Geotechnical Engineering]

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DECLARATION

I hereby declare that the thesis entitled soil stabilization using plastic waste as Soil Stabilizing material has been carried out by me under the supervision of Dr Addis Alem Zeleke during the year 2017 as part of Master of Science program in Geotechnical engineering. All quotations and their sources are specifically acknowledged by means of reference

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LIST OF ABBREVIATIONS

AASHTO	American Association of Highway and Transportation Officials;
ASTM	American Society for Testing and Materials;
BS	British Standard;
CAH	Calcium aluminates hydrate;
CEC	Cat ion Exchange Capacity;
CBR	California Bearing Ratio;
CSH	Calcium Silicate Hydrate;
EC	European Commission;
EPS	Expanded Polystyrene;
ERA	Ethiopian Roads Authority;
FSI	Free swell index;
FSR	Free swell ratio;
IS	Indian Standard;
HDPE	High Density Poly Ethylene;
LLDPE	Linear low density Poly ethylene;
MDPE	Medium Density Poly Ethylene;
MDD	Maximum Dry Density;
MSW	Municipal Solid Waste;
OMC	Optimum Moisture Content;
PI	Plastic Index;
PL	Plastic Limit;
PET	Poly Ethylene Terephthalate;
PP	Polypropylene;
PS	Polystyrene;
PVC	Polyvinyl Chloride;
SP	Swelling pressure;
USCS	Unified soil Classification System;
UCS	Unconfined compressive strength;
USA	United States of America;

Units

gm	Gram
kg	Kilogram
km	Kilometer
kN	Kilo Newton
mm	millimeter
g/cm^3	Gram per centimeter cube
µm	Micrometer
kN/m^2	Kilo Newton per meter square
kPa	Kilo Pascal
^oC	Degree Centigrade
cc	Centimeter cube
Cm3	Centimeter cube

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ABSTRACT

There is a rapid increase in generation of waste plastics all around the country Ethiopia due to economic growth, changing consumption and production patterns. The capital city of Ethiopia annual consumption of plastic materials has increased from year to year and the disposal becomes serious problem and generating around two hundred thousand (200,000) tones in a year according to Addis Ababa city solid waste management report of February, 2010. Due to extremely long period required for natural decomposition, waste plastic is often the most visible components in waste dumps and open landfills.

On the other hand due to the industrialization, many infrastructure projects such as highways, railways, high rise, industrial buildings, airports and seaports construction has gained lot of importance in every part of the world. All these infrastructure projects can be built on and within the sub surface and it needs firm sub grade.

This research has been conducted to mitigate the challenges faced by the civil engineering field and the solid waste management field by analyzing clay soil -PET (Polyethylene Terephthalate) plastic waste composite. The research was conducted by taking soil sample from Addis Ababa around kality sub city and plastic bottle wastes from the surrounding. The laboratory work involved in this research particle size distribution of both soil sample and plastic chips, compaction test, California bearing ratio (CBR) test .CBR-Swell and unconfined compressive strength (UCS) for both soil sample after mixing with plastic chips in different proportion (1.2%, 2.4%, 3.6% and 4.8%) and optimum amount of plastic chips reinforced with black cotton soil is 3.6 % of the soil mass.

The test result showed that slight improvement of the engineering behaviors of plastic stabilized soil by decreasing CBR- Swell, increase CBR value of composite soil and slight increasing of UCS value but the MDD value of composite soil decrease and no change on optimum moisture content of the composite soil when the PET chips content increased up to optimum plastic content.

Therefore from this study it was found out that PET plastic stabilized soil meet only the minimum requirement of ERA pavement manual specification for use as a sub-grade material in road construction.

However only laboratory study was carried out in order to achieve the main objective of the study therefore recommended that a field trail to be done for assuring the research result.

CHAPTER ONE

INTRODUCTION

1.1 Back ground of the study

For any land based structure, foundation is very important and has to be strong to support the entire structure. In order for the foundation to be strong, the soil around it plays a very critical role. So, to work with soils, we need to have proper knowledge about their properties and factors, which affect their behavior. The process of soil stabilization helps to achieve the required properties in a soil needed for the construction work. From the beginning of construction work, the necessity of enhancing soil properties has come to the light ancient civilizations of the Chinese, Romans and Incas utilized various methods were so effective that their building and roads still exist. In India, the modern era of soil Stabilization began in early 1970's, with a general shortage of petroleum and aggregates, it becomes necessary for the engineers to look at means to improve soil other than replacing the poor soil at the building site. Soil stabilization was used but due to the use of obsolete methods and due to the absence of proper technique, soil stabilization lost favor, In recent time, with the increase in the demand for infrastructure, raw materials and fuel, soil stabilization has started to take a new shape. With the availability of better research, materials and equipment, it is emerging as a popular and cost effective method for soil improvement.

Geotechnical engineers often experience problems related to construction sites for which soil properties are unable to meet the required project specifications. The majority of these problems are as a result of some problematic soils such as expansive soils, collapsible soils, dispersive soils and soft clays. Consequently, many techniques have been developed and applied to improve on site soils in order to meet the intended purpose of the site development.

Here, in this project, soil stabilization has been done with the help of randomly distributed poly ethylene terephthalate fibers obtained from waste materials. In our country due to urbanization most of people use plastic bags, water, and perfume and beverage bottles. So both production and use of plastic increased on this time the result of plastic production and usage has an increase in plastic waste.

So according to the accessibility of waste plastic bottle and due the demerit of plastic waste as being non bio degradable, pose a health risk and difficult to reuse or recycle in practice to use as stabilizing material for weak sub grade have many advantage for both civil engineering field and for environmental aspect.

And many research previously has carried out to show reinforcing poor quality soil with fiber of PET plastic waste, greatly improves its performance and durability of weak soil.

Thus soil stabilization using plastic waste economic, environmental and engineering solution for our country case.

1.2 Justification of the Thesis

- ✓ Alternative method of soil stabilization technique
- ✓ It is environmental solution for plastic wastes in our country
- ✓ Waste management field will benefit by the reduction of PET plastic waste which is normally taken to land fill if not recycled or littered and hinders the proper flow water which leads to poor drainage
- ✓ By plastic waste could be used for improve subgrade soil strength
- ✓ Plastic bottle collection and preparation is labor intensive and can create job opportunity for many manpower

1.3 Statement of Problem

In our country Ethiopia, from total of solid waste collected from capital city Addis Ababa 1.58 % of plastic was collected from the city according to the city administration study on February, 2010.The source of waste plastics in the city come from population extensive use of plastic bags and bottle for shopping and material handling purpose because of the plastic bags and bottles are in expensive and light to carry for use and through purpose. But due to extremely long periods required for natural decomposition, waste plastics is often the most visible component in waste dumps and open landfills .This has resulted in the generation of millions of tons of waste leading to environmental challenges such as diminishing land fill space for disposal, release toxic gases, make land infertility, pollute water bodies, blocks the drainage channels and urban littering. However, the demand and supply of PET plastic product is on the rise.

Further more expansive soils cause damage to structures, particularly light buildings and transportation facilities, in many countries. According to Nelson and Miller (1992), the estimates of damage caused by expansive soils contribute much to the burden that natural hazards place on the economy.

So that an appropriate, cost effective technique to improve those soils can be have great benefit to both public and private developers dealing with ground for expansive soils.

The current research was convinced to find an alternative application of PET waste on expansive soil properties namely volume change and strength. The effective application of that waste to improve the properties of expansive soils that would lighten soil replacement cost for construction industry and kept the environment from plastic waste hazard on the other side.

Soil reinforcement is the process of integrating oriented or randomly distributed discrete fibers, like shredded plastics, tire shreds, and metal pieces in the soil (Anagno stopouls et al 2013).The importance of reinforcing soil increase bearing capacity ,stability, and reduce lateral deformation and settlement of poor quality geotechnical soil (Zaimogu l&Yetimogul 2011).However ,this technique is barely used in improving the performance and durability of geo-technical soil of poor quality (Tang et al.2006).

Thus, with these reasons it is very important to re-use the plastic wastes as soil stabilizer as soil reinforcement for improving the sub grade soils.

1.4 Objective of the Research

1.4.1 General Objective

The general objective of this study was to evaluate the effect of PET chips on the expansiveness of expansive soils. The soil strength improvement resulting from the stabilization of swelling soil with PET chips was also studied due to the role of soil strength in all civil engineering works. This is achieved through the following specific objectives.

1.4.2 Specific Objective

1. To improve both index and Engineering properties of soil using plastic wastes as an admixture
2. To provide an economical solution for soil stabilizing using plastic wastes
3. To determine the optimum plastic content to be used for stabilization purpose with this specific soil

1.5 Research Methodology

In order to achieve the above objectives of the study the following methodologies were adopted:-

i) Literature survey: different types of literatures; such as text books, academic journals, seminars and research papers pertaining to expansive soil, different soil stabilization techniques ,physical and mechanical behavior of PET and solid waste management of Addis Ababa were reviewed.

ii) Sampling and testing: material sampling and testing methods that are going to be employed are critical, since they are required to characterize material and physical properties of the soil.

iii) Sample preparation of the experimental work involved air drying, pulverization and sieving of the natural soil sample to the required particle sizes. Classification of soil was made by running grain size distribution and Atterberg limit tests.

iv) Plastic bottle samples waste were collected from dumped area and prepares for sampling by removing tags and caps after that cut the plastic bottles to small plastic chips and sieving of the plastic chips to the required particle size. Then Atterberg limit, , compaction ,CBR-swell ,California bearing ratio and UCS tests are carried out on natural soil as well as on soil-PET mix to study the effect of the stabilizer (PET chips) on different proportion expansive clay soil was tested by mixing with the following PET amount ;

0% of PET Chips

1.2% of PET Chips by dry weight of the soil

2.4 % of PET Chips by dry weight of the soil

3.6 % of PET Chips by dry weight of the soil

And 4.8 % of PET Chips by dry weight of the soil

v) Analysis and discussion of test results: based on the theories and laboratory tests performed, the results obtained have been analyzed and discussed thoroughly.

vi) Formulation of conclusions and recommendations based on the results obtained and finally compiling and writing of the thesis work.

1.6 Research limitations

The findings of this research are limited on the following:-

- ✓ Not easily available researches specifically on this topic
- ✓ only one soil sample considered in this research which is expansive clay soil
- ✓ And also some experiments on PET chips physical and mechanical properties were not conducted due to lack of laboratory equipment though only particle size distribution of PET chips was determined.
- ✓ Due the physical behavior of the stabilizer not possible to conduct the atterberg limit of Composite soil
- ✓ The effect of room temperature on PET didn’t considered
- ✓ The length and width of fiber effect on soil stabilization was not determined

However, therefore, findings should be considered indicative rather than definitive for filed applications.

1.7 Lay out of The Study

This study is structured as stated below:

Chapter 1 Consists of introduction and states the background to the study, the reasons of carrying out this research, the problem statement, justification of the research the objective of the study, specific objective of the study, research limitation and methodology of the research

Chapter 2 Reviews the literature related to expansive soils and their stabilization. It focuses on the problems associated with these problem soils and alternative solutions using natural and synthetic fiber reinforcement technique. In addition plastic characteristics, solid waste management in Addis Ababa and previous literature of stabilization of soil using plastic waste.

Chapter 3 Describes the methodology followed to achieve the objective of the study. The tests to be performed during this research to meet the objectives of this study are also discussed. Various tests are carried out on expansive soils before stabilization and then repeated on stabilized expansive soils.

Chapter 4 Focuses on the analysis of the obtained test results as well as their discussion. The results of non-stabilized soils are compared with the results after stabilization.

Chapter 5 Provides overview of the effect of PET plastic waste chips on properties of expansive soils and the conclusions. In this chapter, the recommendations resulting from the comparison of obtained results and the objectives of the study are mentioned.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter looks at previous publications of different researchers on the subject matter. More so, this chapter presents an overview of expansive soil property and techniques of identification, characteristics of plastics, PET, fiber-reinforced soil, and case studies of fiber-reinforced soils. Furthermore, the chapter highlights the behavior of soil-PET plastic waste composite and potential applications of soil reinforced with PET plastic waste in civil engineering.

2.2 Expansive Soil

Expansive soil is defined as plastic clay soil that exhibits high volume change when its environmental conditions are altered from dry to wet. The degree of expansiveness depends on whether the soil mass contain active clay minerals or not. The most common active clay mineral is montmorillonite. The problems of expansive soil in civil engineering structures were first identified in the late 1930's. Since then so many countries reported the problem.

Expansive soil is a major problem soil of Africa and other parts of the world. Large parts of Ethiopia are covered by black and gray expansive soil. Most of the structural damage on expansive soil results from the differential rather than the total movement of the foundation soil as a result of swell. Damages can occur within a few months following construction, may develop slowly over a period of about 5 years, or may not appear for many years until some activity occur to disturb the soil moisture equilibrium.

The degree of expansiveness of the soils varies from place to place depending upon type of parent material, climate and topography. Amount of clay minerals in the soil, thickness of expansive soil zone, and thickness of the active zone also affects the degree of shrinkage and swell.

Types of structures most often damaged from swelling soil include foundation and walls of residential and light (one-or two-story) buildings, highways, canal and reservoir linings, and retaining walls. Lightly loaded one-or two-story buildings, warehouses, residences, and pavements are especially vulnerable to damage because these structures are less able to suppress the differential heave of the swelling foundation soil than heavy, multi-story structures.

2.3 Origin of Expansive Soil

The origin of expansive soils is related to a complex combination of conditions and processes that result in the formation of clay minerals having a particular chemical makeup which, when in contact with water, will expand. The conditions and processes which determine the clay mineralogy include composition of the parent material and degree of physical and chemical weathering.

The parent materials that give rise to expansive soil are classified into two. The first group comprises the basic igneous rocks, which are low in silica, generally about 45% to 25% and rich in metallic base such as pyroxenes, amphiboles, biotitic and olivine. Such rocks include the basalts and volcanic glass. The second group includes sedimentary rock that contains montmorillonite as a constituent. These include shale’s and clay stone, and limestone and marls rich in magnesium.

There are two fundamental molecular structures as the basic units of the lattice structure of clay soils. These are the silica tetrahedron and the alumina octahedron. The silica tetrahedron consists of a silicon atom surrounded tetrahedral by oxygen ions. The alumina octahedron consists of an aluminum atom surrounded octahedral by six oxygen ions. When each oxygen atom is shared by two tetrahedral, a plate- shaped layer is formed. Similarly, when each aluminum atom is shared by two octahedron, a sheet is formed.

The silica sheets and the aluminum sheets combine to form the basic structural units of the clay particles. Various clay minerals differ in the stacking configuration. The major component of expansive soils, montmorillonite is a three layer clay mineral having a single octahedral sheet sandwiched between two tetrahedral sheets to give a 2 to1 lattice structure

2.3.1 Clay Minerals

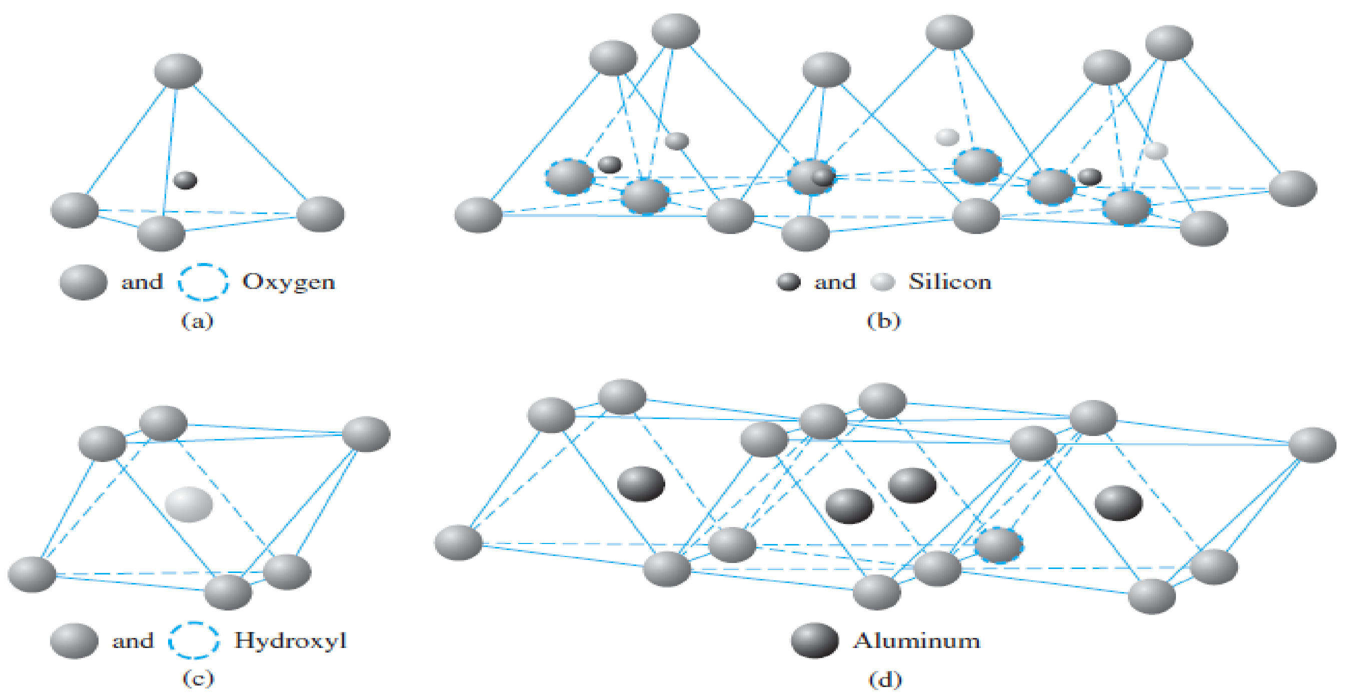
Many classification systems described clay minerals as particles which have an effective diameter of two microns or less (Chen, 1975). However, it has been found that all particles whose diameter is less than two microns are not necessarily clay minerals (Sarsby, 2000). For this, the grain size doesn’t suffice to describe clay mineral; hence the necessity to study the mineralogical composition which is probably the essential property of fine-grained soils (Chen 1975). Das (2010) defined clay minerals as alumina -silicate compounds resulting from the combination of two basic units namely silica tetrahedron and aluminum octahedron.

Each tetrahedral unit is formed by a silicon atom surrounded by four oxygen atoms and the combination of identical units’ results in the formation of a silica sheet in which neighboring tetrahedral share three oxygen atoms at the base of each tetrahedron (Das, 2010). On the other hand, an octahedron consists of an aluminum atom surrounded by six hydroxyls. The combination of octahedral units leads to the formation of octahedral sheet also called gibbsite sheet. When the aluminum atom is replaced by the magnesium, the octahedral sheet is named a brucite sheet (Das, 2010). Those basic units and their combination are illustrated in Figure 2.1.

According to Chen (1975), Sarsby (2000) and Das (2010), there exist a number of clay minerals among which the important ones are kaolinite, illite and montmorillonite. All of them consist of a combination of silica-gibbsite sheets and are characterized by high specific surface i.e. the surface area per unit mass. According to Snethen et al. (1975), "the small grain size and resulting large surface are due to the clay mineral's origin by weathering or digenetic alteration of pre-existing minerals".

Das (2010) describes the three important clay minerals as follows:

- ❖ Kaolinite is composed of a combination of repeating layers of elemental silica-gibbsite sheets held together by hydrogen bonding in 1:1 lattice. The estimated specific surface of kaolinite is 15m2/g.
- ❖ Illite is composed of a gibbsite sheet sandwiched between two silica sheets bonded together by potassium ions which are balanced by the negative charge left by the substitution of aluminum for some silicon in the tetrahedral sheets. This phenomenon consisting in substitution of an element by another one without alteration of crystalline form is called isomorphs substitution. The specific surface of illite particles is estimated to $80m^2/g$.
- ❖ Montmorillonite has the same structure as illite with attracted water molecules between layers instead of potassium ions. The specific surface is estimated to $800m^2/g$



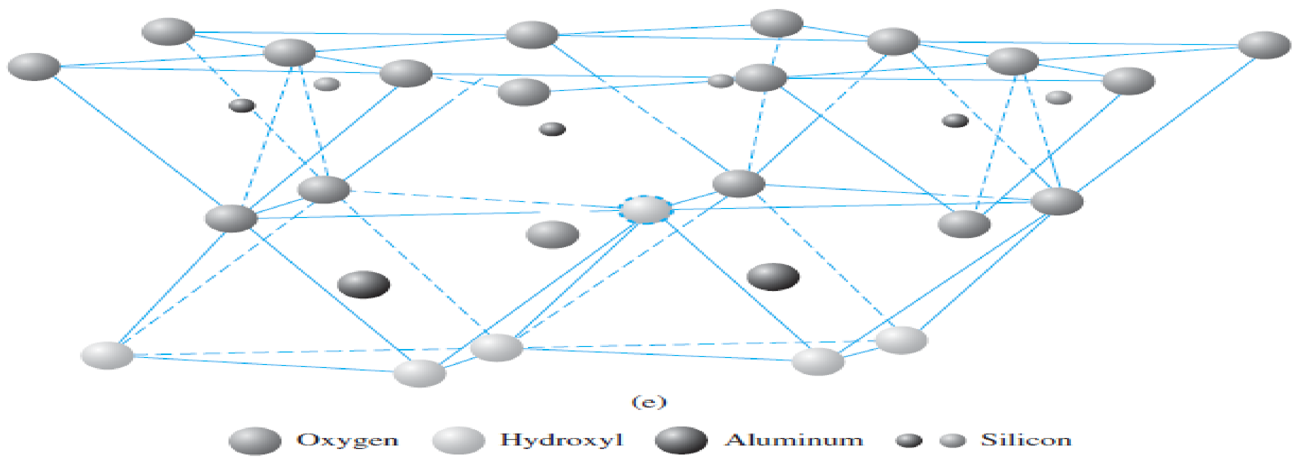


Figure 2.1 (a) Silica tetrahedron; (b) Silica sheet; (c) alumina octahedron; (d) octahedral (gibbsite) sheet; (e) elemental silica-gibbsite sheet (Das, 2010).

In addition to those important clay minerals, other common clay minerals are chlorite, halloysite, vermiculite and attapulgite (Das, 2010). The diagram in Figure 2.2 illustrates the structures of the three important clay minerals mentioned above.

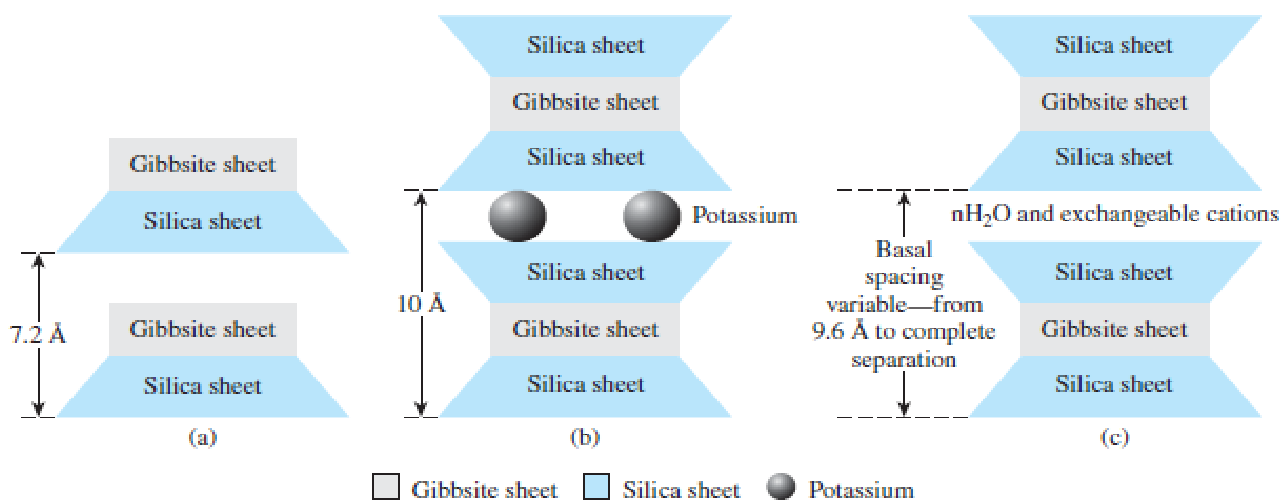


Figure 2.2 Diagram of the structures of (a) kaolinite; (b) illite; (c) montmorillonite (Das, 2010)

2.3.1.1 Some typical clay characteristics

Some typical characteristics of clay particles are their properties including cohesion, adhesion, plasticity, consistency and activity. Hunt (2007) describes those properties as follows:

- ✓ Cohesion of clay is defined as its ability to stick to itself. It results from a bond developing at the contact surfaces of clay particles, caused by electrochemical attraction forces. Two elements are responsible for the cohesion of clay particles namely the high specific surface of the particles (surface area per unit weight), and the electrical charge on the basic silicate structure resulting from ionic substitutions in the crystal structure.

- ✓ Adhesion of clay is its ability to stick to another material to which it comes into contact.
- ✓ Plasticity is the ability of a material to undergo a change in shape without undergoing a change in volume, with its moisture content held constant.
- ✓ Consistency is defined as the relative ease with which a soil can be deformed. It involves cohesion and adhesion as well as its ability to resist deformation and rupture. In other words, soil consistency refers to the description of the resistance of a soil at various moisture contents to mechanical stresses or manipulations. The consistency of soils is generally described at three soil moisture levels: wet, moist and dry. With decreasing moisture content, clays pass from the fluid state (very soft) through a plastic state (firm), to a semisolid state, and finally to a hard brick-like state. The moisture contents at the transitions between these various states are defined by the Atterberg limits, which vary with the clay type and its purity.
- ✓ Activity is defined as the ratio of the plasticity index to the percent by weight finer than 2 μm, Hunt (2007) and Mitchel (1976) respectively summarized other characteristics of some clay minerals in tables 2.1 given here below.

Table 2.1 Characteristics of some clay minerals (Mitchell, 1976, summarized in Nelson and Miller, 1972).

Mineral Group	Basal Spacing(A)	Particles features	Inter layer bonding	Specific Surface	Atterberg Limits			Activity (PI/% clay)
					LL (%)	PL(%)	SI (%)	
Kaolinites	14.4	Thick, stiff 6-sided flakes 0.1 to 4 x 0.005 to 2μm	Strong hydrogen bonds	10-20	30-100	25-40	25-29	0.38
Illites	10	Thin, stacked plates 0.003 to 0.1 x 1.0 to 10 μm	Strong potassium bonds	65-100	60-120	35-60	15-17	0.9
Montmorillonites	9.6	Thin, filmy, flakes > 10 Å x 1.0 to 10	Very week van der Waals bonds	700-840	100-900	50-100	8.5-15	7.2

2.3.1.2 Expansive clay minerals

Some clay minerals such as montmorillonite, vermiculite, chlorite and mixed-layer combinations of these minerals between them or with other clay minerals, which exhibit significant volume change due to variations in moisture content, are termed expansive clay minerals (Snethen et al, 1975). On the other hand, kaolinite and illite, which don't exhibit the same amount of expansion as montmorillonite, vermiculite or chlorite, are classified as non-swelling clay minerals. Although kaolinite is considered as a non-swelling clay mineral, "halloysite, the tubular, hydrous member of kaolinite group may exhibit expansive properties" (Snethen et al, 1975).

According to Snethen et al (1975), the high volume change exhibited by clay minerals is due to three factors viz. the electrical charge characteristics, degree of crystallinity, and size. The charge deficiency of clay minerals which mainly results from the lattice substitution plays a great role in their volume change.

2.4 Identification of Expansive soil

Like other problem soils, the identification of expansive soils is an important phase for every construction project. "Early identification of expansive soils, during the reconnaissance and preliminary stages of a project, is essential to allow for appropriate sampling, testing, and design in later stages" (Nelson and Miller, 1992). For that reason, prior to any other construction project phase, the site investigation should be conducted for identification of the site soil as a problem soil or not for appropriate measures. This identification is followed by soil sampling and preliminary tests which provide the key information for adequate and economic decision making and design.

2.4.1 Field Identification

Soils that can exhibit high swelling potential can be identified by field observations, mainly during reconnaissance and preliminary investigation stages. Important observations include (Chen, F.H., 1988; Nelson, D.J., and Miller, J.D., 1992):

- ✓ Usually have a color of black or grey.
- ✓ Wide or deep shrinkage cracks.
- ✓ High dry strength and low wet strength.
- ✓ Stickiness and low traffic ability when wet.
- ✓ Cut surfaces have a shiny appearance.
- ✓ Appearance of cracks in nearby structures.

Arid and semiarid areas are particular trouble spots because of large variations in rainfall and temperature.

2.4.2 Laboratory Identification

Laboratory identification of expansive soils can be categorized into mineralogical, indirect and direct methods

2.4.2.1 Mineralogical test:-

This method is used for identifying the mineralogy of clay particles such as characteristic crystal dimensions, characteristic reaction to heat treatment, size and shape of clay particles and change deficiency and surface activity of clay particle.

But these methods are not suitable for routine tests because of the following reason; they are time consuming, require expensive test equipment and, the results are interpreted by specially trained technicians

2.4.2.2 Indirect Methods:-

These methods include simple soil property test that a practicing engineer resort to use for identifying expansive soil. Such tests are easy and can be performed in most soil mechanics laboratory, and yield an excellent indices of expansive properties. The various tests under these methods are:

Atterberg limits

In this method, measurement of the plasticity and the shrinkage characteristics of the soil are conducted for identification of all engineering soils and provide a wide acceptable means of rating. Especially when they are combined with other tests they can be used to classify expansive soils. The different types of limits under this method are Liquid limit, Plastic limit and Shrinkage limit. The relation between the swelling potential of clays and the plasticity index is shown in Table 2.5.

Linear shrinkage tests

Linear shrinkage is the change in length of a soil sample as it dries to the shrinkage limit, SL, Expressed as a percentage of the original length. This test also in combination with other tests is used for classification of expansive soil

Table 2.2 Relation between swelling potential, shrinkage limits and linear shrinkage (Altmeyer, 1955).

Linear Shrinkage	SL %	CBR Swell	Degree of Expansion
<5	>12	<0.5	Non critical
5-8	10-12	0.5-1.5	Marginal
>8	<10	<1.5	Critical

Expansion Index test

This test applies on soil passing No 4 sieve (4.75mm) and is similar to PVC tests with the exception that it is conducted under constant surcharge (Nelson and Miller, 1992). In addition to this, before wetting the sample, it is brought to the degree of saturation approximately equal to 50%. The expansion index, expressed to the near whole number, is given by the following equation (Nelson and Miller, 1992).

$EI=100x\Delta hxF$

Where Δh = percent swell and

F = fraction passing No. 4 sieve.

Different categories of expansion potential, established based on the expansion index, are shown in table 2.3 (Nelson and Miller, 1992).

Table 2.3 Categories of expansion potential (Nelson and Miller, 1992)

Expansion Index EI	Expansion- potential
0-20	Very low
21-50	low
51-90	Medium
91-130	High
>130	Very high

2.4.2.3 Direct Methods

These methods offer the most useful data by direct measurement; and tests are simple to perform and do not require complicated equipment. Testing should be performed on a number of samples to avoid erroneous conclusions. Direct measurement of expansive soils can be achieved by the use of conventional one-dimensional consolidometer.

2.5 Classification of Expansive Soil

Parameters determined from expansive soil identification tests have been combined in a number of different classification schemes. The classification system used for expansive soils are based on indirect and direct prediction of swell potential as well as combinations to arrive at a rating. There are a number of classification systems. The following are some of the common methods.

2.5.1 Classification Using General Methods

The most widely used general classification systems are:

i. AASHTO Classification

As shown on Table 2.4 soils rated A-6 or A-7 by AASHTO can be considered potentially expansive (Nelson, D.J., and Miller, J.D., 1992).

Table 2.4 AASHTO soil classification chart

General classification	Granular Materials (35 percent or less of total sample passing No. 200)							Silt-clay Materials (More than 35 percent of total sample 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											
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 max	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					

ii. Unified Soil Classification Systems

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

Category Soil classification system

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:

- ✓ All clay soil and organic soils exhibit high volume change.
- ✓ All clayey gravels and sands and all silts exhibit moderate volume changes.
- ✓ All sands and gravels exhibit little or no expansion.

iii Method of Chen

Chen (1988) presented a single index method for identifying expansive soils using only plasticity index. Chen suggested four classes of clays according to their plasticity index shown in Table 2.5

Table 2.5 Relation between the swelling potential of clays and the plasticity index (Chen, 1988)

Swelling Potential	**Plastic Index**
Low	0-15
Medium	10-15
High	20-35
Very High	35 and above

iv Method of Skempton

This method is developed, by combining Atterberg limits and clay content into a single parameter called Activity. Activity is defined as:

A" = PI/ (percentage by weight finer than 2µm)
Where

A"= activity

PI= plasticity index

Skempton suggested three classes of clays according to their activity shown in Figure 2.3

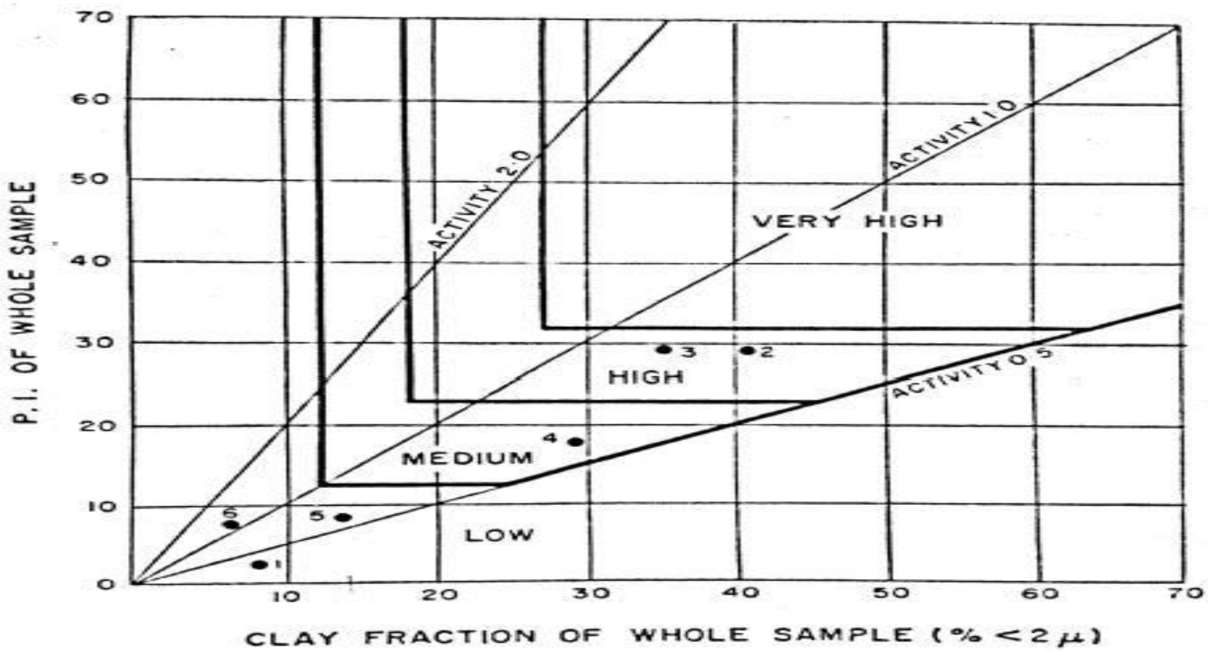


Figure 2.3. Determination of potential expansiveness of soils (Van der Merwe, 1964).

2.6 Plastics

2.6.1 Introduction to Plastic

Polyethylene (PE) is a common thermoplastic polymer used throughout the world. Its name originates from the monomer ethane used to create the polymer produced through radical polymerization, anionic polymerization and cationic polymerization. This is because ethane does not have any extraneous groups which influence the stability of the propagation head of the polymer. Each of these methods results in a different type of PE. (Geo-Synthetic in Civil engineering Edited by R.W.Sarsby).

Plastic (resin or polymer) pellets are the raw materials that are melted and molded to create plastic products. Plastic may be formed into of various shapes (e.g., spherical, ovoid, cylindrical), sizes (range: 1- to 5-mm diameter), and colors (most commonly clear, white, or off-white). The wide variety of plastic products produced internationally has created a demand for many different polymers, or resins' estimated amount of 60 billion pounds of resin are manufactured annually in the United State. The most commonly produced resins include polyethylene, polypropylene, and polystyrene. (EPA 1992 plastic pellets)

2.6.2 Basic Properties of Plastic Product

Generally properties of plastic material are influenced by internal structure, chemical additives and supplementary. (Earth Structure in Transport water and Environmental Engineering by I.Vanicek.M.Vanicek)

Durability is a major issue for all polymeric material including plastic due to Physical and Mechanical properties of plastics material and few of the desirable basic properties of plastic included (EAP 1990)

I. Design Flexibility –plastic can be modified for wide verities of end use

II. Height resistance to Corrosion

III. Low weight

IV. Shatter resistance

V. Resistance to moisture

2.6.3 Waste plastic and Its Source

Plastic is everywhere in today s lifestyle .Most of plastic products for public consummation use and through purpose .And most of the Waste plastic is collected from households, commercial centers and industry

Table 2.6 Waste Plastic and Its source (Anzar Hamid Mir Feb2015, Use of plastic waste in pavement Construction)

Waste plastic	**Origin**
Low-density polyethylene (LDPE	Carry bags, sacks, milk pouches, bin lining, Cosmetic and detergent bottle
High-density polyethylene (HDPE)	Carry bags, bottle caps, water supply pipes , house hold articles etc.
Poly Ethylene Teraphalate	Drinking bottle etc.
Poly propylene	Bottle caps & Closure, wrappers of detergent, biscuit vapors baskets, microwave trays for readymade meal etc.
Poly styrene	Yoghurt pot, clear egg packs, bottle caps, foamed polystyrene Food trays, egg box, disposable cups, protective packaging etc.
Polyvinyl Chloride	Mineral water bottles, credit cards ,toys ,pipe and gutter, electrical fitting, furniture, folders and pen holder, medical disposal etc.

2.7 PET (polyethylene terephthalate)

The abbreviation PET stands for polyethylene terephthalate, a substance that, from a chemical point of view, is a polyester. Polyesters were first manufactured in the 1930’s, for use as synthetic fibers. PET is a strong synthetic fiber and resign and produced by the polymerization of ethylene glycol and terephthalic acid. PET is manufactured from terephthalic acid (a dicarboxylic acid) and ethylene glycol (a dialcohol). The two substances react together to form long polymer chains, with water as a by-product. As in most processes of polymerization, a catalyst is also required

2.7.1 Characteristics and Use of PET

PET is a virtually unbreakable, colorless, lightweight, transparent polymer. As PET is transparent, it allows the content of the container to remain visible. The robustness of PET is vitally important for beverage packaging since it makes the bottles completely safe for on-the-go or sports use. PET is also very light. Over recent years, the weight of PET bottles has been constantly reduced and today a bottle can weigh as little as 20 to 30 grams. This process of light weighting represents a true benefit with regard to the environmental impact a bottle will have during its lifetime: production, transport to the consumer and end of life cycle. With such excellent material properties, PET is widely used today as a packaging material for beverages and is one of the most suitable materials for the packaging of natural mineral and spring water.
PET is also known as (POLYETHYLENE TEREPHTHALATE) is highly crystalline thermoplastic with high tensile strength, stiffness, hardness, low coefficient of friction and very low moisture absorption. This broad range of useful properties in addition to its ability to provide excellent dimensional stability and low wear rates make it an engineering plastic of choice for many applications involving sliding and continuous high loads. (Polymath basic material for engineer)

Furthermore, PET can be used in automobile tire yarns, conveyor belts and drive belts, reinforcement for fire garden hoses, seat belts (Ganga Rao et al, 2006).Also PET can be used in the manufacture of geotextiles for stabilizing drainage ditches, culverts, and rail road beds.

2.7.2 Worldwide production and Use of PET

PET bottles represent a large fraction of total packaging waste and are easy to sort automatically. Large quantities of used (post-consumer) bottles are therefore available and can be economically recycled. Over recent years, the number of bottles collected for recycling in Europe has grown significantly. In 2011, some 1,590,000 metric tons of used PET bottles were collected and recycled Europe-wide (Figure 4), representing approximately 51% of all the PET bottles in the marketplace. In certain countries, such as Germany, Iceland, Norway and Switzerland, the amount recycled accounted for approximately 90% of the total. However in our country Ethiopia no written document or data about PE bottles actual production per year and also how much of the total recycled .Furthermore, plastic bottles waste in Capital town Addis Ababa disposes temporary storage besides of the main road and main square of Addis Ababa.

2.8 Management of Plastic Waste

"Solid waste management is defined as the process of controlling of waste generation, storage, collection, transporting and disposal of solid wastes. Integrated solid waste management includes the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals (Tchobanoglous and Kreith, 2002). Current solid waste management technologies can be summarized as: source reduction, recycling, waste transformation and landfilling (Aklilu Adeferese June 2015)

2.8.1 Solid waste management in Addis Ababa

The current daily waste production of Addis Ababa is estimated to be 765 tones. The waste production rate per person is about 0.45 kg/day. However, there is seasonal variation in the per capita solid waste generation. From the daily solid waste generated in Addis Ababa, 65% is collected, 5% recycled and 5% composted. The remaining 25% is simply dumped on open sites, drainage channels, rivers and valleys as well as on the streets. 70% of the waste generated comes from households, 9% from commercial areas and 6% street sweeping, 5% from industrial waste and the remaining from hotels, hospitals*(Source:* Ethiopia Solid waste and land fill country profile and action plan (community development (2011)

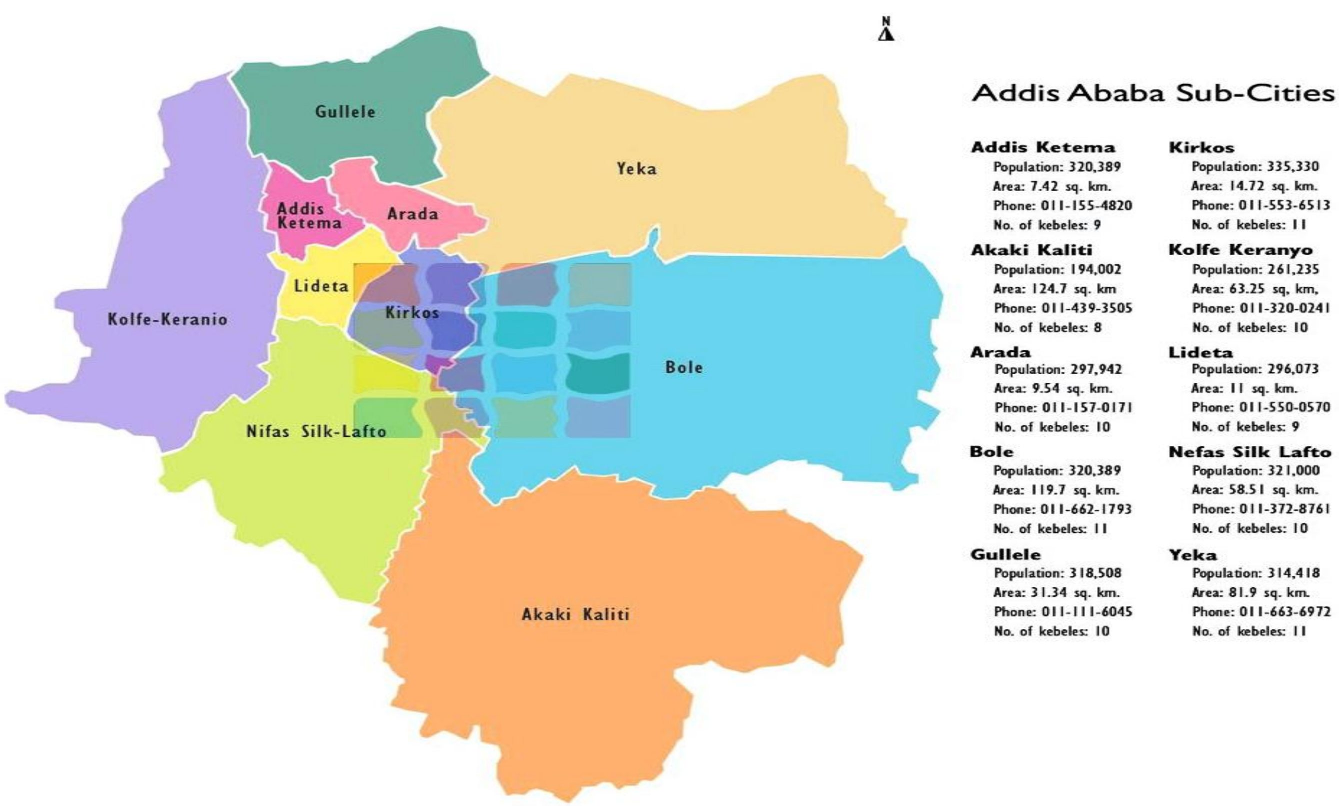


Figure 2.4.Location map of Addis Ababa Sub City, Source (Caro gilb world)

2.8.2 Solid Waste Separation, reusing and Recycling Process

Sorting of waste takes place at various levels in the waste management process

- ✓ The first level of source separation is at household: plastic materials, glass, bottles, are considered as valuable and usually sorted out for reuse
- ✓ Several collectors represent the second stage: Street boys, private sector enterprises, scavengers at municipal landfill, and the korales
- ✓ Recyclable materials include: metal, wood, tires, electricity products, old shoes and plastic.
- ✓ Transportation and Disposal: municipality transports the solid wastes from secondary collection to final disposing site (according to AACSWM)

2.8.3 Management of plastic wastes in landfill

Plastics are non-degradable and do not affect the structural integrity of a landfill. However, plastic wastes do affect the landfill capacity due to their large numbers and continued plastics production.

In Addis Ababa there is currently two solid waste dump site where all collected waste is disposed off. The site known as “Rappi” or “Koshi “which is south east part of the city and around “Sendafa” there is also a new Solid waste land fill damping site established there. However old land fill site rappi has established before 47 years ago and Occupy 32 hectare of land for damping site.((according to AACSWM).More over beside cover land capacity also it is cause of disease for the people around the land fill and the community not support land fill area establishment.

2.9 Soil Stabilization

Soil stabilization is a process whereby increased strength and stability of the soil is attained mainly by mechanical or chemical means. The most common improvements achieved through stabilization include better soil gradation, reduction of plasticity index or swelling potential, increase in durability and strength. In wet weather, stabilization may also be used to provide a working platform for construction operations. These types of soil quality improvement are referred to as soil modification. Soil stabilization decreases damage caused by settlement, washing and collapsing (Departments of US Army, 1994).

The Soil improvement or Stabilization for Construction of Roads, Building and Slope Stability and the like will be achieved by the following Methods

1. Mechanical Stabilization
2. Hydraulic Stabilization

3. Chemical Stabilization
4. Stabilization by inclusion and confinement

2.9.1 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.

2.9.2 Hydraulic Stabilization

In this Method pore water pressure is forced out of the ground through drains or wells lowering the ground water level by dewatering, and vertical drains can be applied for coarse-grained or cohesion less soil. However, for fine grained or cohesive soils application of the long term of preloading will be applied (Nicholson 2014)

2.9.3 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 (Gautrans, 2004).

2.9.4 Stabilization by inclusion and confinement

This method of Soil Stabilization is considered as strengthening soil by materials such as meshes, bars, strips, fibers and fabrics corresponding to the tensile strength. Soil reinforcement depends on friction between soil and reinforcement element leading to tensile force mobilization. Fiber reinforced soil behaves as composite material in which fibers of relatively high tensile strength are embedded in a matrix of soil. Shear Stresses in the mobile tensile resistance in the fiber, which turns imparts greater strength to the soil.

2.9.5 Soil Reinforcement with randomly mixed Soil

Soil reinforcement as one of the ground /soil improvement technique is a process of using synthetic or natural fiber material to improve the soil /ground characteristics or properties (Hausmann1990)d Soil reinforcement with randomly distribute fiber can be done by using either natural or synthetic fiber .Natural fiber can be obtained from coconut fiber, palm fiber, barely straw fiber ,bamboo fiber ,cane fiber .Whereas synthetic or manmade fibers are polypropylene (PP) fiber, polyester (PET) fibers ,polyethylene (PE) fibers ,Glass fiber, Nylon fiber, polyvinyl alcohol(PVA) fibers .

Soils are strong in compression but weak in tension this weak property of soil is improved by introducing reinforcing elements in the direction of tensile stress. The reinforcement is placed or layered at specific direction and position, more or less the same way as steel in concrete. The end product is called reinforced soil, and effectively used for retaining structures, embankments, footings and subgrade etc.

Randomly distributed fibers in soil are among the latest technique in which fibers of desired type and quantity are added in the soil, mixed and laid. Thus the method of preparation of randomly mixed soil is similar to conventional stabilization techniques. Randomly mixed soil is different from the other reinforcing methods in its orientation.

Fiber reinforced soil can be used effectively in embankment, sub grade, sub base and other such cases. The fibers themselves should be readily available, non-degradable capable of being easily blended in to the soils and compacted.

2.9.6 Previous studies of fiber reinforced soil

Gray and Ohashi (1983**),** researched about mechanics of fiber reinforcement in sand, where direct shear tests were performed on dry sand reinforced with natural fibers, synthetic fibers and metal wires. The reinforcements included common basket reeds, PVC plastics, Palmyra (a tough fiber obtained from the African Palmyra palm), and copper wire. The diameter of the fibers used ranged from 1 to 2mm with lengths ranging from 2 – 25 cm; and 0.25 – 0.5% fiber inclusion in the dry sand was used (Gray & Ohashi 1983). The results showed an increase in the shear resistance that was directly proportional to the fibers that were oriented at 60^o to the shear surface. The research findings were found to be relevant in solving diverse problems like stabilizing of sandy, coarse textured soils in granitic slopes, dune and beach stabilization by pioneer plants, tillage in root permeated soils, and soil stabilization with low modulus.

Benson & Khire (1994), used strips of reclaimed High Density Polyethylene (HDPE) as reinforcing fiber in sand; with fiber contents ranging from 1% to 4%. California Bearing Ratio (CBR); resilient modulus and direct shear tests were the main experimental laboratory tests carried out in this research. Test results showed that reinforcing sand with strips of reclaimed HDPE does not only enhance its resistance to deformation but also increases its strength (Benson & Khire 1994). The study suggests that sand reinforced with strips of reclaimed HDPE may be useful in highway and light-duty geotechnical applications.

Chegenizadeh et al (2011), investigated on stabilization of soil using fiber inclusion on CBR ratio. A series of laboratory investigation were carried out to evaluate effects of reinforcing the sub grade soil in pavements system with randomly distributed plastic fibers and natural fibers. The researcher were conducted CBR test on unreinforced samples as well as reinforced ones at different fiber contents (i.e.0.1%,0.3%) and different fiber length (i.e.10mm,25mm and 50mm).The test result showed that and the researcher concluded and findings drawn from the study are:-

1. The CBR value of Clay soil increased when the fiber content and fiber length increased

K.Geeth Manjarje et al(2011),researched on the compressibility and permeability behavior of plastic waste mixed sand .The researchers taken the following laboratory test on properties of sand and after mixing with plastic waste such as specific gravity, moisture content, dry density, relative density, Effective size ,coefficient of uniformity and angle of friction for sand length, width, specific gravity and tension load for plastic waste and compressibility index and permeability of sand soil after mixing with different proportion of plastic waste.

The experimental study used different proportion of plastic waste for this research and the laboratory test result showed that the compressibility of soil reduced with increasing in plastic waste content and with an increase of the percentage of plastic waste the void ratio and permeability decreased. The findings and conclusions of the study can be summarized as follows:-

- ✓ The compressibility of soil reduces as the plastic content increased because the density of plastic being less, more voids where occupied with plastic waste, the compressibility of soil reduces as the plastic waste content increased.
- ✓ The permeability of soil reduce with an increase the percentage of the plastic because of the permeability of plastic is less than the soil
- ✓ The plastic fiber content in the soil was increased from 0.5% to 1% the permeability decrease

Anagnostopoulos et al (2013), investigated the engineering behavior of soil reinforced with polypropylene. Sandy silt and clay soils were reinforced with polypropylene fiber with their inclusion of 0.3% and 1.1%. Polypropylene fibers were tested and tests included: diameter, length, density, tensile strength, elongation at break, elastic modulus, and aspect ratio were determined. Also, Atterberg limit, particle size distribution, specific gravity tests were carried out on study soils to establish their properties. Furthermore, direct shear box tests were performed on soil-fiber composite. In conclusion, it was noted that fiber inclusion of up to 0.5% of sandy silt soil and 0.9% of silty clay soils improved the peak shear stress by 59% and 24% respectively (Anagnostopoulos et al. 2013).

Acharyya et al (2013), investigated the improvement of undrained shear strength of clayey soil with PET bottle strips. The clayey soils were mixed with 10% and 20% of sand; and PET shreds had a length ranging from 5mm to 15mm, with a width of 5mm, and fiber inclusion of 0.5% - 2% by weight of soil. Atterberg limit, compaction, unconfined compressive strength and direct shear tests were carried out for physical properties determination of soil and soil-fiber composite. Tests carried to achieve the properties of PET plastic strips included width, thickness, tensile, and density. Unconfined compressive strength of soil-fiber composite increased as percentage of PET inclusion increased up to 1% (Acharyya et al. 2013) as the results revealed.

F.C Chebet and D.kalumba (2013), investigated the engineering behavior of soil reinforced with polyethylene plastic waste. Sandy soils of Klipheuwel sands and Cape flats sands were used; and High Density Polyethylene (HDPE) plastic waste of length (15mm – 45mm), width (6mm – 18mm) at an increment of fiber (0.1%, 0.2%, 0.3%) were used. Engineering physical properties of sand were determined by carrying out specific gravity, particle size distribution, and direct shear box tests. Also index and mechanical fiber properties such as density, tensile modulus, and tensile strength were determined. Furthermore, direct shear box tests for fiber-soil composite were performed for normal stresses of 25kPa, 50kPa, and 100kPa at a shear loading rate of 1.2mm/min (Kalumba & Chebet 2013). In conclusion, fiber addition of 0.1% to the soil resulted in an improvement of peak friction angle from 38.50 to 44.50, also fiber increment of 0.1% to the soil caused an improvement in the friction angle, but fiber increment of 0.2% and 0.3% caused a decrease in the friction angle

Kartik Jindal (2014), investigated on effect of waste plastic on the strength characteristic of the sub grade for the flexible pavement. The researcher considered as material locally available sand, HDPE, LDPE and PP**.** The experimental study involved grain size distribution, Atterburg limit, Coefficient of curvature, uniformity coefficient and compaction test and also after mixing with different proportion of plastic waste (HDPE, LDPE and PP) the following laboratory test taken such as compaction and CBR.

The result showed that CBR value increase with increase in HDPE content and it was maximum at 5% and after that it decreases with increase in content and maximum value of CBR is 26.9% according to Table 2.7

Table.2.7 Values of CBR @ different HDPE waste plastic content

HDPE waste plastic Content	0%	1%	2%	3%	4%	5%	6%	7%
CBR value (%)	7.9	5.4	3.5	14.9	24.2	26.9	21.7	9.9

The result showed that CBR value increase with increase in LDPE content and it was maximum at 5% and after that it decreases with increase in content and maximum value of CBR is 20.38% according to Table 2.8

Table.2.8 Values of CBR @ different LDPE- waste plastic content

LDPE waste plastic Content	0%	1%	3%	5%	7%	9%
CBR value (%)	7.9	8	11.1	20.38	18.6	18.6

The Result showed that CBR value increase with increase in PP content and it was maximum at 5% and after that it decreases with increase in content and maximum value of CBR is 203.2% according to Table 2.9

Table .2.9 Values of CBR @ different PP waste plastic content

PP waste plastic Content	0%	1%	3%	5%	7%	9%
CBR value (%)	7.9	3.7	8.7	23.2	10.5	10.3

So from the above test result the researcher concluded that addition of HDPE, LDPE and PP waste plastic to local available sand increased the CBR value, the CBR value of the unreinforced soil was 7.9%. Which were increased to 26.9% for 5% HDPE waste plastic content, 20.38% for 5%LDPE and 23.2% for 5% PP and finally the researcher was conducted economical advantage of using plastic waste for subgrade of flexible pavement and he decided pavement Construction cost could save by improved the subgrade by using plastic waste

Akinola Johanson Olarewaju (2016), investigated on Geo-technical properties of plastic stabilized lateritic soil. This was achieved by reinforcing lateritic soil with 30% of by weight of plastic waste. Test on lateritic soil and after mixing with plastic waste carried out in order to establish their engineering properties. Research findings showed that the bulk density and dry density decrease with the amount of plastic increase, CBR of lateritic soil increase with optimum plastic content of 30% and water content 8% but when moisture content increase the CBR value decrease

Abhishekpatil et al (2016), studied on Experimental review for utilization of waste plastic bottles in soil improvement Techniques. The research centered material like black cotton soil and plastic water bottles. The researchers taken the following laboratory test such as Tri-axial test and direct shear test of the soil before and after mixing of with plastic wastes. The result showed that normal stress within 1% of plastic as compared to soil sample without addition of plastic and in triaxial test cohesion of soil increased by 67% and by direct shear test cohesion of soil increased by 24 %.The researcher concluded that plastic bottle strips/chips mixed with soil increase in cohesive property of soil so bearing capacity of soil increase and settlement as well as compressibility decreases.

Table 2.10 Comparison of test result

Test	**Without plastic**	**With 1% plastic**	**% Change**
Tri-axial Test	C=0.21kg/cm2	C=0.64kg/cm2	% increase=67
Direct Shear test	C=0.19kg/cm2	C=0.25kg/cm2	% increase=24

John Groover Luwalaga 2016, studied on analyzing the behavior of soil reinforced with polyethylene Terephthalate (PET) plastic waste. The researcher considered as research material Sand and PET. The sand was medium dense clean quartz sand, rounded shaped particle ranging between 0.075mm to 1.18mm. The experimental study involved Particle size distribution, Compaction, CBR and Direct shear test for both sand soil and after mixed with PET fiber in different proportion and also particle size distribution test were carried out PET flakes. The conclusions and findings drown from the study are;

- ✓ The test result showed that maximum dry density of Sand soil decreased with increasing PET
- ✓ The CBR value of sand soil increased when the PET flakes increase and the optimum percent of PET flake is 32.5%
- ✓ The Direct Shear test result of this research different according to the PET flakes content and not constantly increase or decrease it was vary.
- ✓ Also the researcher were demonstrated the application of direct shear box and Compaction test result in the determination of the bearing capacity of unreinforced sand and sand –PET plastic waste composite. So as the percentage inclusion of PET plastic waste flakes was increased the value of angle of friction increase and the width of the foundation decreased.

- ✓ Also the researcher recommended that in order to attain perfect bond with PET plastic if we try with cohesive soil like clay particle will be faster the interaction of the composite soil to capable and we get good soil reinforcement result.

S.M .Mahajan and Dr.D.K Parbat (2016), studied improvement in Unconfined Compression Strength of Fly Ash Stabilized with PET. The research centered material like black cotton soil and PET fibers. The experimental study involved Atterberg, frees well, compaction and UCS for free soil and UCS test carried out for black cotton, fly ash and PET fiber mixed soil. (1% up to 5%).

The conclusions and findings drown from the study are:-

- ✓ Fly ash is beneficial in improving properties of black cotton soil with the increase in the percentage of fly ash and curing days and by addition of fly ash the unconfined compression strength is increase by 275% as compared to fee soil and optimum proportion of fly ash is laying between 20-30%
- ✓ The Unconfined Compression Strength of Reinforced black cotton soil-fly ash with PET fibers was affected mostly by the amount of fiber and curing period there is significant increase in unconfined compressive strength of fly ash stabilized black cotton soil with fiber at 28 days curing nearly about 30-40% more than UCS of fly stabilized soil.
- ✓ In fly ash mixes, the increase in strength is due to flocculation of dispersed clay particles promoted by cat ions in fly ash in a black cotton soil fly ash mixes the increment in strength is due to the change in the physical properties by addition of PET fibers. The interaction friction and bond strength seems to be the dominant mechanism controlling the reinforcement benefit.
- ✓ 5% of PET fiber by dry weight of the soil was optimum PET content to stabilize the soil

Pijush Kanti Mondal, studied on behavior of a clay soil mixed with plastic waste, the researcher was taken as a research material clay soil and PET water bottle wastes. The experimental study was made by Particle size distribution, Atteriburg, Compaction test, and Unconfined Compressive strength for determining index and engineering properties of clay soil and tensile strength and density for PET plastic and after mixing clay soil with PET plastics compaction and CBR test were taken to demine the effect of PET bottle strip fiber on locally available clay soil. The researcher were taken different proportion of PET plastic waste with different aspect ratio for this research. The main findings of the research can be summarized as:-

- ✓ Maximum dry density of clay soil decreased with increasing fiber content
- ✓ Optimum Moisture content didn't vary much with addition of fiber
- ✓ At higher fiber content CBR value increased with increase of length to width (aspect) ratio of fiber strip

- ✓ The optimum fiber content corresponding to maximum improvement in CBR value is found to be 1 - 1.5%.
- ✓ With increase of water content from (omc+2)% to (omc+5)% , CBR value decreases in general

Kartik Patewl et al (June 2016), investigated on stabilization of black cotton soil of canal road althan using plastic waste bottles. This was done by mixing black cotton soil together with randomly distributed discrete plastic fibers in the range of 0.25 % to 1% (by weight) fiber content. The experimental study was made by Frees well index, Liquid limit, plastic limit, standard proctor test, CBR test for both free soil and mixed with plastic fiber. The conclusions and findings drown from the study are:-

- ✓ CBR value increase from 3.85 to 25.82 by 0.75 % of plastic waste but it decrease when further amount of plastic bottle strips were added

CAPTER THREE

RESEARCH METHODOLOGY AND MATERIALS

3.1 Introduction

In this chapter, the materials used, the methods adopted, laboratory experiment carried out for the research are described with respect to their source. Therefore, this chapter describes the laboratory experiment carried out on the research material, introduction test method, sample preparation, apparatus used and the like to achieve the aim of this research.

3.2 Research material

3.2.1 Expansive soil

The Expansive soil sample used for this research work is collected from Addis Ababa, Akaki kality sub city around Addis Ababa Science and Technology University @ at 9º 81’ 70.60’’N and 47º 75’ 04’’E from one test pit. The soil is grayish black in color highly plastic clay. A disturbed sample is collected from test pit at a depth below 1.5m in order to avoid the inclusion of organic matter.

3.2.2 PET plastic waste chips

Plastic waste chips of the type of polyethylene Terephthalate (PET) were used as reinforcing material .The material were obtained from secondary storage area around ayat whereas taking different types of water and soft drink bottles as material.

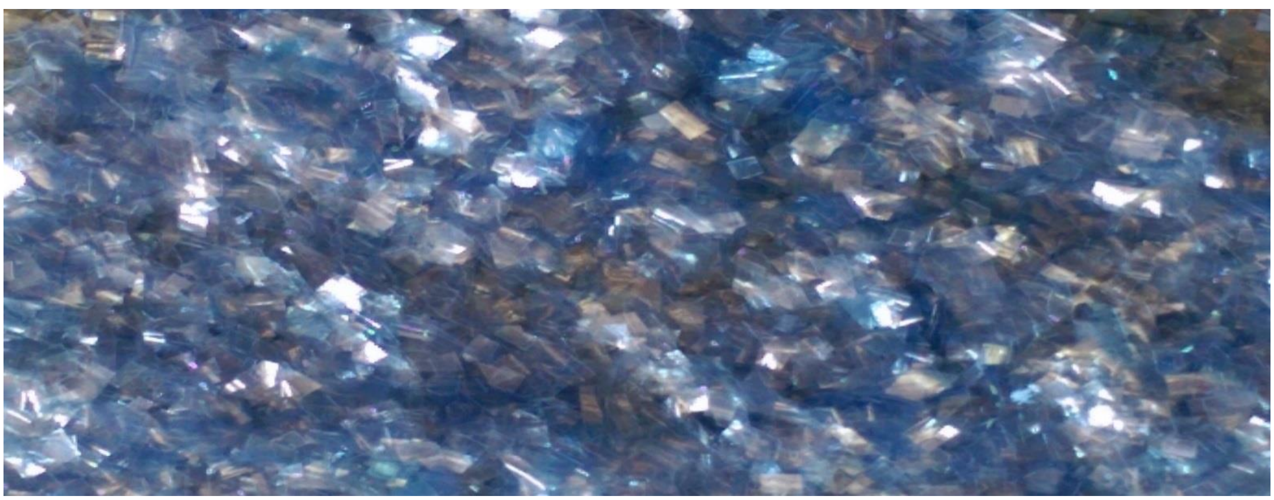


Figure. 3.1 PET plastic Chips

3.3 Methods

3.3.1 Sample Preparation

The collected natural soil samples of the black cotton soil sample prepared in accordance with the method described in AASHTO T87-86.

1. Air drying the soil sample
2. Prepares for sampling by removing tags, caps and strong part of the bottle around the cap and after that cut the plastic bottles to small plastic chips
3. Then sieve analysis performed for determined particle size distribution of soil sample and plastic chips
4. From the dried soil sample prepare for different laboratory tests such as Atteriberg, Compaction, CBR and UCS
5. Then, soil and plastic chips is mixed manually to get uniform mix ratio for each test

Figure.3.2 Soil mixing with plastic chips

3.3.2 Particle Size distribution Test

The test used to determine the percentage of various grain size. The grain size distribution helps in determining the textural classification of soils whether it is gravel, sand, silt, clay etc. This is then useful in evaluating the engineering characteristics.

The dry sieve analysis test of PET plastic waste flakes and hydrometer test for clay soil of representative specimens each weighting 50g were performed. The tests are conducted in accordance with ASTM D 422 testing procedures.

3.3.3 Moisture Content

This test is performed to determine the water (moisture) content of soils. The apparatus used for this test drying oven, balance, moisture can, gloves, spatula and the test carried out in accordance with ASTM D 2216.

3.3.4 Compaction Test

This laboratory test is performed to determine the relationship between the moisture content and the dry density of a soil and Stabilized soil for a specified comp active effort.

3.3.5 Atterberg Limits Testing

The three Atterberg limits which are liquid limit, plastic limit and shrinkage limits are the boundary between each of the two consecutive states of the soil-water phases.

3.3.6 CBR and CBR-Swell

The CBR and CBR-swell tests are conducted in accordance with AASHTO T193-93 for the natural soils and soil- plastic chips mix. For stabilized soil samples tests were conducted for both soil samples and mixed. The CBR is the resistance to a penetration of 2.5mm of a standard cylindrical plunger of 50mm diameter expressed as a percentage of the known resistance of the plunger to 2.5mm in penetration in d. CBR can be carried out on most types of soil ranging from heavy clay to medium gravel Soils. This test can be used on the sub grade, sub base and base course materials and the results obtained enable maximum utilization to be made of low cost material where better quality material is not available.

3.3.7 Unconfined Compression Strength

The purpose of this laboratory is to determine the unconfined compressive strength of a cohesive soil sample. We will measure this with the unconfined compression test, which is an unconsolidated undrained (UU or Q-type) test where the lateral confining pressure is equal to zero (atmospheric pressure).

The American Society for Testing and Materials (ASTM) defines the unconfined compressive strength of untreated material as either the maximum stress or the stress at 15 % axial strain whichever is secured first during the UCS test (ASTM D2166-06) and the UCS of treated material as either the maximum stress or the stress at 5 % axial strain, whichever is reached first during UCS test (ASTM D5102-09).
According to ASTM D4609-08 (2008), the UCS is one of the methods used to assess the effectiveness of admixtures for soil treatment. The standard states that the admixture is considered to be effective once an increase in UCS of at least 345 kPa is achieved.

Figure 3.3 UCS mold and soil specimen ready for UCS test

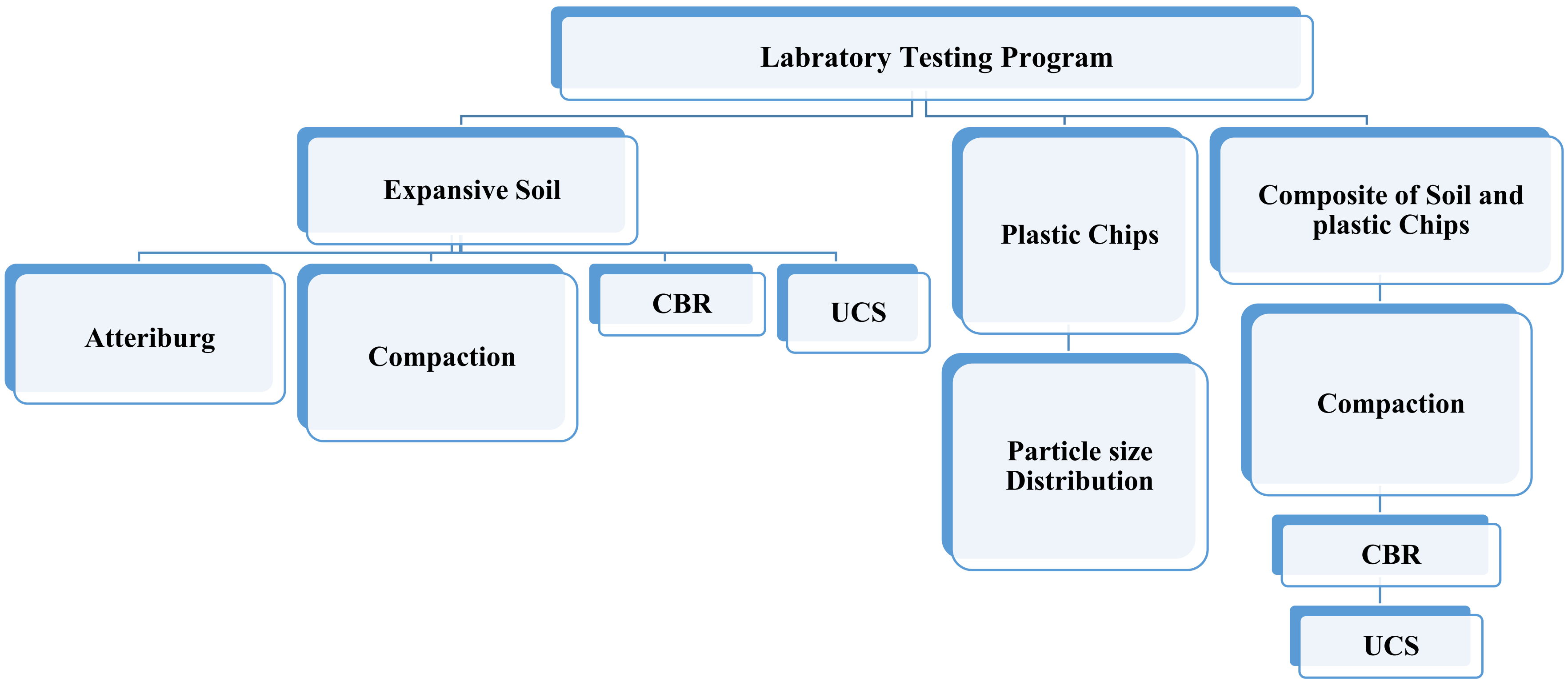


Figure 3.4 Labratory testing program

CHAPTER FOUR

TEST RESULT AND DISCUSSION

4.1 Introduction

This chapter covers presentation of laboratory testing results, their analysis and discussion. As mentioned in chapter four, the tests conducted include grain size analysis, Atterberg limits, compaction characteristics, unconfined compressive strength, swell tests and California Bearing Ratio (CBR). Most of the tests were performed on both reinforced and unreinforced soil. The unreinforced soil served as reference to evaluate the effect of PET plastic waste on studied soil

4.2 Properties of Material Used in the Study

4.2.1 Natural Soil

The results of the tests conducted for identification and/or determination of properties of the natural soil before applying PET chips are presented in Table 4.1. The soil is grayish black in color. As shown in Figure 4.1 on the particle size distribution curve almost 79.96 % of the soil is passing through No. 200 sieve; it exhibits a liquid limit of 78.22%, a plastic limit of 41.93% and plasticity index of 36.29 % .Liquid limit less than 35% indicates low plasticity, between 35% and 50% intermediate plasticity, between 50% and 70% high plasticity and between 70% and 90% very high plasticity (Whitlow, R., 1995). Hence, these values indicate that the soil is highly plastic clay. Accordingly the soil falls under the A-7-5soil class based on AASHTO soil classification system. Soils under this class are generally classified as a material of poor engineering property to be used as a sub-grade material.

The soil has a maximum dry density of 1.827g/cm3, optimum moisture content of 19.06%, and soaked CBR value of 0.64%. The general relationship between CBR values and the quality of the subgrade soils used in pavement applications is as follows (Bowles, J., 1992)

Table 4.1 Some engineering and index property of the natural soil

Property	Quantity
Percentage passing No. 200 sieve, %	79.96
Liquid limit, %	78.22
Plastic limit, %	41.93
Plasticity index, %	36.29
Maximum dry density, kg/m3	1827
Optimum moisture content, %	19.06
AASHTO soil classification	A-7-5
Soaked CBR value, %	0.64
CBR-swell,%	9.03
Color	grayish black

Hence, the soil was found to be highly plastic expansive clay with low bearing capacity when it is soaked and high swelling potential and fell below the standard recommendations for most construction works especially highway construction. Therefore, the soil requires initial modification and/or stabilization to improve its workability and engineering property

Table 4.2 Quality of sub grade according to CBR-Values (Bowles, J., 1992)

CBR value of sub grade	Quality of sub grade
0-3%	Very poor sub grade
3-7%	Poor to fair sub grade
7-20%	Fair sub grade
20-50%	Good sub grade
>50%	Excellent sub grade

4.2.2 Particle Size Distribution of Soil

Particle Size distribution of black cotton soil was carried out using hydrometric analysis and the result showed that the maximum and minimum size of soil grain is 1.18mm and 0.075mm respectively

Grain size distribution curve

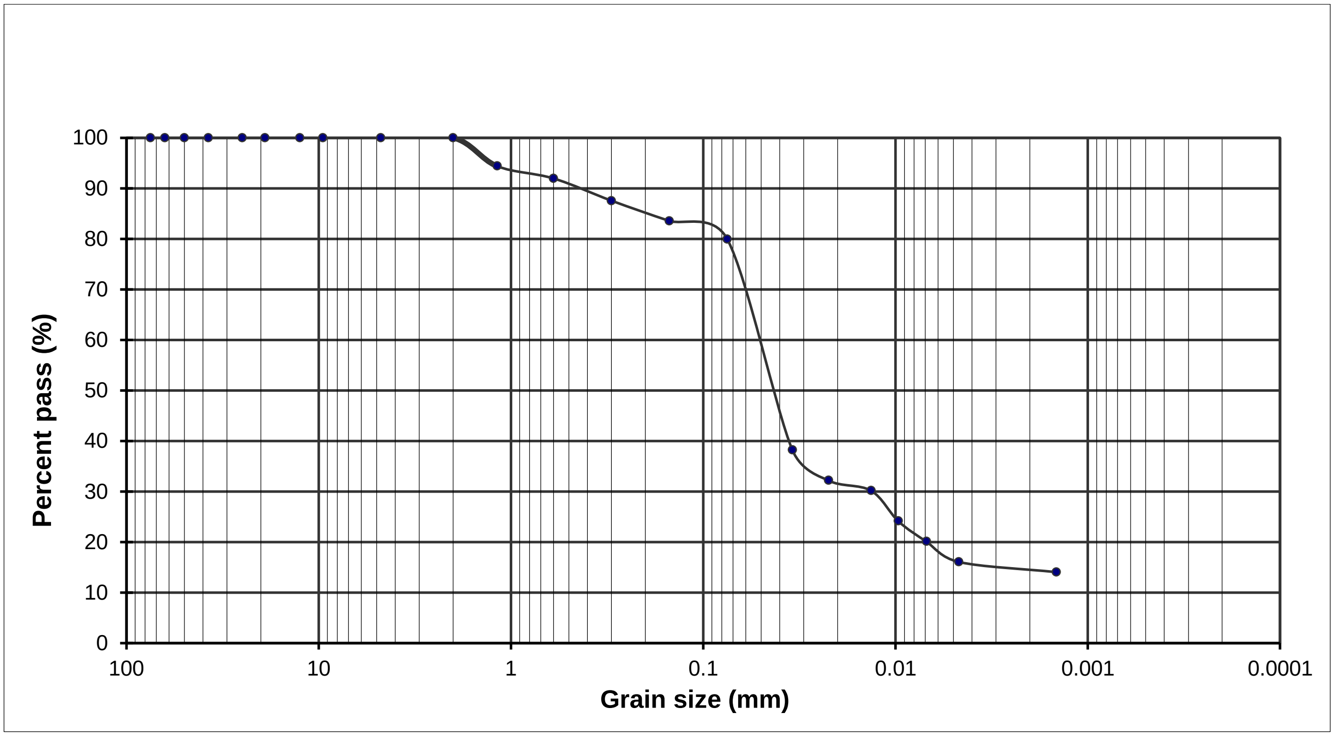


Figure 4.1. Particle size distribution curve of expansive soil

4.2.3 Plastic Chips

The particle size distribution test of plastic chips have been conducted and the following result was obtained such as the maximum size of PET chips was 12.5mm and the minimum one 4.75mm.

Grain size distribution curve

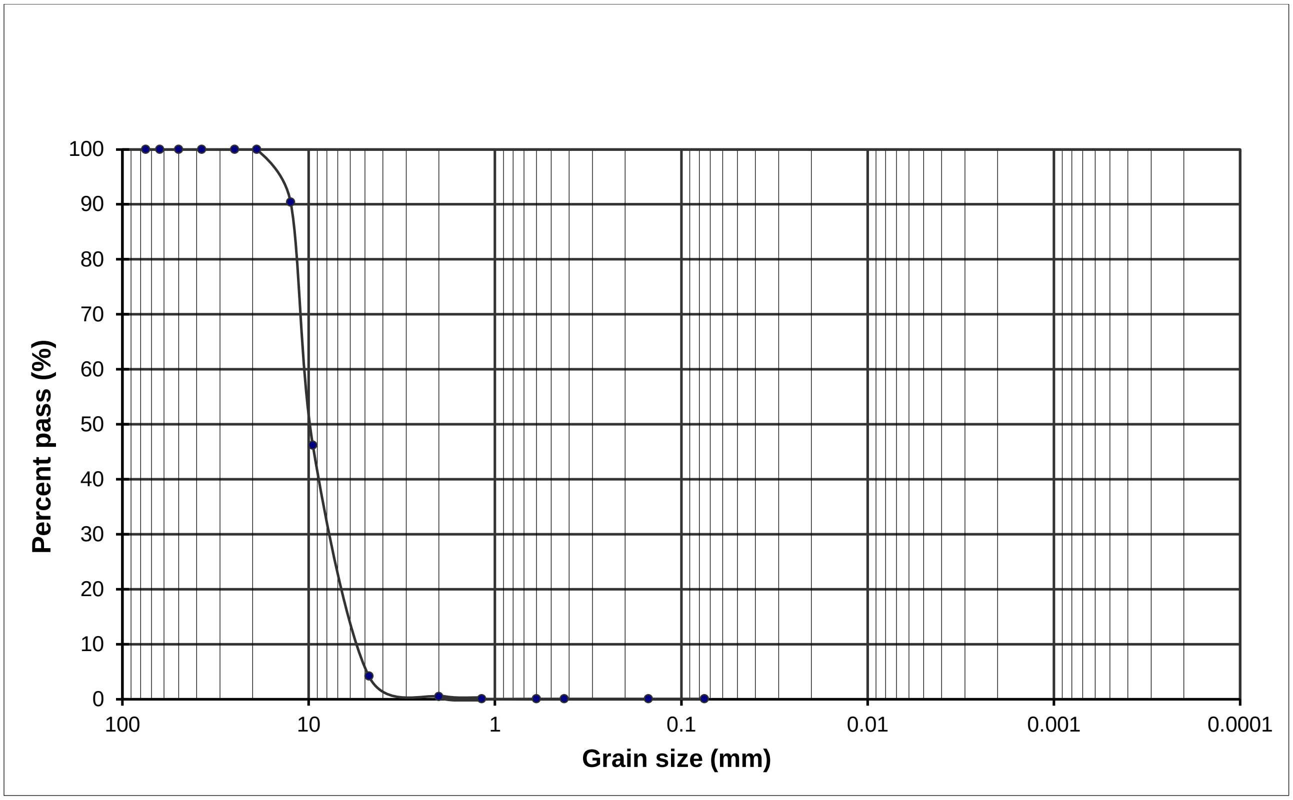


Figure 4.2. Particle size distribution curve of plastic chips

4.3 Effect of plastic chips on Atterberg

Atterberg limits have been conducted only for free soil sample but the effect of plastic chips on the soil samples not carried out.

4.4 Effect of plastic chips on Compaction Characteristics

4.4.1 Maximum Dry Density

The effect of plastic chips on the maximum dry density of soil sample test result as shown in the Table 4.3,the maximum dry density slightly decrease from 1.827 gm/cm^3 to 1.789gm/cm^3 with increased the plastic chips in the soil sample from 0% to 4.8%

Table 4.3**.** Maximum dry density of soil mixed with different proportion of plastic chips

Trial no	PET plastic waste (%)	MDD(gm/cm^3)
1	0	1.827
2	1.2	1.804
3	2.4	1.798
4	3.6	1.795
5	4.8	1.789

The decrease in the maximum dry density is mainly due to;

· The partial replacement of comparatively heavy soils with the light weight plastic chips

· And comparatively low specific gravity value (1.38) of plastic chips than that of replaced soil

4.4.2 Optimum Moisture Content

The effects of Plastic chips (PET Chips) on the optimum moisture content for the soil plastic chips mix are shown in Table 4.4.

Table 4.4 Optimum moisture content of soil mixed with different proportion of plastic chips

Trial no	PET plastic waste (%)	OMC (%)
1	0	19.06
2	1.2	19.06
3	2.4	19.06
4	3.6	19.06
5	4.8	19.06

There were no variation in the optimum moisture content was mainly due to;

The optimum moisture content of soil constant with increasing the plastic (PET) content due to water absorption behavior of PET according to ASTM D570 is around 0.1 %

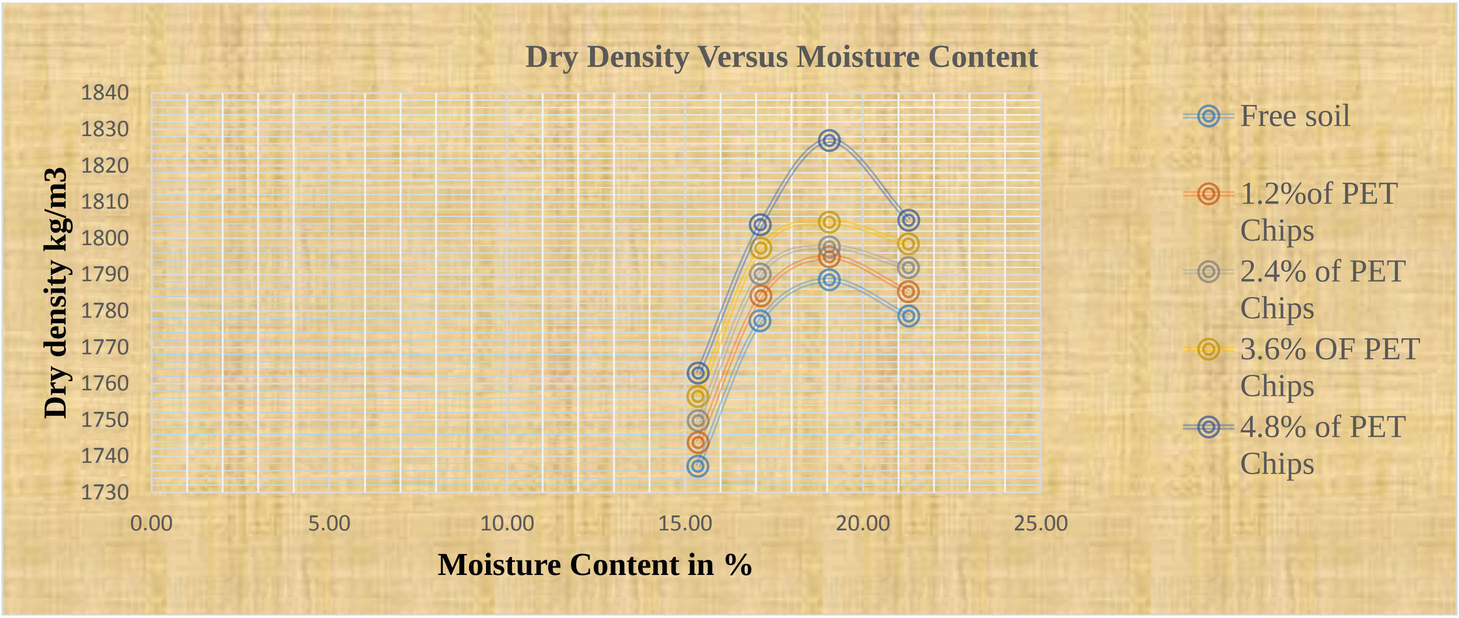


Figure 4.3 Summary of compaction curves for soil and different percentage of plastic chips

4.5 Effect of plastic chips on CBR and CBR-Swell

4.5.1 CBR Values

CBR values are used as index of soil strength and bearing capacity in the design of sub grade and sub base of pavement. So the effect of PET plastic waste on the CBR value of Soil –PET plastic waste composite are shown in the figure 4.4 .When treating the expansive soil at different percentage of PET waste and the peak value of CBR @ 3.6% and after that the CBR value of the composite soil decreased

Table 4.5 Class of sub grade according to ERA 2002 manual

Class	**CBR value of subgrade (%)**
S1	2
S2	3-4
S3	5-7
S4	8-14
S5	15-29
S6	30+

This shows that the load bearing capacity of the sample increased significantly with PET inclusion .Hence the PET chips treated black cotton soil meet the minimum criteria as specified by Ethiopian Road Autority (ERA) pavement manual 2002 specification for material suitable for use as sub grade material not less than 3% CBR determined at MDD and OMC according to Table 4.5.

The reason for this improvement is due to:

1.This may be have been attributed lack of coarser material in the black cotton soil and when the PET plastic waste add to the soil causing high inclusion or reinforcement between clay soil and the PET plastic waste chips

2.The partial replacement of soaked soil with PET plastic waste due to the nature of tensile strength at break (According to ASTM test method D638) of PET no change in water soaking process and to help the soil to resist penetration load.

3. Because of the behavior of stabilizer the tensile strength of the soil increase and this causes

- ✓ Control or reduce tension cracks
- ✓ Improve tensile behavior of soil
- ✓ Change the brittle tensile failure not behave to more ductile one

4. Also because of the behavior of clay soil that cohesive and adhesive nature helps to mobilized the tensile strength of PET fiber to the soil

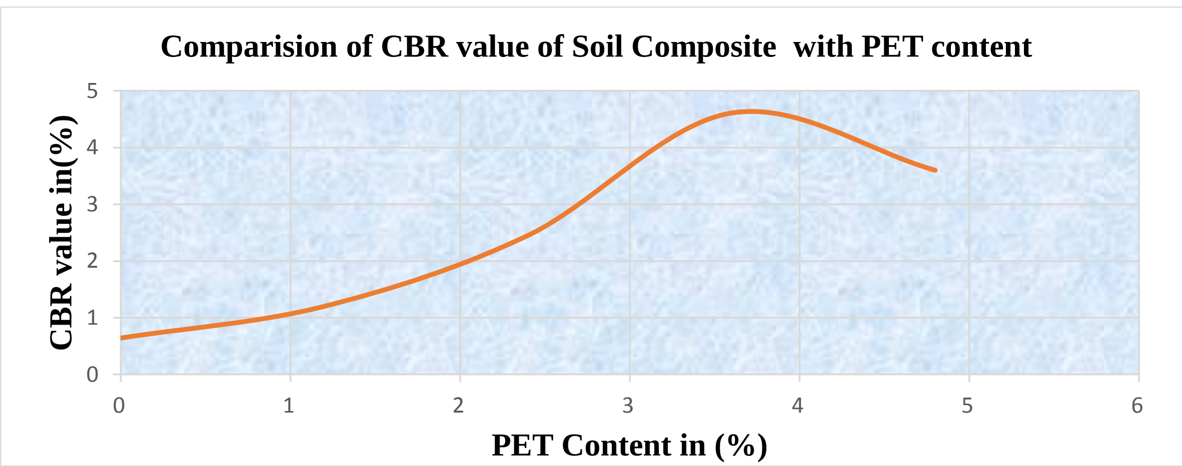


Figure 4.4 Summary of soaked CBR value of composite soil with different percentage of PET plastic waste

4.5.2. CBR-Swell

The effect of PET plastic waste on the CBR –Swell for the soil PET plastic mixtures are shown in the Figure 4.5 for both free soil and PET plastic mixture samples. When treating the expansive soil at 3.6 % PET plastic waste content the composite soil sample gives CBR-Swell of 2.31% from a value of 9.03 % while the natural soil .The CBR –Swell of black cotton soil decrease with increasing of PET plastic waste up to optimum content of PET plastic chips. This shows that the swelling potential of the soil composite sample decrease with PET chips stabilization.

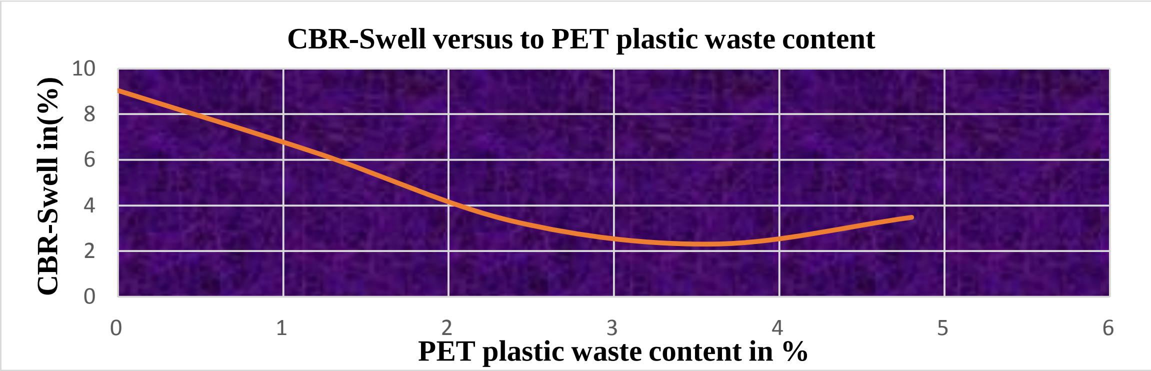


Figure 4.5 Summary of soaked CBR-Swell value of composite soil with different percentage of PET plastic waste

PET plastic waste decreases CBR-Swell of expansive soil .This due to PET Plastic waste randomly distributed in soil composite and it makes fiber inclusion because of this increasing the tensile strength of black cotton soil to resist Volumetric Change and the tensile strength of PET helps to control the development of tension cracks.

4.6. Effect of PET plastic chips on Unconfined Compressive Strength (UCS)

The effect of PET plastic waste treatment on unconfined stress-strain behavior of black cotton soil is shown in Figure 4.6 .It can be observed that the specimen, the maximum stress increases with increasing PET plastic waste content up to 2.4 % PET content .The UCS value increased from 78 kN/m^{2}to 116 kN/m^2 at 1.2%, 174kN/m^2 at 2.4, 145 kN/m^2 at 3.6.

The Increase in Shear strength (Unconfined Compression Strength) may have been attributed to;

The PET Plastic waste randomly distributed in soil composite and it makes fiber inclusion were employed to improve soil tensile behavior

The PET plastic waste mixed with black cotton soil the UCS increased due to interaction between the soil particles and PET fibers and the result indicated that the increase strength of soil was due to tensile stress mobilized in the reinforcement

Table 4.6.UCS Values relative to sub grade strength kPa

Serial no	Consistency	q_u, kN/m^2	Serial no	Consistency	q_u, kN/m^2
1	Very Soft	<25	3	Stiff	100-200
2	Soft	25-50	4	Very Stiff	200-400
3	Medium	50-100	5	Hard	>400

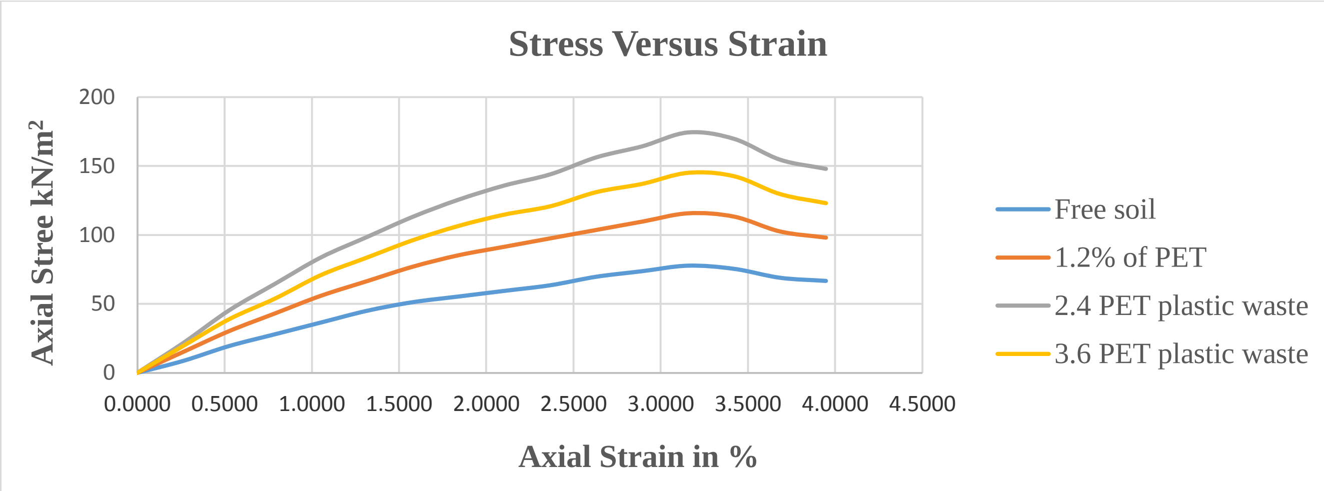


Figure 4.6: Summary of UCS for soil and different percentage of PET plastic waste plastic chips

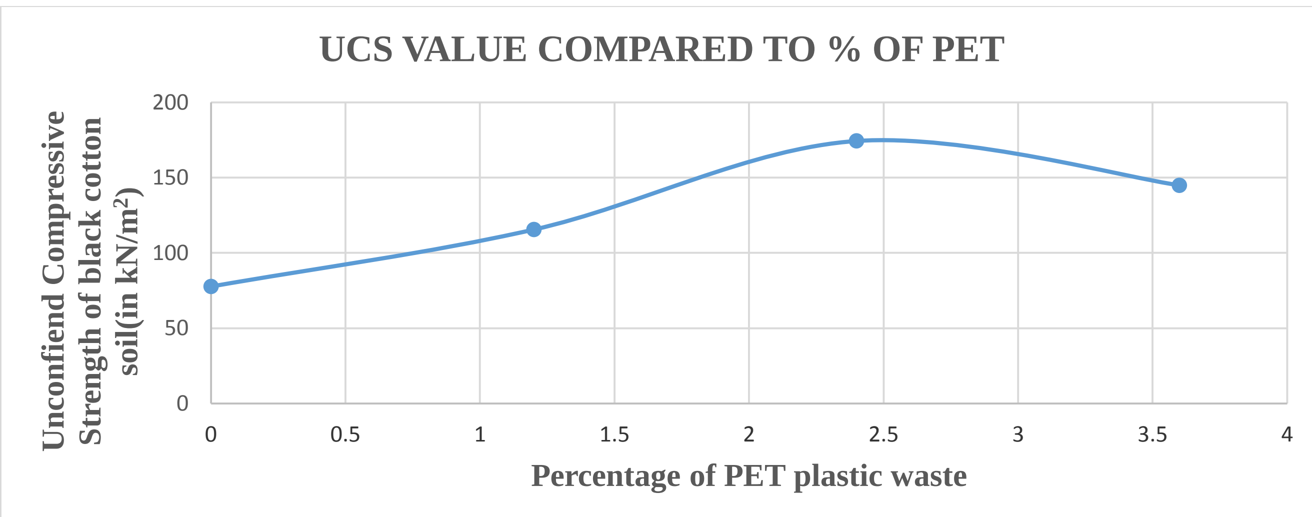


Figure 4.7: UCS value compared with percentage of PET plastic waste added in soil

Table 4.7. Summary of all laboratory test result carried out in this research

Serial no	**Sample**	**Modified Proctor test**		**CBR and CBR Swell Test**							**Unconfined Compression Strength Test**
		MDD (g/cc)	**OMC (%)**	**No. of Blows**	**Density (g.cc)**	**Load in kN at 2.54 mm**	**Load in kN at 5.08 mm**	**CBR – Swell (%)**	**Average CBR-Swell (%)**	**CBR at 95% MDD (%)**	**UCS at OMC (kN/m^2)**
1	Soil and 0% of PET	1.827	19.06	10	1.433	0.311	0.300	9.449	9.03	0.64	78
				30	1.645	0.545	0.490	9.055			
				65	1.829	0.780	0.780	8.583			
2	Soil and 1.2 % of PET	1.824	19.06	10	1.422	0.803	0.740	6.889	6.30	1.2	116
				30	1.621	1.053	0.960	6.229			
				65	1.821	1.160	1.160	5.708			
3	Soil and 2.4 % of PET	1.798	19.06	10	1.416	1.917	1.690	3.543	3.29	2.45	174
				30	1.613	2.152	2.070	3.346			
				65	1.801	2.730	2.450	2.992			
4	Soil and 3.6 % of PET	1.795	19.06	10	1.404	3.864	3.600	2.598	2.31	4.61	145
				30	1.602	4.492	4.230	2.362			
				65	1.793	4.890	4.650	1.968			
5	Soil and 4.8 % of PET	1.789	19.06	10	1.428	3.182	3.600	3.937	3.48	3.60	
				30	1.590	3.485	4.230	3.543			
				65	1.786	3.710	4.650	3.953			

Table 4.8.Comparision of previous research test result with this research

Serial No	Title of the research	Author	Material used		Test performed	Existing research result		This research result	
			Soil type	Fiber type		Before Stabilization	After Stabilization	Before Stabilization	After Stabilization
1.	Stabilization of black cotton soil of canal road using plastic waste bottle	Karik patel et al (2016)	Black cotton	PET	CBR (%)	3.85 @ free soil	25.82 @ 1% Plastic Strip	0.64 @ free soil	4.61 @ 3.6 % of PET chips
					MDD (g/cc)	1.86		1.827	1.795
					OMC (%)	12.71		19.06	19.06
2	Improvement in unconfined compression Strength of fly ash stabilized with PET fiber	S.M.Mahajan and Dr .D.K.Parbat (2016)	Black cotton and fly ash	PET	MDD(g/cc)	1.5		1.827	1.795
					OMC (%)	29%		19.06	19.06
					UCS (kN/m^2)	52.39	265 @3% PET fiber	78	174 @2.4% PET fiber

3	Effects of HDPE Plastic on the Unconfined Compression Strength of Black Cotton soil	Akshat Mehrotra et al(2014)	Black cotton	HDPE	MDD (g/cc)	1.58	1.87	1.827	1.795
					OMC (%)	25	20.7	19.06	19.06
					UCS (kN/m^2)	71.35	234.71 @2.4% PET fiber	78	174 @2.4% PET fiber
4	Laboratory performance of randomly oriented plastic waste in sub grade of flexible pavement	Dr.A.I.Dhatrak et al (2016)	Clay	Plastic Strip or Chips	PI (%)	27.11		36.30	
					MDD (g/cc)	1.6	1.52 @ 2.5%	1.827	1.795
					OMC (%)	19.6	18.94	19.06	19.06
					UCS (kN/m^2)	16.25 KN/m^2		78	174
					CBR	1.7%	3.0%	0.64	4.61

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Introduction

The application of PET plastic waste has a positive effect on the engineering properties of the black cotton soil. PET plastic waste chips have the potential to improve the strength and the bearing capacity of the treated black cotton soil.

This chapter presents the conclusions and recommendations of the research findings and also suggests further research to be under taken by future researchers.

5.2 Conclusions of the study

The following conclusions can be drawn from the results of the study/investigation carried out within the scope of the study:-

1.The optimum moisture content no change from 19.06 % while the maximum dry density values decreased from 1827 kg/m^3 to 1795 kg/m^3 with increment of PET plastic waste from 0% to 3.6%.

2. CBR Swell of the stabilized samples decreased from 9.03 % to 2.31 with increasing PET plastic waste from 0% to 3.6%

3. CBR values increased from 0.64 to 4.61 % with the addition of PET plastic waste from 0% to 3.6%

4. The results also showed that PET plastic waste can be substantially used to improve the unconfined compressive strength (UCS) of treated soils by increasing the UCS value from 78 kN/m^2 to 174 kN/m^2 with increment of PET plastic waste from 0% to 3.6%.So from the UCS test result concluded that the clay soil at optimum moisture content change from medium to stiff clay soil.

However the improvements in the UCS values of samples not satisfy the minimum requirements that qualify them as the standard states that the admixture is considered to be effective once an increase in UCS of at least 345 kPa is achieved according to (Little, 1995)

And use of plastic products such as bottle is increasing daily .The disposal of the plastic waste without causing any ecological hazard has become a real challenge to the present society. So Successful application could help to reduce on the amount of plastic waste disposed of to landfills and contribute to sustainable development by providing low-cost material to the resource intensive geo-technical industry.

5.3. Recommendations

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

1. From the CBR result of the composite soil recommended that the plastic chips with black cotton soil used as sub grade material for access roads however not enough bearing capacity to heavy traffic load carrying roads
2. The black cotton soil-PET plastic waste composite generally resulted in to lower densities compared to the unreinforced soil. Therefore, the light weight nature of black cotton –PET plastic waste composite is a distinctive advantage for weight sensitive structures. Though it should be noted that with its lower densities it may fail in certain projects which may require materials of high densities.
3. Further investigation using large scale tests will be beneficial to better understanding the reinforcement mechanism, eliminate scale effects on the results and optimize the plastic strip parameters for maximize strength increase in various soils types and the five (5) specimens tested of 0%,1.2%,2.4%,3.6% and 4.8% PET plastic waste chips inclusion where too few to draw conclusive result .So additional tests required for more effective use of the studied PET plastic waste and recommendations for further research.
4. Only laboratory test was conducted in order to achieve the main objective of this study of analyzing the engineering behavior of black cotton soil PET plastic waste Composite. It's therefore recommended that a field trail be done in order to investigate the performance of the black cotton – PET plastic waste composite in the field
5. On my research the size of plastic chips were prepared handmade ,Some were flaky, round and sharp edge also their size range random .So there is a need to carry out further investigations on the different length and width.

REFERENCES

1. AASHTO (1995),“Standard specification for transportation materials and methods of sampling and testing,” America
2. ASTM C618 – 03 (2003), “*Specification* for Fly Ash and Raw or Calcined Natural Pozzolanas for Use as a Mineral Admixture in Portland cement Concrete”. American Society for Testing and Materials, Vol.04.02, Philadelphia
3. A.S.Soganci (2015), “The effect of polypropylene fiber in the soil stabilization of expensive soil”. International journal of environment, chemical, ecological, geological and geophysical engineering.
4. Acharyya, R et al (2013), “ Improvement of untrained shear strength of clayey soil with PET bottle strips’’
5. Aklilu Adefris (2015), “Evaluation of Solid Waste land Fill Potential Site Using GIS based Multi Criteria Evolution Method”. Master thesis of Addis Ababa University.
6. Alfred byiringiro (2014), “Effect of paper mill ash on properties of expensive soil”. Master thesis at Stellenbosch University.
7. Amin chegenizedeh (2011), “Compaction characteristics of Reinforced clayey sand”.
8. Anagnostopoolos et al (2013),”Shear strength behavior of polypropylene fiber reinforced cohesive soil”. Geo mechanics and geo engineering.
9. Arpanlaskar (2013), “Effects of waste plastic fibers on compaction and consolidation behavior of reinforced soil’’.
10. Azemeraw Tadesse Mengistu (2013), “Modeling and analysis of long term shifts in bio-energy use” With special reference to Ethiopia .Master thesis KTH School of industrial engineering and management.
11. Bowles, J (1992), “Engineering properties of soil and their measurements” .McGraw-Hill Boston, 4th edition.
12. Benson,C & khire, M (1994), “Reinforcing sand with strips of reclaimed high density polyethylene”. Journal of geotechnical engineering.
13. Britannica (2015), “Polyethylene Terephthalate” encyclopedia Britannia.
14. Chen, F.H. (1988), “Foundation on expansive soils” .Elsevier, Amsterdam, 1988.
15. Community development research (2011).”Ethiopian solid waste and land fill country profile and action plane”. By global methane imitative.

16. Craig H.Benson (1992), “Hydraulic and mechanical characteristic of compacted municipal solid waste compost”.
17. Daniel Teklu (2003), “Examining the swelling pressure of Addis Ababa expensive soil” .MSc thesis of Addis Ababa University.
18. Das, B (2012), “Fundamental of geotechnical engineering”.
19. Das, B (2013), “Advanced soil mechanics foundation”.
20. Delfin G.carreon (2006), “Stabilization of marginal soils using recycled material”. University of south Florida.
21. Department of the Army and Air force (1994), “Soil Stabilization for pavements”. USA, Washington DC
22. E.C (2011), “Plastic waste in the environment”.
23. E.C (2007), “Assessment of the environmental advantage and draw backs of existing and emerging polymers recover process”.
24. ERA (2002), “Ethiopian roads authority, pavement design manual”, Addis Ababa.
25. EPA (1990), “Methods to manage and control plastic wastes”. Report to congress, Environmental Protection.
26. Feroz Hanifkhan (2016). “Analysis of the influence of waste polymer on soil sub grade” .International research journal of engineering technology.
27. Freilich,B,J,Li,C.andzornbeg J,G,(2010), “Effective strength of fiber rain forced clays”.9th international conference on geo-synthesis Brazil .
28. Filemon,U.,(2008), “Solid waste management :Principles and practices :an introduction to the Basic Function Element of solid waste management ,with special Emphasis on the needs of Developing Countries” .Philippines; UP press
29. Ganga Rao et al, (2006), “Reinforced Concrete Design with FRP Composites”.CRC Press
30. Gary E.wellis (2012), “Engineering performance of polymer amended soil”.
31. Geotechnical design manual of Ethiopian roads authority.
32. Habip Eroglu et al (2003), “Soil stabilization with waste of paper industry (WPI) for sub base of forest roads”.
33. Hema kumar /LLUR/ (2007), “Development of Soil-EPS mixes for geotechnical application “.A thesis summated to doctor of philosophy queens Land University of technology, Australia.
34. John Groover Luwalaga (2016), “Analyzing the behavior of soil reinforced with polyethylene terephthalate /PET/ plastic waste”. MSc thesis Stellenbosch University.

35. Kartik Jindal (2014), "Effect of waste plastic on the strength characteristics of the sub grade for the flexible Pavement". Master thesis Thapar University, Patiala.
36. Kalumba, D &Chebet, F.C (2013), "Utilization of polyethylene (plastic) shopping bags waste for soil improvement in sand soils". proc,18th ICSMGE
37. Little, D.N. (1995),"Handbook for stabilization of pavement subgrades and base courses with lime". United States of America: Lime Association of Texas.
38. Little, D.N. (1996), "Fundamentals of the stabilization of soil with lime". National Lime Association Bulletin No.332. Arlington, USA.
39. Li,C.,(2005). "Mechanical response of fiber –reinforced soil. PhD Dissertation". The University of Texas at Austin, U.S.A
40. Muawia Adefalla et al (2017), "Enhances Tensile strength In Clays Using Poly propylene fibers". International Journal of Geo mat
41. Meron Wubshet (2013), "Bagasse ash as a sub grades oil stabilizing mixing MSc thesis Addis Ababa University".
42. Mohammed Gedefaw (2015) , " Assessing the current status of solid waste management of Gonder town". Ethiopia International journal of scientific technology research value 4.
43. Mahan Haten Nsaif (2013), "Behavior of soil strengthened by plastic waste material". Journal of engineering and development
44. Nicholson, P.G., (2014), "Soil Improvement and Ground Modification Methods". Elsevier Science
45. Nelson D and Millar 1992, "Problems and practices in foundation and Pavement engineering" .New York.
46. Over view of Addis Ababa city solid waste management system (2010).
47. Pijushkant Mondale (2012), "Behavior of a clayey soil mixed with plastic waste" .
48. Sami Birhe (1999), "Solid waste management in Ethiopia".
49. Sanjay kumanshuka (2006), "Fundamentals of geo-synthetic engineering".
50. Science for environmental policy (2011), "Plastic waste ecological and human health impacts". DG environment news alert service.
51. Snethen, et al (1975), "A review of engineering experiences with expansive soils in highway subgrades". Washington D.C Federal Highway Administration Offices of Research & Development.
52. Teklu, D (2003), "Examining the Swelling Pressure of Addis Ababa Expansive Soil". MSc. Thesis, Addis Ababa University, Addis Ababa

53. Texas Department of Transportation (2005). “Guidelines for modification and Stabilization of soil and base for use in pavement Structure”. Unpublished report
54. Zaimoglu, A.S. & Yetimoglu, T.,(2011), “Strength Behavior of Fine Grained Soil Reinforced with Randomly Distributed Polypropylene Fibers”. Geotechnical and Geological Engineering,

APPENDIXCES

APPENDIX A.: Literatures about Key properties of PET and Physical Composition of solid waste in Addis Ababa

Table A.1. PET Key properties value

Item	Description	Unit	PET Value
1	**Physical Properties**		
i	Density	g/cm3	1.3-1.4
ii	Water absorption	%	<0.7
iii	Flammability		Self-Existing
iv	Refractive index		1.58-1.64
v	Resistance to Ultra Violet		Good
2.	**Mechanical Properties**		
i	Coefficient of friction		0.2-0.4
ii	Poisson's ratio		0.37-0.44(oriented)
iii	Young's Modulus of Elasticity	10^9 N.m^2	
iv	Tensile Modulus	Gpa	2.758
v	Tensile Strength	Mpa	
vi	Elongation at break	%	60-165
3.	Chemical Resistance		
i	Acid		Good
ii	Alcohols		Good
4.	Thermal Properties		
i	coefficient of Thermal Expansion	10^{-6} k^{-1}	20-89
ii	Lower working Temperature	^{0}c	-40-60
iii	Upper Working Temperature	^{0}c	115-170

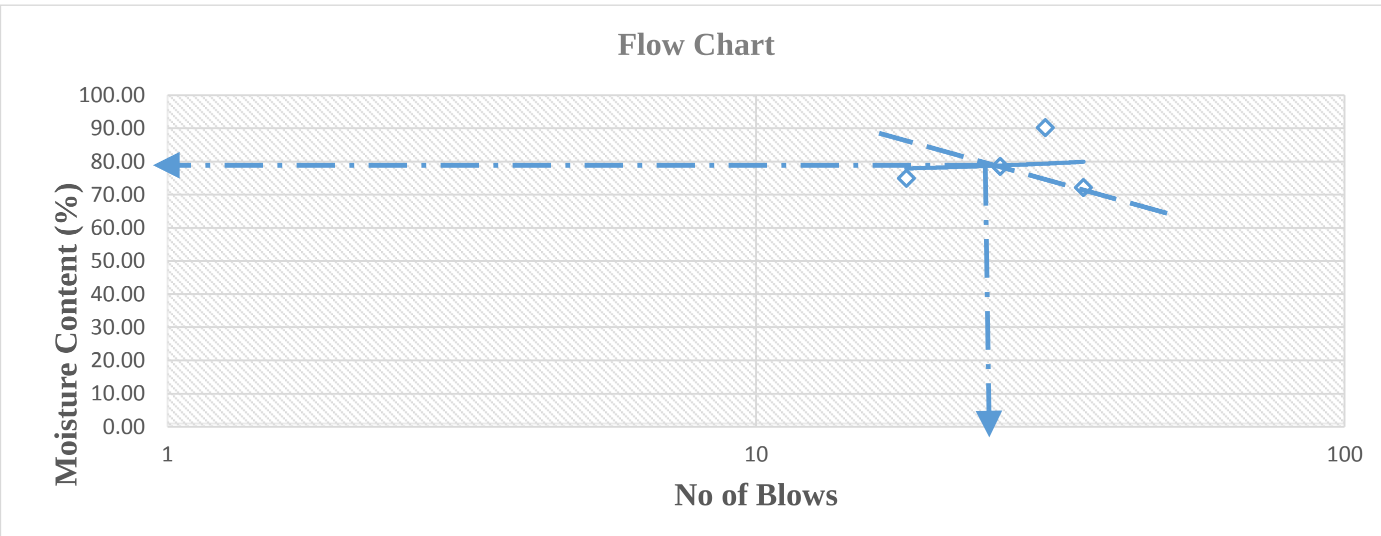
Table A.2**.** Physical Composition of solid waste in Addis Ababa

Constituent	**In percent**
Vegetable	1.93
Paper	2.9
Rubber	0.19
Leather	0.41
Wood	2.89
Plastic	1.58
Bone	2.11
Textile	1.39
Ferrous material	0.69
Aluminum	0
Glass	0.79
Compostable (leave, grass etc.)	26.26
Non Compostable (Sand, Grit, Soil etc	26.26
Soil/Fines <10mm	30.82
Fines<55 but >10mm	25.87
Total	100%

APPENDIX B :Atterberg Limit Test

Table B.1. Computation of Atterberg limit of free soil

LIQUID LIMIT	1	2	3	4	PLASTIC LIMIT	
N° of blows	36	31	26	18	-------	-------
Mass of Wet Soil+Can(gm)	55.1	54.4	48.5	59	40.5	42.4
Mass of Dry Soil+Can(gm)	45	43.3	40.8	47	37.9	38.8
Mass of Can(gm)	31	31	31	31	31	31
Mass of Moisture(gm) g	10.1	11.1	7.7	12	2.6	3.6
Mass of Dry Soil(gm) g	14.00	12.30	9.80	16.00	6.90	7.80
Moisture Content, WL(%)	72.14	90.24	78.57	75.00	37.68	46.15



PI	
LL	78.22
PL	41.92
PI	36.30

APPENDIX C: Particle Size Distribution Test

Table C.1. Computation of particle size distribution of free soil

				Grain Size with Hydrometer		
Sieve size		Retained for 1st Sieving		Hydrometer Retained		Percent Passing
	(mm)	Weight	% Rtd.	Weight	% Rtd.	(%)
3"	75	0	0			100
21/2"	63	0	0			100
2"	50	0	0			100
11/2"	37.5	0	0			100
1"	25	0	0			100
3/4"	19	0	0			100
1/2"	12.5	0	0			100
3/8"	9.5	0	0.00			100
N° 4	4.75	0	0.00			100
N° 10	2	0	0.00			100
N° 16	1.18	0	0.00	2.80	5.60	94.40
N° 30	0.6	0	0.00	2.50	2.44	91.96
N° 50	0.3	0	0.00	2.20	4.40	87.56
N° 100	0.15	0	0.00	2.00	4.00	83.56
N° 200	0.075	0	0.00	1.80	3.60	79.96
	0.034					38
	0.022					37
	0.013					35
	0.010					32
	0.007					29
	0.005					25
	0.001					22
Pan		0.00	0.00	1.50	3.00	
Total		50		50		

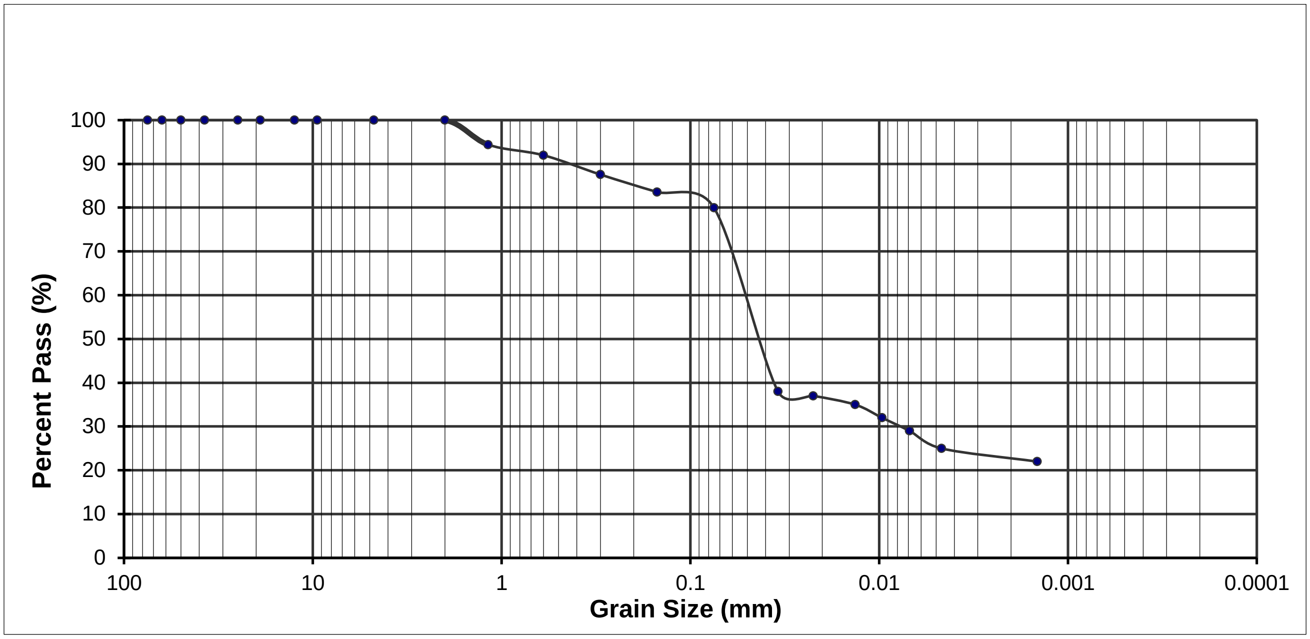


Figure C.1. Particle Size distribution curve of black cotton soil

Table C.2. Computation of particle size distribution of PET plastic chips

Sieve size		Retained for 1st Sieving		Percent Passing
	(mm)	Weight	% Rtd.	(%)
3"	75	0	0	100
21/2"	63	0	0	100
2"	50	0	0	100
11/2"	37.5	0	0	100
1"	25	0	0	100
3/4"	19	0	0	100
1/2"	12.5	134	10	90
3/8"	9.5	615	44.19	46
Nº 4	4.75	585	42.02	4
Nº 10	2	51	3.70	0
Nº 16	1.18	6	0.42	0
Nº 30	0.6	0	0.00	0
Nº 50	0.3	0	0.00	0
Nº 100	0.15	0	0.00	0
Nº 200	0.075	0	0.00	0
Pan		0.00	0.00	0.04
Total		1392	0.42	

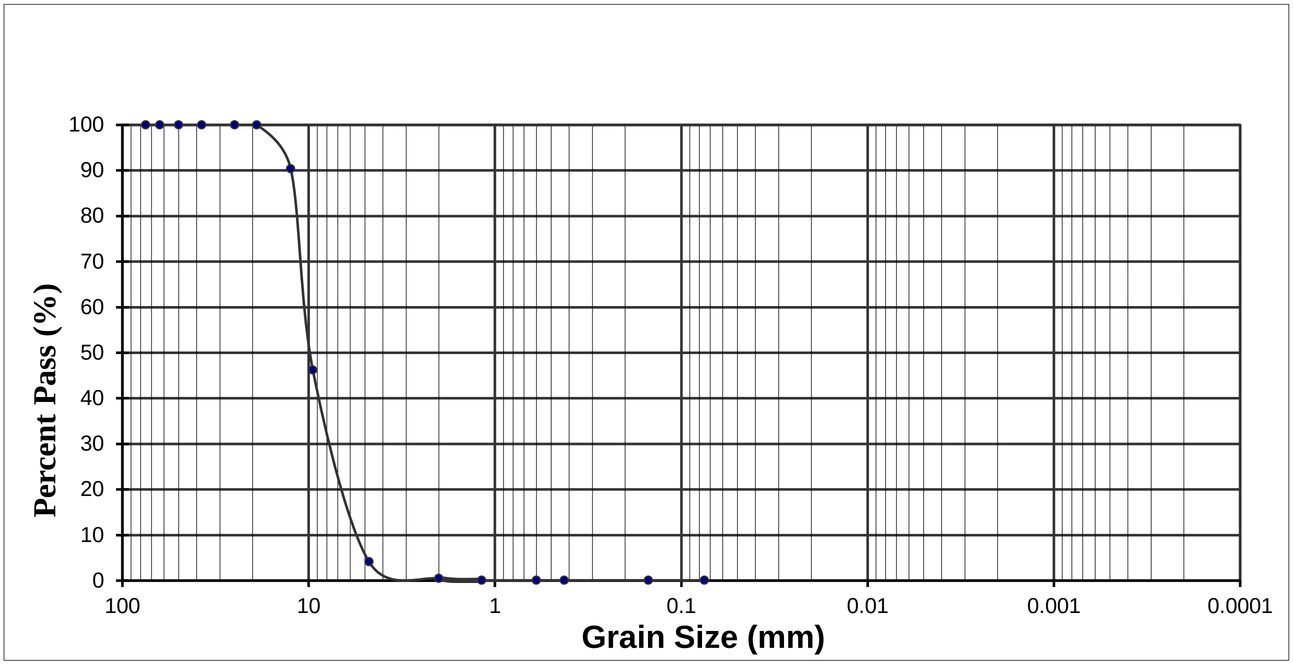


Figure C.2**.** Particle Size distribution curve of PET plastic chips

APPENDIX D: Compaction test with varying percentage of PET plastic waste

Table D.1**.** Computation of optimum moisture content and maximum dry density of black cotton soil 0% of PET chips

Trial	1	2	3	4
Mass of mould+wet soil (g)	10900	11000	11200	11230
Mass of mould(g)	6580	6580	6580	6580
Mass of wet soil(g)	4320	4420	4620	4650
Volume of mould(gm/cm3)	2124	2124	2124	2124
Wet Density(kg/m3)	2034	2081	2175	2189
Mass of can +wet soil (g)	106.60	103.10	116.80	120.80
Mass of can+ dry soil(g)	96.5	92.5	103	105
Mass of can(g)	30.8	30.6	30.6	30.8
Mass of water(g)	10.10	10.60	13.80	15.80
Mass of dry soil(g)	65.7	61.9	72.4	74.2
Water Content (%)	15.37	17.12	19.06	21.29
Dry density(kg/m3)	1763	1804	1827	1805

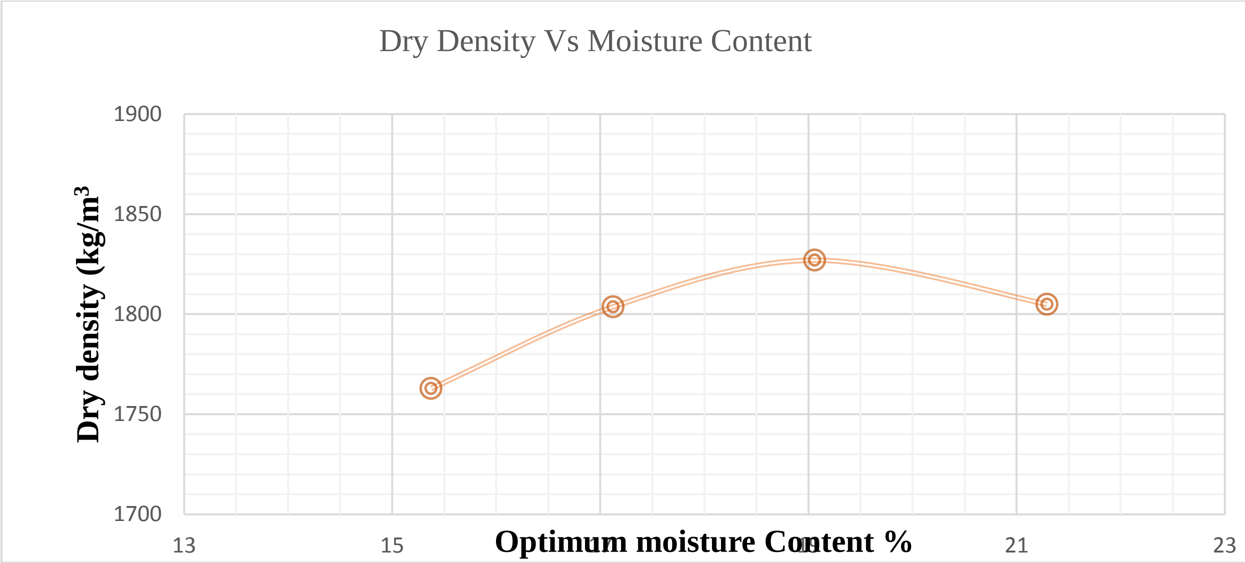


Figure D.1. Compaction results of black cotton soil with 0% of PET chips of MDD vs OMC curve

Table D.2. Computation of optimum moisture content and maximum dry density of black cotton soil 1.2 % of PET chips

Trial	1	2	3	4
Mass of mould+wet soil (g)	10884	10984	11143	11213
Mass of mould(g)	6580	6580	6580	6580
Mass of wet soil(g)	4304	4404	4563	4633
Volume of mould(gm/cm^3)	2124	2124	2124	2124
Wet Density(Kg/m^3)	2026	2073	2148	2181
Mass of can +wet soil (g)	106.32	102.84	116.49	120.47
Mass of can+ dry soil(g)	96.26	92.27	102.74	104.73
Mass of can(g)	30.8	30.6	30.6	30.8
Mass of water(g)	10.06	10.57	13.75	15.74
Mass of dry soil(g)	65.46	61.67	72.14	73.93
Water Content (%)	15.37	17.14	19.06	21.29
Dry density(kg/m^3)	1756	1797	1804	1798

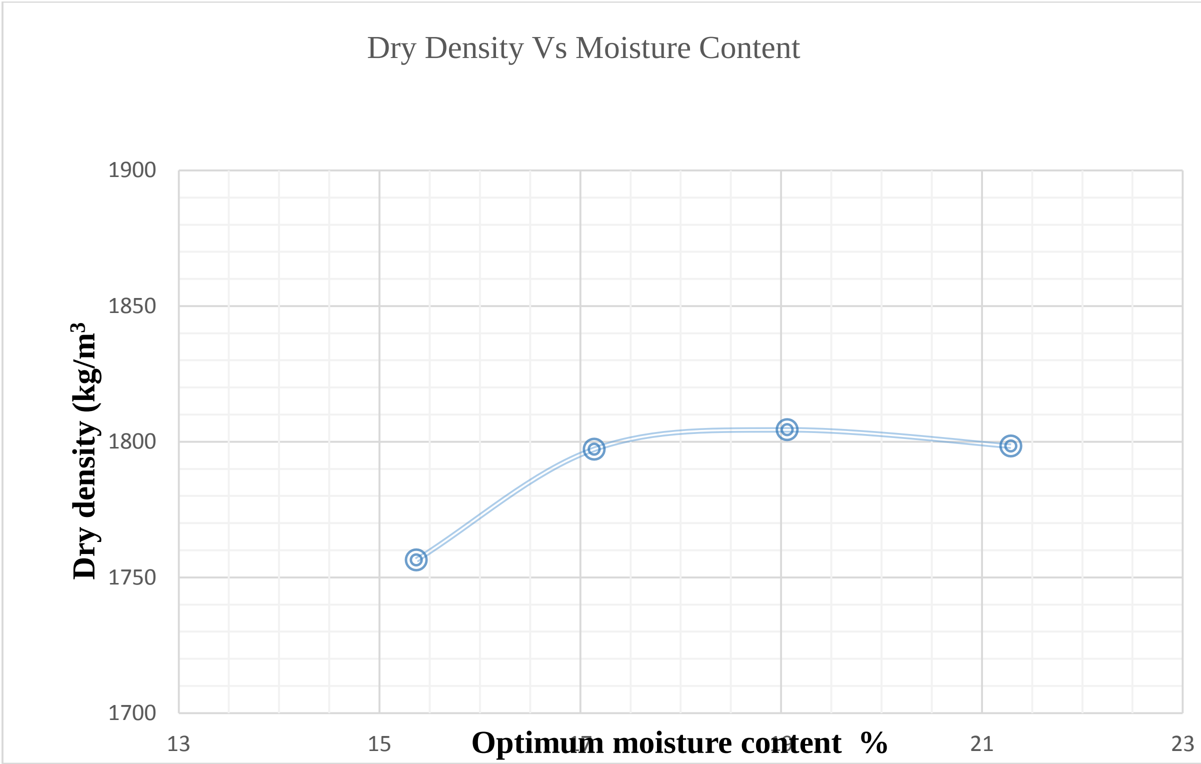


Figure D.2. Compaction results of black cotton soil with 1.2 % of PET chips of MDD vs OMC curve

Table D.3. Computation of optimum moisture content and maximum dry density of black cotton soil 2.4 % of PET chips

Trial	1	2	3	4
Mass of mould+wet soil (g)	10868	10967	11126	11196
Mass of mould(g)	6580	6580	6580	6580
Mass of wet soil(g)	4288	4387	4546	4616
Volume of mould(gm/cm3)	2124	2124	2124	2124
Wet Density(Kg/m3)	2019	2065	2140	2173
Mass of can +wet soil (g)	106.05	102.57	116.17	120.14
Mass of can+ dry soil(g)	96.02	92.05	102.47	104.46
Mass of can(g)	30.8	30.6	30.6	30.8
Mass of water(g)	10.03	10.52	13.70	15.68
Mass of dry soil(g)	65.22	61.45	71.87	73.66
Water Content(%)	15.38	17.12	19.06	21.29
Dry density(kg/m3)	1750	1790	1798	1792

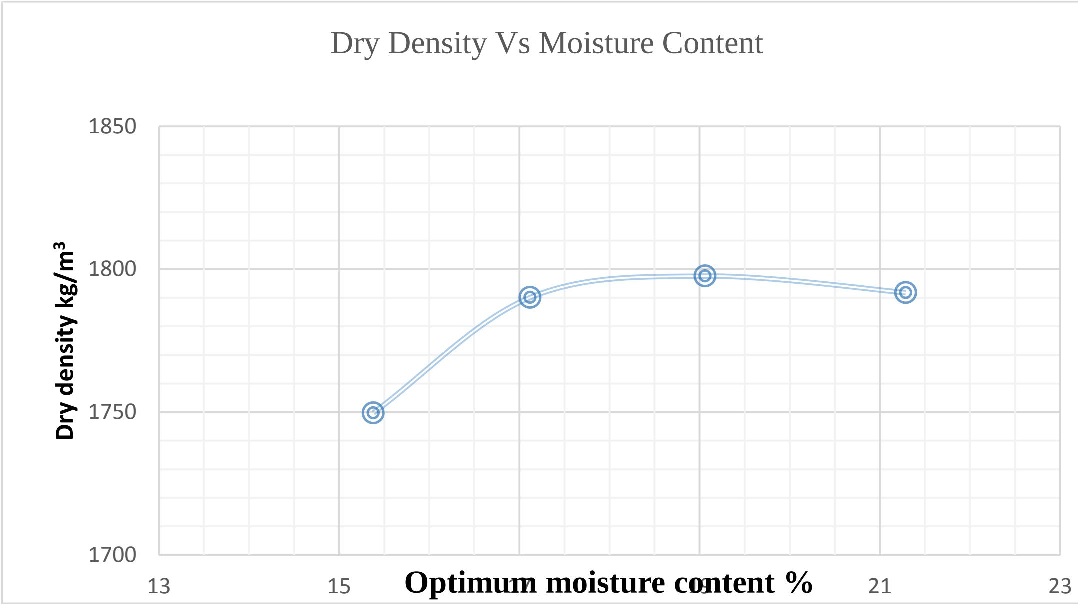


Figure D.3. Compaction results of black cotton soil with 2.4 % of PET chips of MDD vs OMC curve

Table D.4. Computation of optimum moisture content and maximum dry density of black cotton soil 3.6 % of PET chips

Trial	1	2	3	4
Mass of mould+wet soil (g)	10853	10952	11119	11179
Mass of mould(g)	6580	6580	6580	6580
Mass of wet soil(g)	4273	4372	4539	4599
Volume of mould(gm/cm^3)	2124	2124	2124	2124
Wet Density(Kg/m3)	2012	2058	2137	2165
Mass of can +wet soil (g)	105.77	102.31	115.86	119.81
Mass of can+ dry soil(g)	95.78	91.82	102.21	104.19
Mass of can(g)	30.8	30.6	30.6	30.8
Mass of water(g)	9.99	10.49	13.65	15.62
Mass of dry soil(g)	64.98	61.22	71.61	73.39
Water Content(%)	15.37	17.13	19.06	21.28
Dry density(kg/m^3)	1744	1784	1795	1785

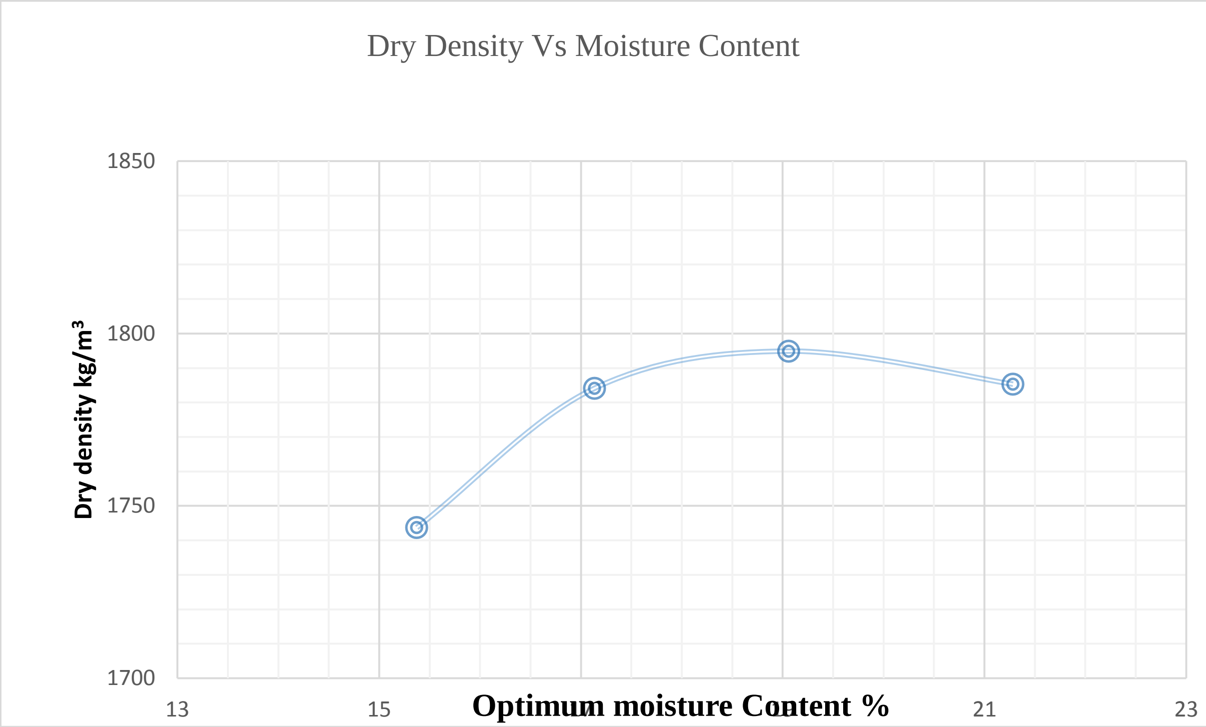


Figure D.4. Compaction results of black cotton soil with 3.6 % of PET chips of MDD vs OMC curve

Table D.5. Computation of optimum moisture content and maximum dry density of black cotton soil 4.8 % of PET chips

Trial	1	2	3	4
Mass of mould+wet soil (g)	10837	10935	11103	11162
Mass of mould(g)	6580	6580	6580	6580
Mass of wet soil(g)	4257	4355	4523	4582
Volume of mould(gm/cm^3)	2124	2124	2124	2124
Wet Density(Kg/m3)	2004	2050	2129	2157
Mass of can +wet soil (g)	105.49	102.04	115.54	119.49
Mass of can+ dry soil(g)	95.54	91.6	101.94	103.92
Mass of can(g)	30.8	30.6	30.6	30.8
Mass of water(g)	9.95	10.44	13.60	15.57
Mass of dry soil(g)	64.74	61	71.34	73.12
Water Content(%)	15.37	17.11	19.06	21.29
Dry density(kg/m^3)	1737	1777	1789	1779

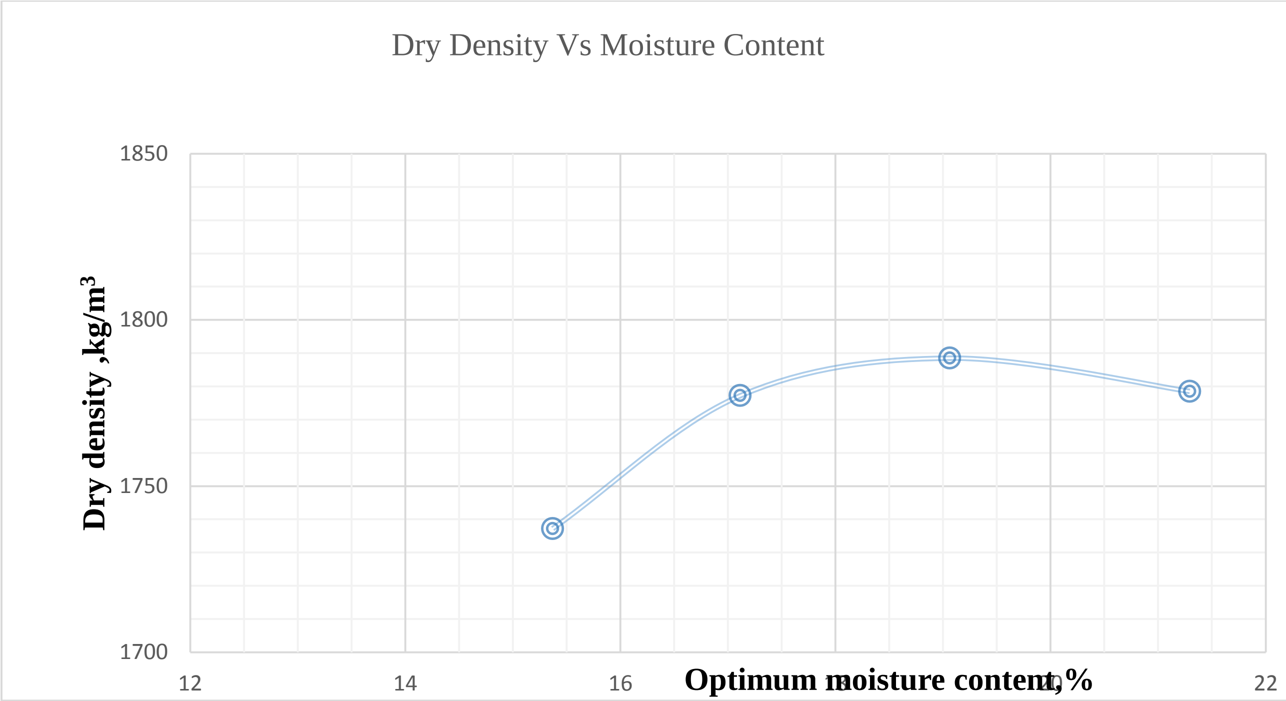


Figure D.5. Compaction results of black cotton soil with 4.8 % of PET chips of MDD vs OMC curve

APPENDIX E: California Bearing Ratio (CBR) of black cotton soil with different proportion of PET waste

Table E:1.Penteration data for soil with 0% of PET chips

Penetration, mm	10 blows		30 blows		65 blows	
	Dial RDG	Load kN	Dial RDG	Load kN	Dial RDG	Load kN
0	0	0	0	0	0	0
0.64	0.5	0.013	0.8	0.021	1	0.026
1.27	1	0.026	1.6	0.041	2	0.052
1.91	1.3	0.034	2.5	0.065	3	0.077
2.54	1.6	0.041	2.8	0.072	4	0.103
3.18	1.8	0.046	3.1	0.08	4.5	0.116
3.81	2	0.052	3.3	0.085	5	0.129
4.45	2.1	0.054	3.6	0.093	5.5	0.142
5.08	2.3	0.059	3.8	0.098	6	0.155
7.62	2.8	0.072	4.1	0.106	6.5	0.168
10.16	3	0.077	4.4	0.114	7	0.181
12.7	3.1	0.08	4.8	0.124	7.5	0.194

Ring factor=25.8 N/Div

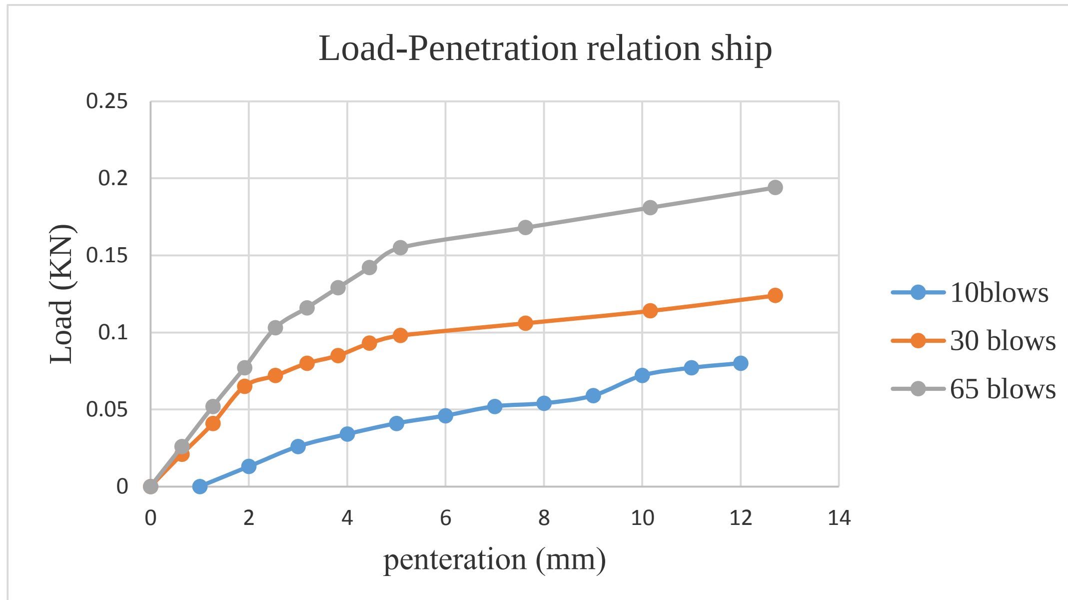
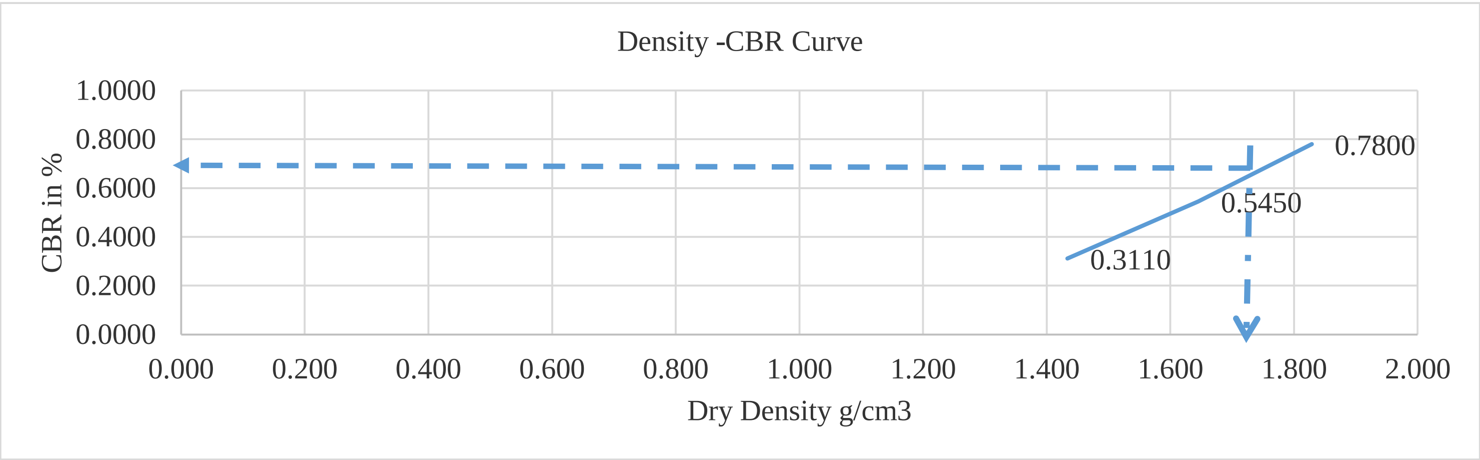


Figure E.1.Load -Penetration relationship of soil and 0% of PET chips composite

Table E.2.CBR value at Standard Loads and CBR summary for black cotton soil and 0% of PET waste composite

No of Blows	DD g/cm^3	Load in kN		Standard Load in kN		CBR(%)		CBR(%)
		2.54 mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.433	0.041	0.059	13.2	20	0.311	0.300	0.3110
30	1.645	0.072	0.098	13.2	20	0.545	0.490	0.5450
65	1.829	0.103	0.155	13.2	20	0.78	0.780	0.7800



From the Density-CBR Curve at 95% MDD (1.736 g/cm^3): CBR = 0.64

Figure E.2.Density- CBR curve of soil with 0 % of PET Chips

Table E:3.Penteration data for soil with 1.2% of PET chips

Penetration , mm	10 blows		30 blows		65 blows	
	Dial RDG	Load kN	Dial RDG	Load kN	Dial RDG	Load kN
0	0	0	0	0	0	0
0.64	0.5	0.013	0.8	0.021	1	0.026
1.27	1	0.026	1.6	0.041	2	0.052
1.91	1.5	0.039	2.5	0.065	3	0.077
2.54	4.1	0.106	5.4	0.139	7	0.181
3.18	4.3	0.111	5.8	0.15	7.5	0.194
3.81	4.8	0.124	6	0.155	7.8	0.201
4.45	5.2	0.134	6.2	0.16	8.2	0.212
5.08	5.7	0.147	7.4	0.191	9	0.232
7.62	5.9	0.152	7.6	0.196	9.5	0.245
10.16	6	0.155	7.8	0.201	9.7	0.25
12.7	6.5	0.168	8	0.206	9.8	0.253

Ring factor=25.8 N/Div

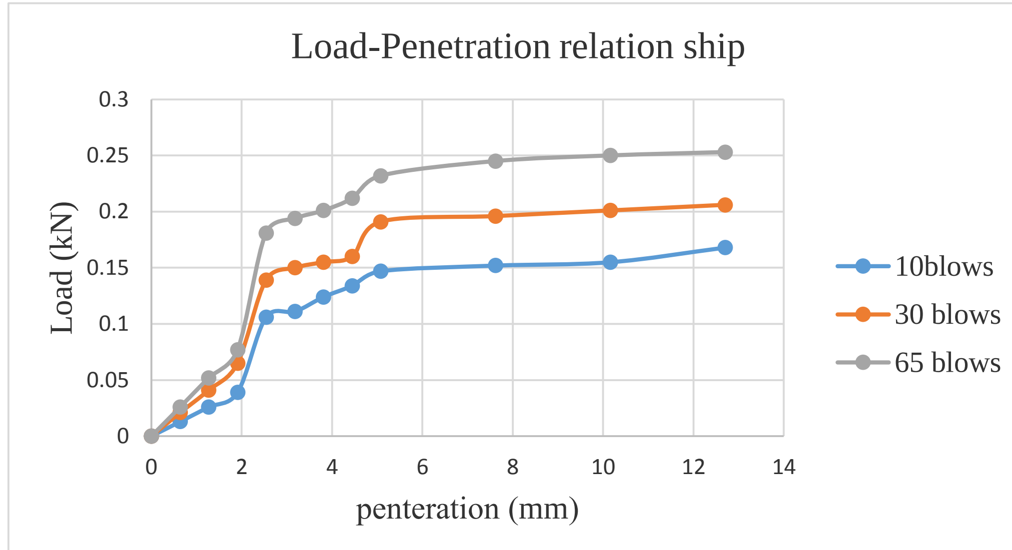
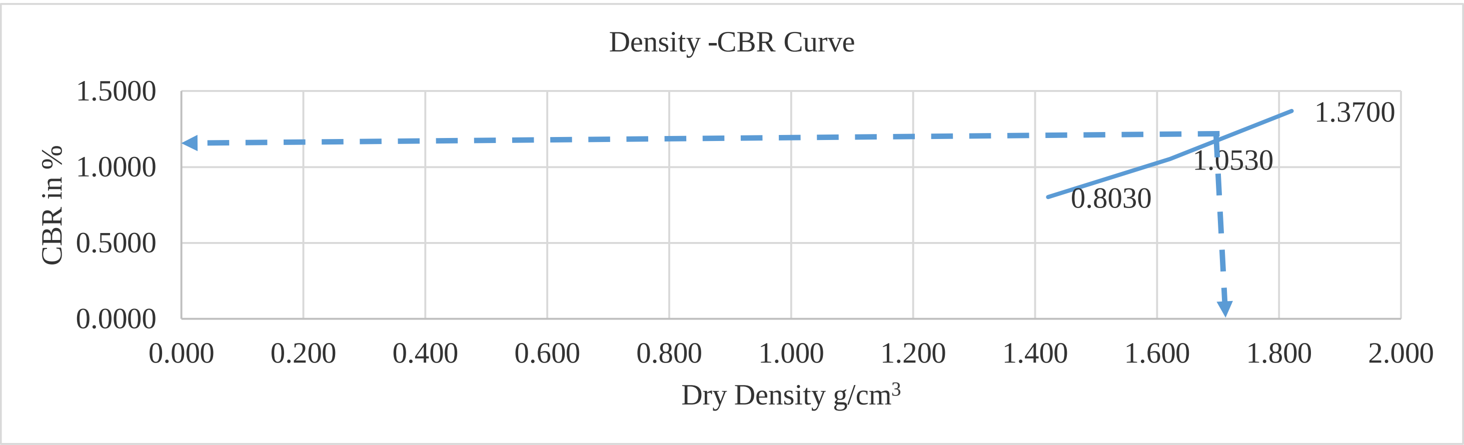


Figure E.3.Load -Penetration relationship of soil and 1.2% of PET chips composite

Table E.4.CBR value at Standard Loads and CBR summary for black cotton soil and 1.2 % of PET waste composite

No of Blows	DD g/cm^3	Load in kN		Standard Load in kN		CBR(%)		CBR(%)
		2.54 mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.422	0.106	0.147	13.2	20	0.803	0.740	0.8030
30	1.621	0.139	0.191	13.2	20	1.053	0.960	1.0530
65	1.821	0.181	0.232	13.2	20	1.37	1.160	1.3700



From the density -CBR curve 95% MDD(1.714g/cm^3)=1.2

Figure E.4.Density- CBR curve of soil with 1.2% of PET Chips

Table E:5.Penteration data for soil with 2.4 % of PET chips

Penetration, mm	10 blows		30 blows		65 blows	
	Dial RDG	Load kN	Dial RDG	Load kN	Dial RDG	Load kN
0	0	0	0	0	0	0
0.64	3.3	0.085	5	0.129	6	0.155
1.27	6.6	0.17	8	0.206	9	0.232
1.91	8.2	0.212	10	0.258	11	0.284
2.54	9.8	0.253	11	0.284	14	0.361
3.18	10.7	0.276	13	0.335	16	0.413
3.81	11.5	0.297	14	0.361	17	0.439
4.45	12.3	0.317	15	0.387	18	0.464
5.08	13.1	0.338	16	0.413	19	0.49
7.62	14.8	0.382	18	0.464	21	0.542
10.16	16.4	0.423	20	0.516	22	0.568
12.7	18	0.464	21	0.542	23	0.593

Ring factor=25.8 N/Div

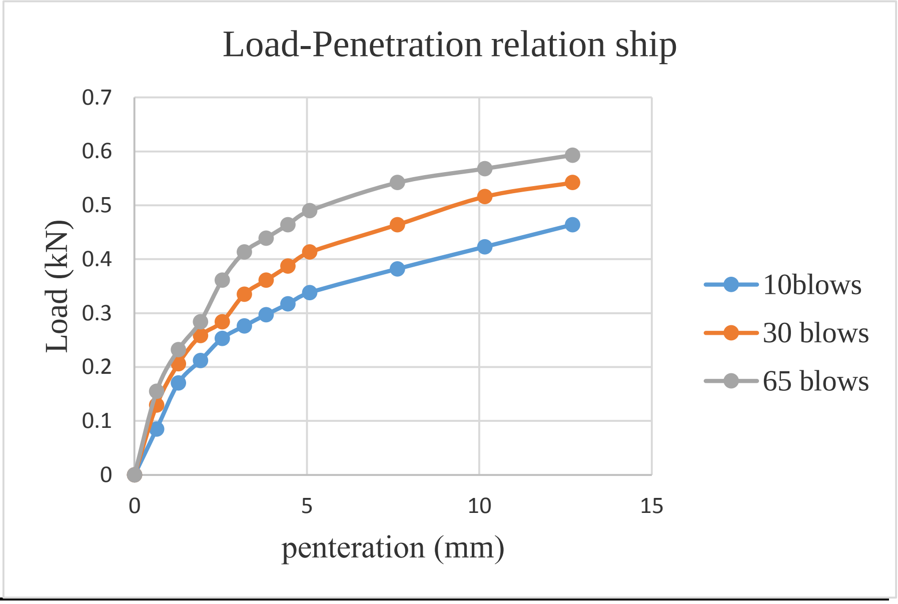
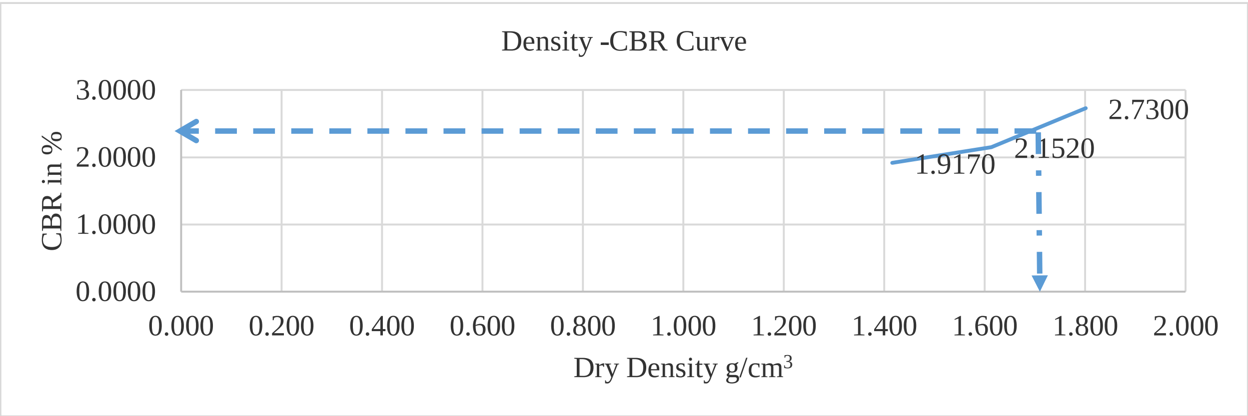


Figure E.5.Load -Penetration relationship of soil and 2.4 % of PET chips composite

Table E.6.CBR value at Standard Loads and CBR summary for black cotton soil and 2.4% of PET waste composite

No of Blows	DD g/cm³	Load in kN		Standard Load in kN		CBR(%)		CBR(%)
		2.54 mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.416	0.253	0.338	13.2	20	1.917	1.690	1.9170
30	1.613	0.284	0.413	13.2	20	2.152	2.070	2.1520
65	1.801	0.361	0.49	13.2	20	2.73	2.450	2.7300



From the Density-CBR Curve
at 95% MDD (1.708 g/cm^3):
CBR = 2.45

Figure E.6.Density- CBR curve of soil with 2.4 % of PET Chips

Table E:7.Penteration data for soil with 3.6 % of PET chips

Penetration, mm	10 blows		30 blows		65 blows	
	Dial RDG	Load kN	Dial RDG	Load kN	Dial RDG	Load kN
0	0	0	0	0	0	0
0.64	6.6	0.17	8.2	0.212	8	0.206
1.27	9.8	0.253	11.5	0.297	11	0.284
1.91	13.1	0.338	14.8	0.382	15	0.387
2.54	19.7	0.508	23	0.593	25	0.645
3.18	20	0.516	25	0.645	27	0.697
3.81	21.5	0.555	25.7	0.663	28	0.722
4.45	23	0.593	27	0.697	32	0.826
5.08	27.9	0.72	32.8	0.846	36	0.929
7.62	31.2	0.805	33	0.851	37	0.955
10.16	32	0.826	34	0.877	38	0.98
12.7	32.7	0.844	35	0.903	38.5	0.993

Ring factor=25.8 N/Div

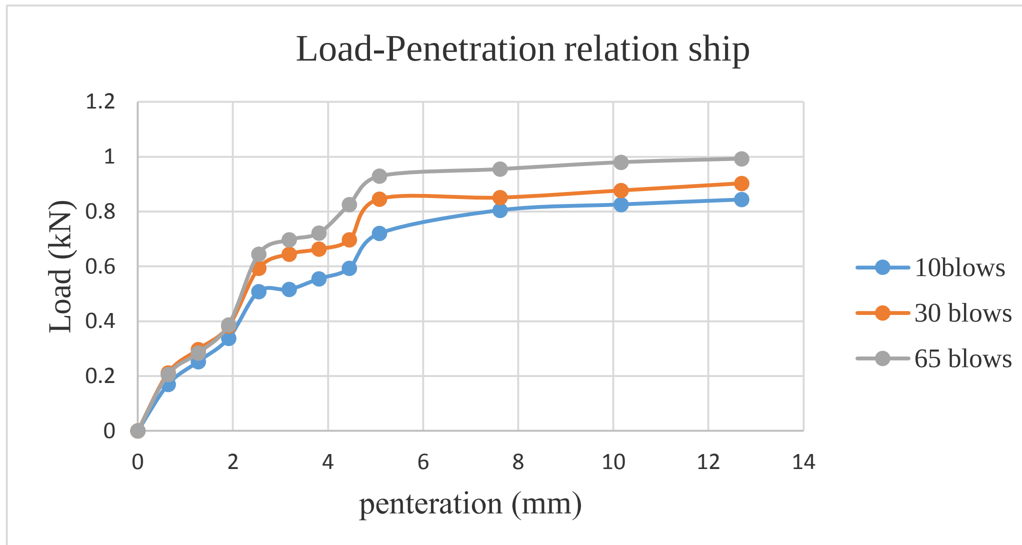
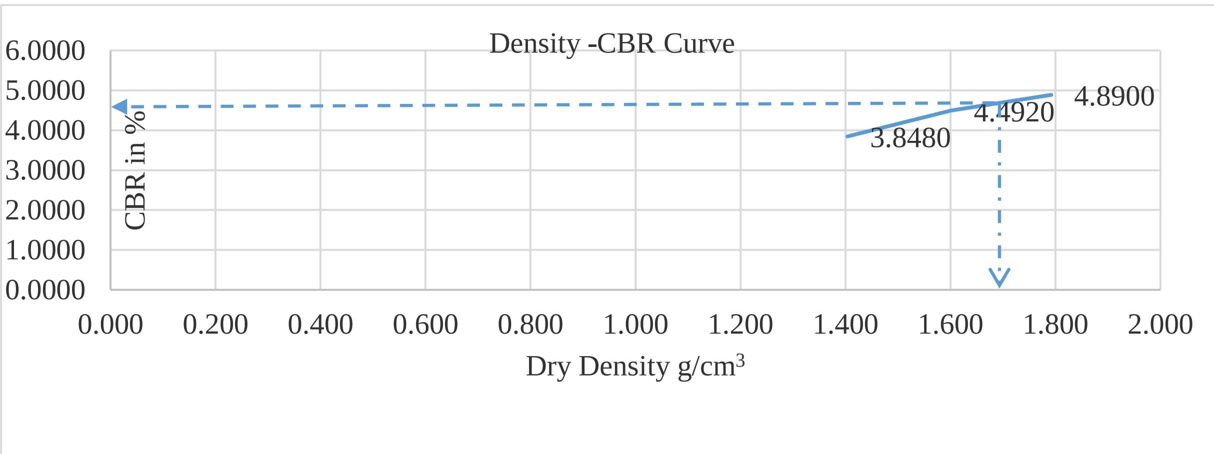


Figure E.7.Load -Penetration relationship of soil and 3.6 % of PET chips composite

Table E.8.CBR value at Standard Loads and CBR summary for black cotton soil and 3.6 % of PET waste composite

No of Blows	DD g/cm^3	Load in kN		Standard Load in kN		CBR(%)		CBR(%)
		2.54 mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.404	0.508	0.72	13.2	20	3.848	3.600	3.8480
30	1.602	0.593	0.846	13.2	20	4.492	4.230	4.4920
65	1.793	0.645	0.929	13.2	20	4.89	4.650	4.8900



From the Density-CBR Curve at 95% MDD ($1.705\ g/cm^3$): CBR = 4.61

Figure E.8.Density- CBR curve of Soil with 3.6 % of PET Chips

Table E:9.Penteration data for soil with 4.8 % of PET chips

peniteration in mm	10 blows		30 blows		65 blows	
	Dial RDG	Load kN	Dial RDG	Load kN	Dial RDG	Load kN
0	0	0	0	0	0	0
0.64	4	0.1	8.2	0.21	10	0.26
1.27	9	0.23	11.5	0.3	12	0.31
1.91	12	0.31	14.8	0.38	15	0.39
2.54	16.1	0.42	18	0.46	19	0.49
3.18	17.3	0.45	19.7	0.51	20	0.52
3.81	18.8	0.49	21.3	0.55	22	0.57
4.45	20.2	0.52	23	0.59	25	0.65
5.08	23	0.59	24.6	0.63	28	0.72
7.62	25.2	0.65	26.2	0.68	30	0.77
10.16	27	0.7	27.9	0.72	31	0.8
12.7	28.6	0.74	29.5	0.76	33	0.85

Ring factor=25.8 N/Div

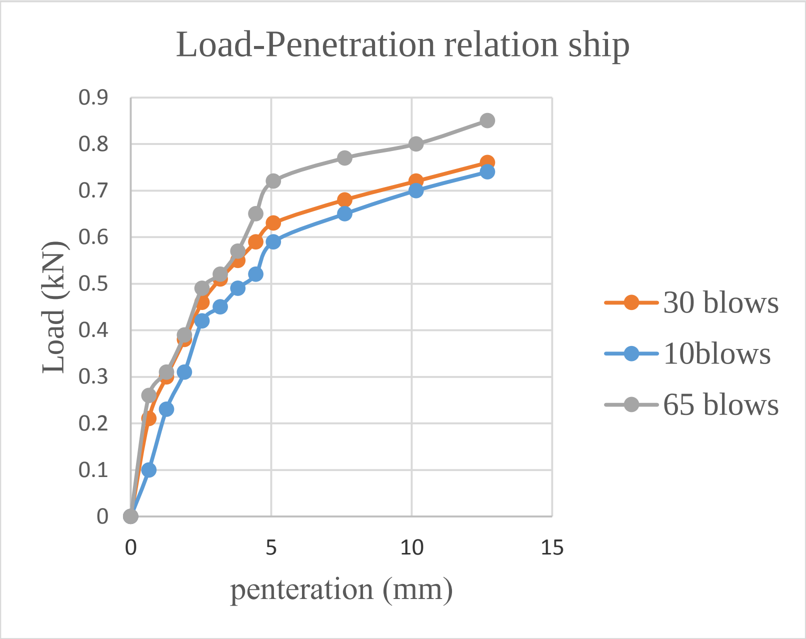
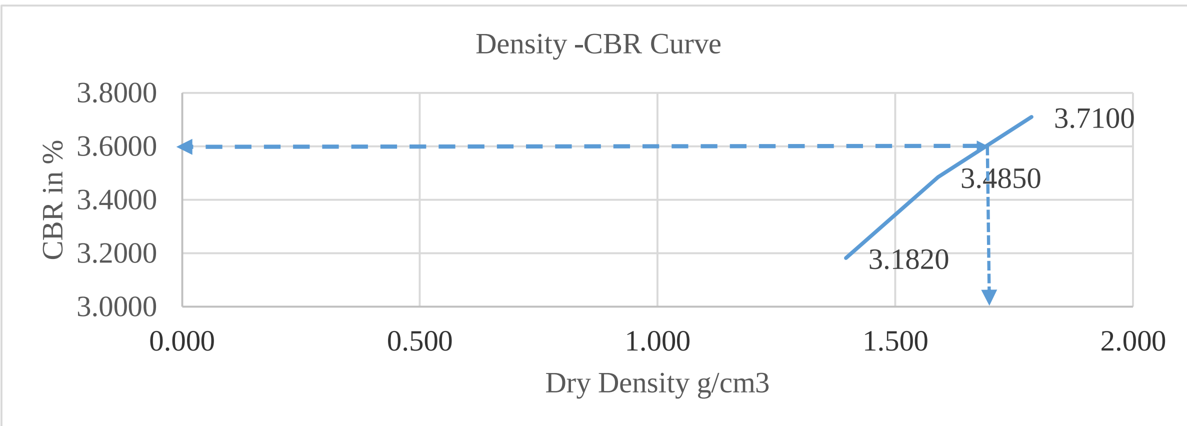


Figure E.9.Load -Penetration relationship of soil and 4.8 of % PET chips Composite

Table E.10.CBR value at standard loads and CBR summary for black cotton soil and 4.8 % of PET waste composite

No of Blows	DD g/cm^3	Load in kN		Standard Load in kN		CBR(%)		CBR(%)
		2.54 mm	5.08mm	2.54mm	5.08mm	2.54mm	5.08mm	
10	1.396	0.42	0.59	13.2	20	3.182	2.950	3.1820
30	1.590	0.46	0.63	13.2	20	3.485	3.150	3.4850
65	1.786	0.49	0.72	13.2	20	3.71	3.600	3.7100



From the Density-CBR Curve at 95% MDD (1.700 g/cm^3): CBR = 3.6

Figure E.10.Density- CBR curve of soil with 4.8 % of PET Chips

APPENDIX F: California Bearing Ratio –Swell (CBR-Swell) of black cotton soil with different proportion of PET waste

Calculation of Swell

Height of Specimen=H=127mm

Division of the swelling dial gauge=0.01mm

Initial dial reading =H_1

Final dial reading=H_2

% of Swell =$\frac{H1-H2}{H} * 0.01 * 100$

Table F.1.CBR -Swell value of black cotton soil and 0 % of PET chips

No of blows	H ,mm	H1 ,mm	H2,mm	Div of the swelling reading	CBR-Swell %	Average CBR-Swell in %
10	127.000	200	1400	0.01	9.4488	9.0300
30	127.000	300	1450	0.01	9.0551	
65	127.000	180	1270	0.01	8.5827	

Table F.2.CBR -Swell value of black cotton soil and 1.2 % of PET chips

No of blows	H ,mm	H1 ,mm	H2,mm	Div of the swelling reading	CBR-Swell %	Average CBR-Swell in %
10	127.000	175	1050	0.01	6.8898	6.3000
30	127.000	250	1050	0.01	6.2992	
65	127.000	150	875	0.01	5.7087	

Table F.3.CBR -Swell value of black cotton soil and 2.4% of PET chips

No of blows	H ,mm	H1 ,mm	H2,mm	Div of the swelling reading	CBR-Swell %	Average CBR-Swell in %
10	127.000	250	700	0.01	3.5433	3.2900
30	127.000	200	625	0.01	3.3465	
65	127.000	270	650	0.01	2.9921	

Table F.4.CBR -Swell value of black cotton soil and 3.6 % of PET chips

No of blows	H ,mm	H1 ,mm	H2,mm	Div of the swelling reading	CBR-Swell %	Average CBR-Swell in %
10	127.000	250	580	0.01	2.5984	2.3100
30	127.000	250	550	0.01	2.3622	
65	127.000	250	500	0.01	1.9685	

Table F.5.CBR -Swell value of black cotton soil and 4.8 % of PET chips

No of blows	H ,mm	H1 ,mm	H2,mm	Div of the swelling reading	CBR-Swell %	Average CBR-Swell in %
10	127.000	250	750	0.01	3.9370	3.4800
30	127.000	200	650	0.01	3.5433	
65	127.000	225	600	0.01	2.9528	

Appendix G: UCS curves with varying percentage of PET plastic waste

Table G.1 .Computation and test result of free black cotton soil

Compression dial reading mm	Strain (ΔL/L0) *100(%) (Ɛ)	Corrected Area A $=A_0/(1-Ɛ)$ cm^2	Load Dial Reading	Axial Load (kN)	Compressive Stress (kN/m^2)
0.0	0.0000	11.3354	0	0.0000	0
0.2	0.2632	11.3653	4	0.0098	9
0.4	0.5263	11.3954	9	0.0221	19
0.6	0.7895	11.4256	13	0.0320	28
0.8	1.0526	11.4560	17	0.0418	37
1.0	1.3158	11.4865	21	0.0517	45
1.2	1.5789	11.5173	24	0.0590	51
1.4	1.8421	11.5481	26	0.0640	55
1.6	2.1053	11.5792	28	0.0689	59
1.8	2.3684	11.6104	30	0.0738	64
2.0	2.6316	11.6418	33	0.0812	70
2.2	2.8947	11.6733	35	0.0861	74
2.4	3.1579	11.7050	37	0.0910	78
2.6	3.4211	11.7369	36	0.0886	75
2.8	3.6842	11.7690	33	0.0812	69
3	3.9474	11.8012	32	0.0787	67

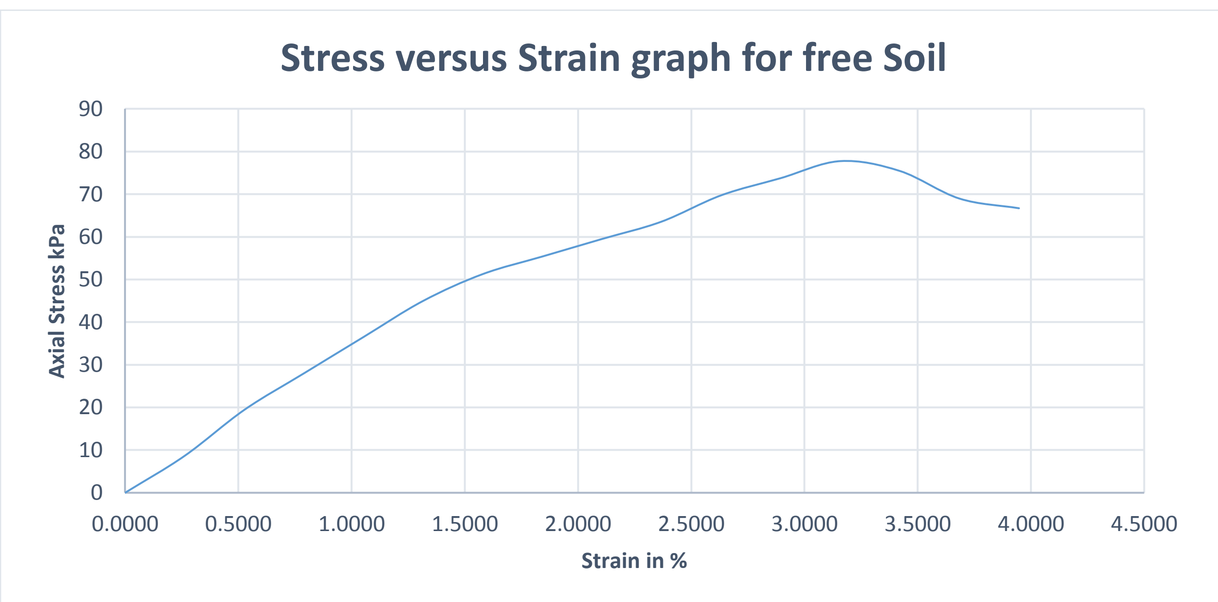


Figure G.1 .Stress versus strain for free soil

Table G.2 .Computation and test result of black cotton soil and 1.2% of PET chips

Compression dial reading mm	Strain (ΔL/L0) *100(%) (Ɛ)	Corrected Area A $=A_0/(1-Ɛ)$ cm^2	Load Dial Reading	Axial Load (kN)	Compressive Stress (kN/m^2)
0.0	0.0000	11.3354	0	0.0000	0
0.2	0.2632	11.3653	7	0.0172	15
0.4	0.5263	11.3954	14	0.0344	30
0.6	0.7895	11.4256	20	0.0492	43
0.8	1.0526	11.4560	26	0.0640	56
1.0	1.3158	11.4865	31	0.0763	66
1.2	1.5789	11.5173	36	0.0886	77
1.4	1.8421	11.5481	40	0.0984	85
1.6	2.1053	11.5792	43	0.1058	91
1.8	2.3684	11.6104	46	0.1132	97
2.0	2.6316	11.6418	49	0.1205	104
2.2	2.8947	11.6733	52	0.1279	110
2.4	3.1579	11.7050	55	0.1353	116
2.6	3.4211	11.7369	54	0.1328	113
2.8	3.6842	11.7690	49	0.1205	102
3	3.9474	11.8012	47	0.1156	98

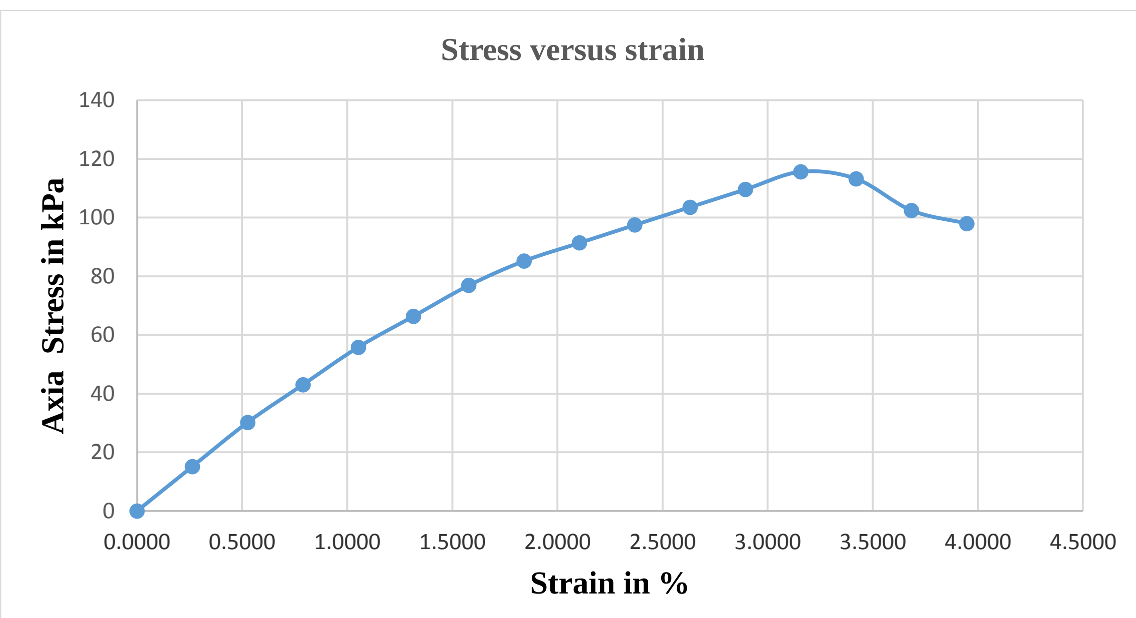


Figure G.2 .Stress versus strain for black cotton soil with 1.2% of PET chips

Table G.3 .Computation and test result of black cotton soil and 2.4 % of PET chips

Compression dial reading mm	Strain(ΔL/L0) *100(%) (ε)	Corrected Area A $=A_0/(1-ε)$ cm^2	Load Dial Reading	Axial Load (kN)	Compressive Stress (kN/m^2)
0.0	0.0000	11.3354	0	0.0000	0
0.2	0.2632	11.3653	10	0.0246	22
0.4	0.5263	11.3954	21	0.0517	45
0.6	0.7895	11.4256	30	0.0738	65
0.8	1.0526	11.4560	39	0.0959	84
1.0	1.3158	11.4865	46	0.1132	99
1.2	1.5789	11.5173	53	0.1304	113
1.4	1.8421	11.5481	59	0.1451	126
1.6	2.1053	11.5792	64	0.1574	136
1.8	2.3684	11.6104	68	0.1673	144
2.0	2.6316	11.6418	74	0.1820	156
2.2	2.8947	11.6733	78	0.1919	164
2.4	3.1579	11.7050	83	0.2042	174
2.6	3.4211	11.7369	81	0.1993	170
2.8	3.6842	11.7690	74	0.1820	155
3	3.9474	11.8012	71	0.1747	148

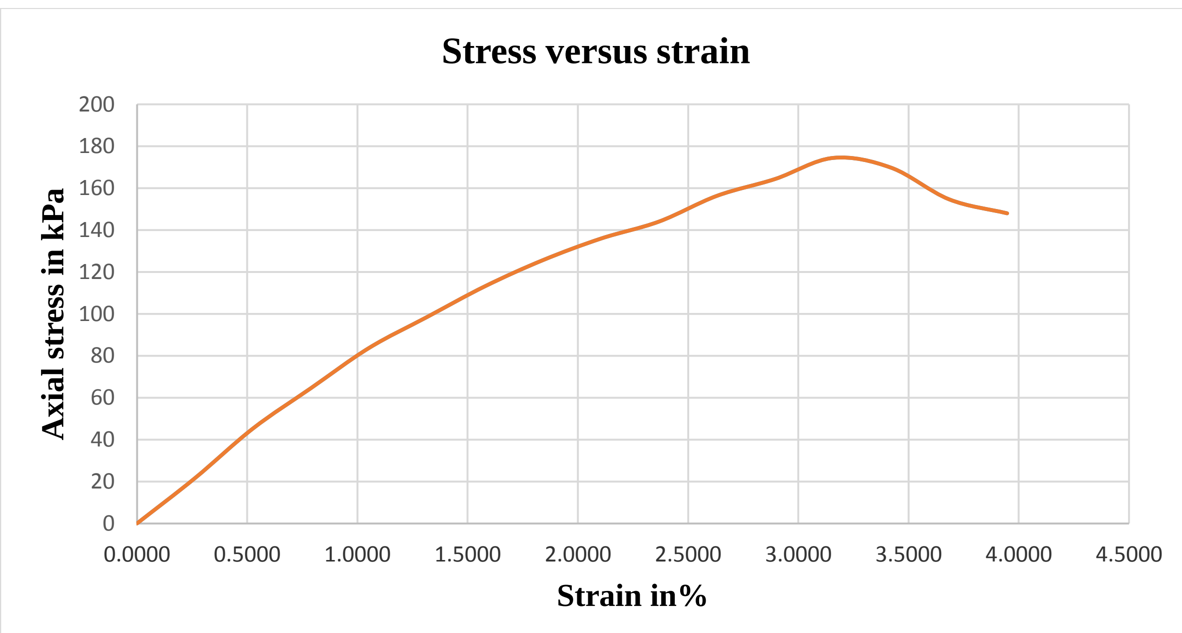


Figure G.3 .Stress versus strain for black cotton soil with 2.4 % of PET chips

Table G.4 .Computation and test result of black cotton soil and 3.6 % of PET chips

Compression dial reading mm	Strain (ΔL/L0) *100(%) (Ɛ)	Corrected Area A $=A_0/(1-Ɛ)$ cm^2	Load Dial Reading	Axial Load (kN)	Compressive Stress (kN/m^2)
0.0	0.0000	11.3354	0	0.0000	0
0.2	0.2632	11.3653	9	0.0221	19
0.4	0.5263	11.3954	18	0.0443	39
0.6	0.7895	11.4256	25	0.0615	54
0.8	1.0526	11.4560	33	0.0812	71
1.0	1.3158	11.4865	39	0.0959	84
1.2	1.5789	11.5173	45	0.1107	96
1.4	1.8421	11.5481	50	0.1230	107
1.6	2.1053	11.5792	54	0.1328	115
1.8	2.3684	11.6104	57	0.1402	121
2.0	2.6316	11.6418	62	0.1525	131
2.2	2.8947	11.6733	65	0.1599	137
2.4	3.1579	11.7050	69	0.1697	145
2.6	3.4211	11.7369	68	0.1673	143
2.8	3.6842	11.7690	62	0.1525	130
3	3.9474	11.8012	59	0.1451	123

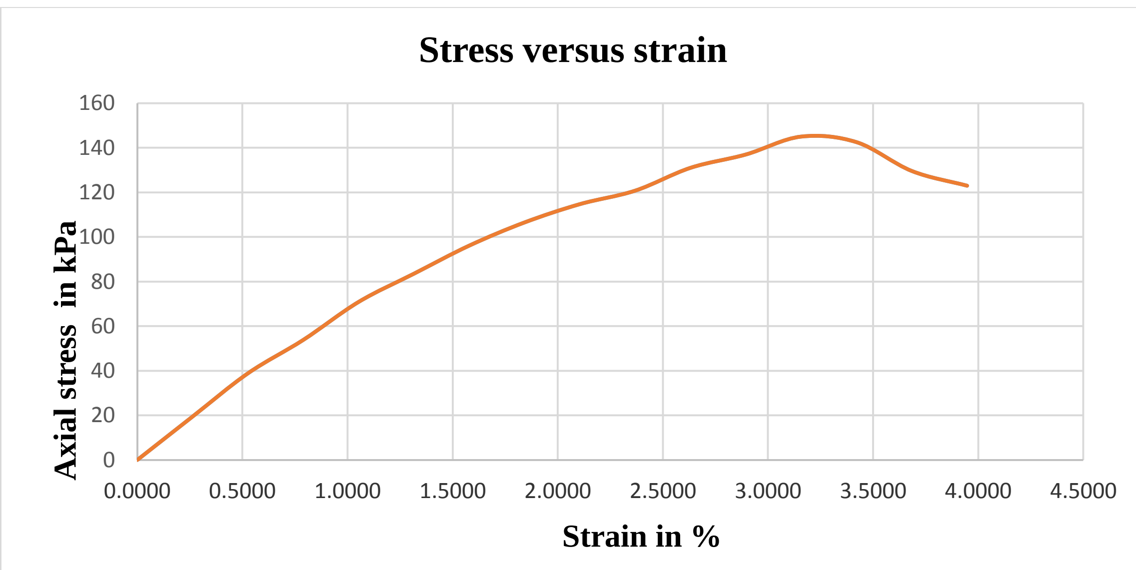


Figure G.4 .Stress versus strain for black cotton soil with 3.6 % of PET chips

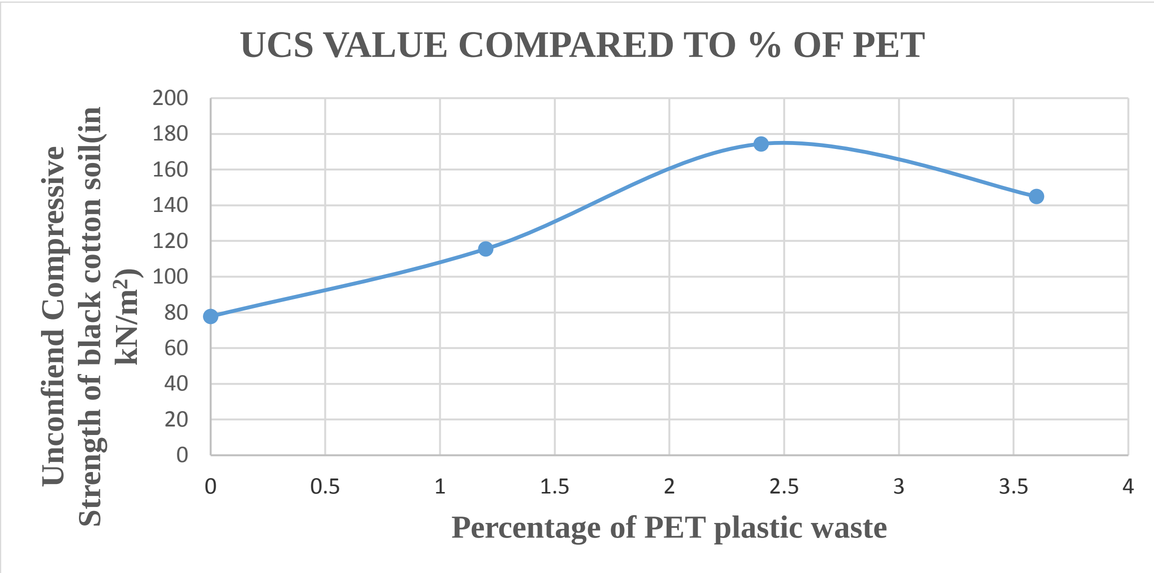


Fig G.5.Unconfined compressive strength of black cotton soil with different proportion of PET plastic waste

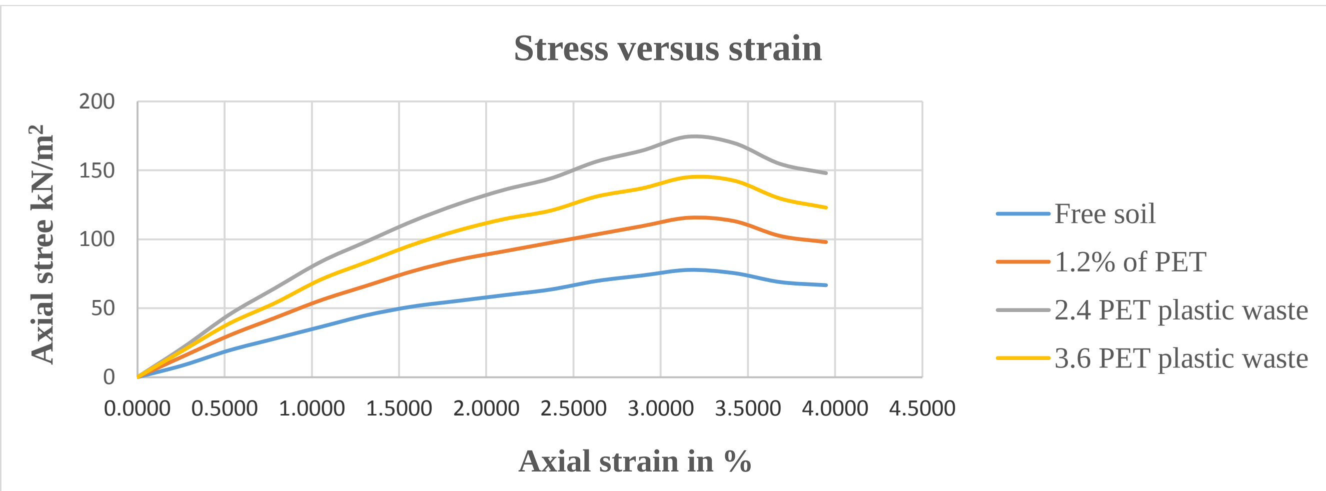


Fig G.6 Summary of unconfined compressive strength test of black cotton soil with different proportion of PET plastic waste