

ADDIS ABABA UNIVERSITY  
SCHOOL OF GRADUATE STUDIES



ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

THE EFFECT OF RANDOM INCLUSION OF TEFF STRAW ON SHEAR  
STRENGTH CHARACTERISTICS OF ADDIS ABABA EXPANSIVE  
SOIL

A Thesis Submitted to the School of Graduate Studies in Partial  
Fulfillment of the Requirement of Master of Science in Civil  
Engineering (Geotechnical Engineering)

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The Effect of Random Inclusion of Teff Straw on Shear Strength  
Characteristics of Expansive Soils Found in Addis Ababa

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## **DECLARATION**

I hereby declare that the thesis entitled “effect of random inclusion of teff straw on shear strength characteristics of expansive soils found in Addis Ababa” have been carried out by me under the supervision of Dr.ImSooBeen in Geotechnical Engineering Master of Science program. This thesis is my original work and has not been presented for a degree in any university and that all sources of materials used for the thesis have been duly acknowledged.

Abebe Arega

Signature .....

Date .....

## ABSTRACT

*Investigation of agricultural crop products as a reinforcement material in Geotechnical engineering has brought both economic and environmental advantages due to rising cost of the physical and/or chemical methods of conventional soil stabilization.*

*In Ethiopia, there is huge byproduct of teff straw which is used as reinforcing material for the locally constructed mud houses. This research work focuses on using of teff straw with varying percentages and examines its effects on shear strength characteristics of expansive soils. The laboratory investigations conducted includes particle size analysis, free swell test, Atterberg limit tests, unsoaked CBR tests and unconfined compression tests.*

*Accordingly, the investigation of the soil belongs to A-7-5 class of soil in the AASHTO classification system and CH in the USCS classification which has very poor strength.*

*The soil was reinforced with teff straw in stepped proportions of 0.2%,0.4%,0.6%,0.8% and 1% by dry weight of soil.*

*The test results reveal that the inclusion of randomly distributed teff straw in the soil increases unconfined compressive strength and unsoaked CBR values and reduces the liquid limit and plasticity index of the treated soil.*

*It is observed that the optimum teff straw content for achieving maximum unconfined compressive strength and unsoaked CBR is 0.6% in terms of dry weight of the soil.*

**Key words:** Teff straw, unconfined compression test, unsoaked CBR test

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## ABBREVIATION

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
CEC	Cation Exchange Capacity
CBR	California Bearing Ratio
CH	Highly compressible clays
ERA	Ethiopian Roads Authority
LL	Liquid Limit
MC	Moisture content
MDD	Maximum Dry Density
OMC	Optimum Moisture Content
PI	Plasticity Index
PL	Plastic Limit
GW	Well graded gravel
GP	Poor graded gravel
SP	Poor graded sand
SW	Well graded sand
SM	Silt sand
CH	Inorganic Clay
CO	Fatty or organic clay
Pt	Peat
$q_u$	Unconfined Compressive Strength
C	Cohesive
kPa	Kilo Pascal
cc	Cubic centimeter
d	diameter
mm	Millimeter
$\text{cm}^3$	Centimeter cube
gm	gram
$f_c$	fiber content
$f_l$	fiber length
$\phi$	angle of shearing resistance
Gs	specific gravity

## CHAPTER ONE

### 1. INTRODUCTION

#### 1.1 General Background

Construction on expansive soils usually bears a problem for civil engineers because of the soil unique behavior of cyclic swell and shrink. These types of soils usually swell when there is contact with water and shrinks when the water withdraws.

Application of soil strengthening or stabilization has been used a variety of techniques in order to get an improved and stabilized subgrade material especially in weak or soft soils. Soil stabilization is the alteration or modification of the properties of natural soil either by blending (mingling) two or more materials and perk up particle size distribution or by the use of stabilizing additives to meet the required engineering properties (Guyer,J.P..2011, US Army,1994).

The most common methods of soil stabilization are mechanical methods, chemical methods and physical methods.Construction of buildings,roads, and other civil engineering structures on weak or soft soil is extremelyperilous because such soil is vulnerable to differential settlements due to its poor shear strength and high compressibility(Pradhan et al. 2011).

Soil strengthening has been widely practiced in many types of geotechnical engineering construction projects. According to Qu et.al. (2013) reinforced soil technique is a method of earth improvement, the idea was initially known by Vidal of France in 1966. The efficacy of the reinforcements in the soil matrix is to improve the shear strength and to reduce the deformation of soil (Pradhan et al., 2011).

In reinforcing of soils a wide range of inclusions from low modulus of polymeric materials to relatively stiff high strength metallic inclusions have been used.Reinforcement of soils with fibers or straws has muchimplication in both nature and engineering practices. The action of tree roots in stabilizing of natural slopes can best demonstrate the basic principles of reinforced earth.Soil strengthening by fiber material is taken into account as an efficient ground enhancement method due to its economic value, easy flexibility, and reproducibility (Prabakar et al. 2002).Thus,

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stabilization of soil with agricultural products such as fibers and straws draw the attention of geotechnical engineers.

In Ethiopia, there is significant coverage of expansive soil in different parts of the country. It is very crucial to treat the expansive soil and search for an economical advantage of using the soil as a subgrade for different civil engineering structures. In the country, there is an abundant distribution of agricultural products such as wheat and teff. The byproduct of these cereal crops is used locally in most rural areas of Ethiopia to stabilize the walls of mud houses.

Hence, in this thesis, teff straw is used as the reinforcement material, and it is planned to randomly include into the soil at different percentages by weight of row soil. Hereafter, there is a need to improve certain preferred properties like bearing capacity, shear strength parameters and CBR of subgrade soil.

## 1.2 Statement of the Problem

In soil stabilization, one of the major problems is escalating cost in using of processed materials for improving the engineering properties of expansive soils. As more processed materials are used in stabilization of expansive soils, the cost incurred is very high. On the other side, Ethiopia has huge amount of locally available agricultural raw materials as byproducts. Among these materials one of the most productive and widely grown crops is teff. This study focuses on the use of teff straw in improving shear strength characteristics of expansive soils.

Soils which consist of significant amount of clay usually exhibit volume change when exposed to variation of moisture. As a result of the change in volume, structures built on the expansive soil will be subjected to uplifting pressure. The south east and south west of Addis Ababa soils are mostly expansive. At the same time, in these areas huge civil engineering constructions are undertaking. Moreover in the new expansion areas of the city more road infrastructures and buildings are under construction and the road density increase time to time. Due to these the soil has to be stabilized with economically available materials to reduce the cost of treated stabilizing materials. With a view point to stabilize the soil, some cost effective methods such as reinforcing with straws have been taken as an alternative solution. For this reason the effect of straw on the improvement of shear strength properties of these soils were investigated.

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## 1.3 Objectives of the Research

### 1.3.1 General Objective

The general objective of this research is to identify the effect of random inclusion of teff straw to the shear strength properties of expansive soils.

### 1.3.2 Specific Objectives

- To investigate the shear strength properties of soils before and after inclusion of straws.
- To fix the optimum amount of teff straw needed for stabilization of expansive soils.
- To study the effect of teff straw on consistency of expansive soils

## 1.4 Research Methodology

For the fulfillment of the objectives of the study, the following methods were applied.

### A. Citation of different literature reviews

The study started by arranging of the research through citing and reviewing secondary resources from different literature, research bulletin, text books, journals and previous studies

### B. Sampling and Testing Techniques

Samples of soil that represent expansive soils were collected from Addis Ababa, Bole Arabsa condominium site. Primary data was collected for the study by conducting a series of laboratory tests and secondary data from citation of different literature

### C. Sample preparation for experimental test

Sample preparation of experimental works involve air drying and sun drying, pulverization of expansive clays and sieving of soil to the required particle size according to ASTM testing manual. Classification of soil was determined by running index property and grain size analysis laboratory tests.

Expansive clay soil was treated through the varying of teff straw until optimum reinforcement achieved. Accordingly the expansive soil was stabilized through the proportion of teff straw as 0%, 0.2%, 0.4%, 0.6%,0.8% and 1% of straw by dry weight of soil. Then series of compaction, unsoaked CBR, unconfined

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compressive strength & Atterberg limit tests were conducted to determine the shear strength properties of the expansive soil.

## 1.5 Scope and Limitations of the Study

The scope of the study mainly focuses on evaluating the effect of random inclusion of teff straws on engineering properties of expansive soils. In addition the study provides transforming the use of teff straw which is an agricultural product into modern construction industry for the reinforcement of expansive soils.

In this study there were limitations on;

- Availability of triaxial testing machine for testing the expansive soil
- Determining of the aspect ratio of the straw
- Finding mechanical properties of the straw

Therefore, the findings should be considered as indicative rather than definitive for the application and further studies and additional tests are required.

## 1.6 Organization of the thesis

The thesis is organized and briefly discussed by arranging into five chapters. The first chapter is introductory part, which discusses mainly about expansive soils and the potential damages occurred, locations and worldwide distributions. The second chapter deals with different literatures on stabilization of expansive soils and the different reinforcement materials. The third chapter deals with materials and methods followed in this research. In this chapter, different laboratory determination procedures and methods were followed. The fourth chapter is about discussion on the laboratory results. Finally, the fifth chapter deals with the conclusions and recommendations drawn from the thesis.

## CHAPTER TWO

### 2. LITERATURE REVIEW ON EXPANSIVE SOILS

#### 2.1 Soil Improvement Techniques

The different soil improvement techniques are soil replacement, water table lowering, ground freezing, electro-osmosis, compaction control, chemical stabilization and soil reinforcement (Merzababaei, 2012).

The soil available on a project site might not meet all the engineering requirements for the intended purpose. In some cases, the soil might not even be desirable for simple engineering construction. Engineers can avoid problematic soils by either changing the project site or replacing the undesirable soil with suitable soils from other sites. In the early days of construction of high ways, bridges and buildings, soil replacement methods were widely employed. However, with increasing use of land and growth of cities, highways and industrial zones, decisions to avoid use of poor grounds are less frequently made and ground improvement methods have been developed extensively (Lambe and Whitman, 1979).

Shear strength is that the primary engineering property that controls the firmness of a soil mass subjected to loads. The bearing capacity of soils, the stability of slopes and the earth pressure against retaining structures are governed by this engineering property. All the problems of soil engineering are associated in one way or the other with shear strength of the soil. Thus, the shear strength is one of the most complex engineering properties of the soil (Arora, 2004).

Expansive soils are clays with enormous plasticity. As the name of the soils suggests, these soils are known for their peculiar nature of expanding or shrinking when exposed to moisture changes. These soils are known as black clays or in some areas as “black cotton” soils. The name black cotton come from the fact that soils are found favorable in some regions for growing cotton (Tefera and Leikun, 1999).

Usually soils show high bearing capacity in dry state, which is gradually lost with rise in moisture content. If barred from swelling following exposure to moisture, the soils

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exert high swelling following exposure to moisture; the soils exert high swelling pressure. The pressure build-up is usually responsible for cracking of buildings, distortion of pavement surfaces and damage to the other structures (Tefera and Leikun, 1999).

In most common ways soils are stabilized for construction due to the following main reasons.

- Enhance the strength characteristics of soils such as stability and bearing capacity for the purpose of improving subgrade, sub base, base and low-cost road surfaces.
- Improve the volume stability by avoiding objectionable properties including swelling, shrinkage, high plasticity characteristics, and difficulty in compaction caused by change in moisture are improved.
- Enhance durability by increasing the resistance to erosion, weathering or traffic and
- Improve drainage conditions, poor workability, dust nuisance, frost vulnerability etc.

Research conducted on shear strength characteristics of expansive soils in Ethiopia mainly along five main trunk roads which connect Addis Ababa to the other parts of the country. This research reveals that the cohesion and the angle of internal friction were in the range of 30kPa-150kPa and 3°-25° respectively (Zewdie, 2004).

Sanjay et al. (2018) studied the strength characteristics of coconut coir fiber reinforced soil stabilize using marble dust by dry weight of expansive soil with percentages of 0.25%, 0.5%, 0.75 percent and 1 percent and to each coconut fiber unsoaked and soaked CBR tests were conducted in the laboratory. According to Shukla Devdatt et al. (2015) Soaked California bearing ratio value increases from 3.9% to 8.6% and unsoaked CBR value increased from 8.1% to 13.2%.

### 2.2 Fiber Reinforcement

The use of tensile element in soil structures isn't new. Some 3,000 years ago, the Babylonians were the primary ancient nations to use palm branches to manufacture clay bricks. The Agar-Quf Ziggurat, an Iraqi temple, was made from clay bricks steel-clad with woven reed mats, laid horizontally on a layer of sand and gravel at vertical

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center spaces between 0.5m and 2m (Kersel,1975). The Babylonians were followed by the Romans who used earth-reinforcing techniques, as evidenced by thereed, to strengthen earth levees constructed along the Tiber River (Ekinici, 2016).

The modern concept of soil strengthening was suggested by Casagrande before nine decades, during his lecture in the University, who idealized the matter within the sort of a fragile soil armored by high strength sheaths laid level horizontally in layers ([www.iare.ac.in](http://www.iare.ac.in)). Later on, Vidal in 1960s investigated intimately ([www.researchgate.net](http://www.researchgate.net)). His idea was to get flat reinforcing strips horizontally in a frictional soil, as this aided the interaction between the soil and the stabilizing material, to build a frictional force, to carry the soil in situ (Jones, 1996). Reinforcing soil with tensile element remains usual practice in unindustrialized nations where soil and agricultural byproducts are mixed to be used as a source of building material (Ekinici, 2016).

Fiber-reinforced soil is considered as a soil mass comprising arbitrarily spread separate elements (fibers), that deliver an improvement within the mechanical behavior of the soil composite (Li, 2005). Numerous experiments were conducted to work out the consequences of discrete fibers on the behavior of granular soils, the overwhelming majority focusing only on short term characteristics and total shearing strength of the fiber soil mixture. Therefore, there is a scarcity of figures relating to the long-term effects of the fiber buttressing within the clay structure and really little is understood about their behavior in place.

Chandra et. al.(2008) have armored the three major sorts of soils typically clay, silt & silty sand with polypropylene fiber of 0.3mm diameter. The fibers were expurgated into pieces of 15, 25 and 30mm long and aspect ratio of fifty, eighty and hundred with percentages of 0.75, 1.5, 2.25, and three in terms of dry weight of soil. The static triaxial test of unreinforced soil was conducted. Their laboratory test result divulges that the uniaxial compressive strength is 3.824, 4.836 and 9.712 MPa respectively.

Researchers conducted on fiber reinforced soil revealed that the inclusion of fibers to a soil stratum caused an increase in peak shear strength and decrease in the post peak strength. Researchers qualified the increase in shear strength to the increase in frictional angle and cohesion, which can be determined by testing fiber-reinforced

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specimens, in present geotechnical practice, the design of fiber armored specimens, which can be expensive and inefficient (Ekinici, 2016).

Maher and Ho (1994) reinforced the Kaoline (LL=45, PL=15) with monofilament polypropylene ( $d = 0.32, f_1 = 2.5$  to 20mm,  $f_c = 1$  to 5%) and glass fibers ( $d = 0.05\text{mm}, f_1 = 6$  to 25mm,  $f_c = 1$  to 5). The unconfined compression test, splitting tensions and three point bending were done and for this test the polypropylene fiber is added from one percent to five percent on soil. Alok Sharan (2011), depicts that 'the addition of polypropylene fibers advances the unconfined compressive strength from 1.2 times to 1.4 times, increasing fiber length from 5mm to 20mm, decrease  $q_u$  from 1.4 to 1.2 times'.

Kumar, Wallia and Bajaj (2007) have reinforced the expansive soil with specific gravity = 2.72, liquid limit 68%, plastic limit 50, optimum moisture content = 29.4%, maximum dry density = 1.32g/cc with polyester synthetic. They scrutinized unconfined compression of fly ash, lime and erratically oriented fibers on the geotechnical characteristics of expansive soil. The result portrays that unconfined compressive strength surge with increase in fiber content, which shows that fibers are more efficient when soil is imperiled to tension instead of compression.

The fundamental principles involved in earth reinforcement techniques are simple and are employed by mankind for many years. One among the vital characteristics of reinforced soil is that it's made with two kinds of elements, soil grains and reinforcements. The essential mechanism of reinforced earth involves the inception of frictional forces between the soil and reinforcement ([www.onlinepubs.trb.org](http://www.onlinepubs.trb.org)). The soil transfers the forces developed in earth mass to the reinforcement by means of friction; as a result tension is developed. The soil develops virtual cohesion within the direction during which strengthening is placed and thus the cohesion is proportional to tension developed in reinforcements (Sharan , 2011).

Merzababaei conducted his PhD dissertation on reinforcement of clay soils using waste carpet fibers by varying fiber contents of 1%, 3%, and 5% of dry mass of soil. The research reveals that, unconfined compression strength of the clay soils effectively improved by including fibers controlling the dry unit weight and moisture content of the fiber reinforced soil. Shear strength parameters of fiber reinforced soil increased with addition in fiber content. For instance cohesion intercept and internal

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friction angle with 5% fiber reinforced soil compacted at dry unit weight of  $17.8\text{KN/m}^3$  increased by 118% and 82% respectively compared to those of unreinforced soil compacted at dry density of  $21.1\text{KN/m}^3$ . Fiber reinforced soils showed increased ductility and better energy absorption capacity compared to those of non-reinforced soils with brittle failure. The projected ductile behavior of fiber reinforced soils was manifested in reduced size of main cracks with apparent increase in number of small cracks (Merzababaei, 2012).

Gosavi et al.(2004) have studied on black cotton soil with liquid limit = 38%, Plastic limit = 14%, cohesion =  $41\text{KN/m}^2$ , angle of internal friction =  $14^\circ$  and California bearing ratio = 4.9% reinforced with fibers glass (  $d = 0.1\text{mm}$ , aspect ratio = 250 and 500,  $f_c = 1,2,3\%$ ) mixed randomly. They revealed that the direct shear test and CBR test and therefore the result and cohesion increases & maximum dry density and angle of internal friction reduces up to 2% of  $f_c$  and safe bearing capacity increases by 33.58% and 29.67% owing to addition of glass fiber with aspect ratio 250 and 500 respectively

Prabakar and Srindahar (2012) studied the effect of inclusion of sisal fiber on strength behavior of  $C-\phi$  soils in India. According to their findings the following conclusions were drawn.

- The OMC is higher than the raw soil for all percentages of reinforcement
- The value of cohesion increases up to certain level
- Sisal fiber is found to be good reinforcement material

### 2.3 Shear Strength of Soil

The shear strength of a soil is its maximum resistance to shear stresses just before the failure (Arora,2004). The most important shear strength characteristics of soils are cohesion and angle of internal friction. Various experiments were conducted in increasing the shear strength characteristics of expansive soils using different agricultural products such as fibers, straws and many more cost effective by-products. These byproducts are used in the form of reinforcements so as to increase the strength characteristics of soils and the soil stabilized to use for the intended construction purpose.

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A study conducted at Chittur in Palaghat District of black cotton soil of India having high swelling and shrinkage characteristics and extremely low CBR value and shear strength (Krishna and Sayida, 2009). The test result shows an improvement in CBR value and unconfined compressive strength of soil due to the addition of sisal fiber (Prabakar, 2002).

Another laboratory experiment was conducted on shanghai expansive soils using wheat straws. In this soil, a series of direct shear tests were showed on unreinforced and reinforced soils in order to study the shear strength characteristics of cohesive soils. The test results disclosed that the shear strength increase to the random addition of fibers in the soils (Jili Qu, 2013).

An investigation was conducted in clayey sand soil, with polypropylene fibers 0.5% and 1% by weight and clay with content of 10 percent and 20 percent by weight to see the effect of the test parameters. It has been perceived that inclusion of clay particles to the sands reduced the shear strength of the samples. A study conducted on shear strength of fiber reinforced sands in Kharazmi University in 2017 reveals that, increase in clay content reduced dilation and increased compressibility of the mixed soil. Adding of the fiber to both sands and clayey sands samples enhanced the shear strength and increased ductility and axial strain at failure (Moradi et al., 2017).

Engineering properties of Addis Ababa soils were investigated by taking samples at six selected areas of the city. The laboratory result divulges that the basic properties as indicated in Table 2.1.

Table2-1. Engineering properties of Addis Ababa Soils (Tefera. and Yohanese.)

Location	Depth	Specific Gravity	Moisture Content	Total unit Weight	Dry unit Weight	Liquid Limit	Plastic Limit	Plasticity Index	Free Swell	Clay Fraction	Activity
AMCE	1.2	2.63	38.6	18.4	13.3	102	24	78	130	50	1.6
	2	2.6	32.6	18.5	13.9	123	30	93	120	70	1.3
Bole road	1	2.65	32.4	17.9	13.5	110	35	75	150	60	1.3
	2	2.64	34.8	18.3	13.6	108	22	76	140	55	1.4
Civil Aviation	1.2	2.66	36.7	18.2	13.3	94	22	72	130	45	1.6
EBCA	1	2.69	30.2	18.2	14	100	26	75	140	50	1.5
	3	2.48	34.8	18	13.4	87	15	72	90	40	1.8
Old Airport	1	2.78	39.3	18.2	13.1	98	30	68	140	50	1.4
	1	2.69	40	17.6	12.6	114	25	89	125	60	1.5
Yared Church	2	2.56	32.9	17.7	12.6	107	25	82	170	47	1.8

## 2.4 Origin and Formation of Expansive Soils

The parent materials for expansive soils can be classified broadly into two groups. The first groups of origin of expansive soils are basic igneous rocks whereas the second groups are sedimentary rocks. In igneous rocks, they are formed by decomposition of feldspar and pyroxene and in sedimentary rocks; they are the constituents of the rock itself (Tefera and Leikun, 1999).

Expansive soils are widely distributed in USA, Mexico, Argentina, South Africa, Ethiopia and India.

## 2.5 Damages Caused by Expansive Soils

A number of failure reports are revealing worldwide due to problematic expansive soils. Jones and Holtz reported in American Society of Civil Engineers (ASCE, 1973) that the estimated damage attributed to expansive soil movements in construction categories like single family homes, commercial buildings, multi-story buildings, highway streets etc. estimated an average loss of 2.255 million dollars.

## 2.6 Identification and Classification of Expansive Soils

Expansive soils can be identified by using different methods. These are general methods, mineralogical investigation and index tests.

### 2.6.1 Classification by General Methods

There are two widely accepted classifications of soils for engineering purpose.

#### I. Unified Soil Classification System

This classification system is the most widely used in all types of engineering problems involving soils. The classification depends on identification of the type and major constituents considering grain size, plasticity and gradation. According to this method, the following are the three major groups.

- ❖ Coarse grained soils(GW,GP,SW,SP)
- ❖ Fine grained soils(M,H,C,O and Pt)
- ❖ Highly organic peat(Pt)

Depending on the correlation of swelling potential and the Unified Soil Classification System the above three groups can be described in terms of their degree of expansion as shown in Table 2.2.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Table2-2.Relationship between USCS and Degree of expansion

Soil classification category	Degree of expansion
GW,GP,GM,SW,SP and SM	Little or no expansion
GW,SC,MC, and MH	Moderate expansion
CL,OL,CH and OH	High volume change of expansion
Pt	No visible rating of expansion

### II. ASHTO Soil classification

The AASHTO Soil classification System is based on the following three soil properties.

- Grain size distribution/Particle size analysis
- Liquid limit
- Plasticity Index

This system is normally used by highway engineers, for classification of sub-grade soils for highway pavements. Conforming to this system soils are classified into seven major groups,A-1 through A-7 as shown in Table 2.3.

Table2-3. AASHTO Soil Classification (V.N.S, Murthy)

General classification	Granular materials (35% percent or less of total sample passing sieve No 200)							Silty clay Materials( More than 35% of the total sample passing No 200)			
	A-1		A-3	A-2				A-4	A-5	A-6	A-7
Group classification	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		51 min								
No 40	30 max	50 max	10 max	35max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
No 200	15 max	25 max									
Characteristics of fraction passing No 40											
Liquid limit				40 max	41 min	40 max	41min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		NP	10 max	10 max	11 min	11 max	10 max	10max	11 min	11 min
Usual types of significant constituent materials	Stone fragments-gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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The following methods were used in closely examining of expansive soils. Mineralogical investigation and index property test were discussed as follows.

### 2.6.2 Mineralogical Investigation

The constituents of expansive soils in terms mineralogical configuration has an important bearing on the swelling potential as explained under clay structure.

The negative electric charges on the surface of clay minerals, the strength of the interlayer bonding, and the cation exchange capacity all contribute to the swelling potential of clay (www.researchgate.net). Hence, it is claimed by the clay mineralogist that the swelling potential of any clay can be evaluated by the identification of the constituent mineral of this clay (Fu Hua Chen, 1975).

The most common methods of mineralogical investigation include X-ray diffraction, differential thermal analysis, dye adsorption, chemical analysis and electromagnetic resolution. These methods needs costly equipment and skilled technical persons and are usually used in selected important research projects.

### 2.6.3 Index Tests

Simple soil property tests can be used for the evaluation of the swell potential of expansive soils. Index tests are easy to conduct and should be included as routine tests in the investigation of building sites in areas having expansive soils. Such tests include Atterberg limit tests, free swell test, linear shrinkage test, colloid content/activity.

Results of the above tests which are very important in identifying expansive soils are percentage of clay fraction smaller than 2 micron, liquid limit, plastic limit, shrinkage limit and free swell. These methods are mostly used and applied in laboratories.

### 2.6.4 Classification of Expansive soils

From the laboratory results one can classify expansive soils depending on the results obtained. United States Bureau of Reclamation (USBR) Method developed by Holtz and Gibbs is based on the simultaneous several soil properties. The typical relationships of these properties with swelling potential curves are plotted and are used.

- These depending on the size of clay particles from the chart it is easy to identify the expansive soil.

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Activity line

- It is an improvement over the USBR method

$$A = \frac{PI}{\text{Clay fraction } < 0.002\text{mm}} \quad (2.1)$$

Where

A = activity

PI = plasticity Index

Table2-4. Indicative properties of Ethiopian expansive soils (Tefera and Leikun, 1993)

Clay content smaller than (2micron) or 0.002mm	50-80%
Liquid limit	80-120%
Plastic limit	55-90%
Shrinkage limit	10-16%
Free swell	90-23%

## 2.7 Potential application and merits of fiber reinforcements

Fiber reinforced soils can be extensively used in different geotechnical and civil engineering projects involving slope stabilization, road construction, construction of embankments, repairing or construction of landfill covers and crack controlling.

The merits of such reinforcement can be summarized as follows (*Merzababaei, 2012*)

- As fiber reinforcement method can be used for stabilizing shallow layers or constructing an embankment from scratch, mixing fibers with local soils can be fulfilled using conventional construction equipment for instance rotary mixer in separate lifts. The mixed fiber-soil lift can then be compacted using conventional compactors. In such reinforcement technique owing to random placement of fibers in the soil, no extra considerations are required for maintaining the arrangement and direction of reinforcing elements.
- Conventional stabilizers such as lime, cement, fly ash or other chemical agents used in soil stabilization practice require careful considerations against weather

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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conditions. However, fibers due to their neutral compositions are not significantly sensitive to changes in weather condition.

- C) Fibers are relatively cheaper material compared to other reinforcing materials such as geotextiles and geogrids or stabilizing agents like lime and cement. Variety of different types of fiber including natural fibers, virgin fibers, recycled fibers and waste fibers which are abundantly available at economical costs may be used for fiber reinforced soil application.

One of the potential applications of fiber reinforcement method is to repair the localized failure zones of slopes especially in steep slopes. Since the shape and direction of the failed zone and its extent may not be suitable enough for application of continuous planar reinforcement methods such as use of geotextiles and geogrids, fiber reinforcement is available alternative. Hemoloidal reinforcement material requires considerations for suitable anchorage at boundaries. However, fibers due to their simple application do not need such considerations.

Application of fiber reinforcement method does not require any special design for their application other than finding optimum fiber content based on the experimental work. Nevertheless, planar strengthening must be considered precisely.

### 2.8 Reinforcing Mechanisms

Soil stabilization by reinforcing mechanism is technique where tensile elements are placed in the soil to improve stability and control deformation. Strains within the soil mass generate strains and tensile loads within the reinforcements. These tensile loads tend to limit soil movements and therefore impart additional strength. This effect in the amalgamated soil strengthening system has significantly greater shear strength than the soil mass unaided.

## CHAPTER THREE

### 3. MATERIALS AND METHODS

#### 3.1 Introduction

This chapter mainly focuses on description and classification of materials used and the methods adopted for the research are presented.

#### 3.2 Sample collection and preparation

Sample soil was collected from Eastern Addis Ababa, Bole Arabssa housing project site. The soil is black cotton and the sample was taken from 1.5m depth below the original ground level so as to avoid inclusion of organic matter.

Soil tests were done in the Geotechnical engineering and highway laboratories of GIA Engineering. Other relevant and related data of material characterization were obtained from secondary resources. The geographical coordinates of the area is indicated in Table 3.1.

Table 3-1 Location of Test Pit

S.N	Northing	Easting	Elevation
Sample area(pit location)	990339	0487068	2317

#### 3.2.1 Teff Straw

Teff straw is an agricultural waste that is produced in high volume every year in Ethiopia. Due to its low cost, good mechanics and environmentally friendly nature, there is abundant potential for the use of teff straw to reinforce soil. To evaluate the feasibility of using teff straw to reinforce expansive soil, a series of experiments are conducted. In addition, the effectiveness of reinforcing straw will be verified by comparing with the unreinforced soil.

The straw sample was prepared by cutting with scissors. The longest straws were cut into average lengths randomly. Then it was mixed with the dry soil at percentages of 0.2%, 0.4%, 0.6%, 0.8% and 1%. The natural soil was used as control.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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Figure 3-1 Teff Straw Preparation and Mixing Process

### 3.2.2 Specification of Soil

Soil samples were collected, prepared for test by drying, pulverizing in the case of expansive soils, and screened through 4.75mm opening/aperture before preparing the specimens for testing. Grain size analysis of samples was determined based on ASTM 422.

Index properties of soils were determined using Atterberg limit tests according to ASTM D 4318. Soil classification or identification was made conforming with ASTM D 2487 and AASHTO soil classification standards. According to the AASHTO classification systems, the soil is classified as A-7-5 and according to the Unified soil classification systems soil is CH (Clay with high plasticity) as indicated in Table 3.2.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

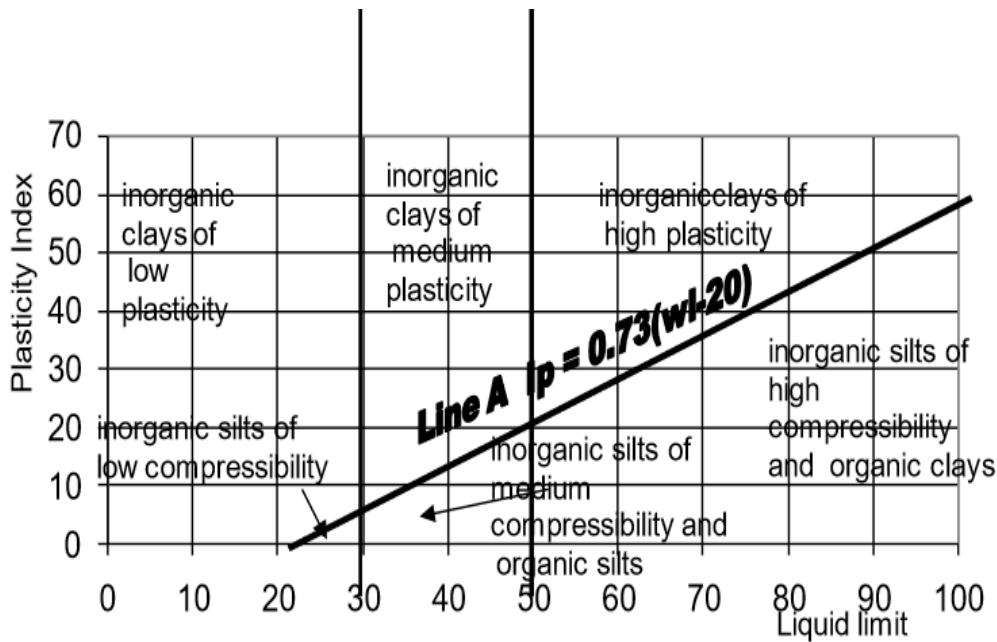


Figure 3-2 Plasticity Chart

Table 3-2 Soil Classification

Index properties					Soil classification	
Description	LL(%)	PL(%)	PI(%)	Free swell(%)	Unified Soil Classification System	AASHTO Standards
Soil sample	101	39	63	105	CH(clays with high plasticity)	A-7-5

### 3.3 Preparation and Testing of Samples

The collected soil sample was dried completely to remove the moisture. Then the dried sample was mixed with air dried teff straw thoroughly to obtain uniform mix for each of the tests conducted.

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

## 3.4 Methodology Flow Chart

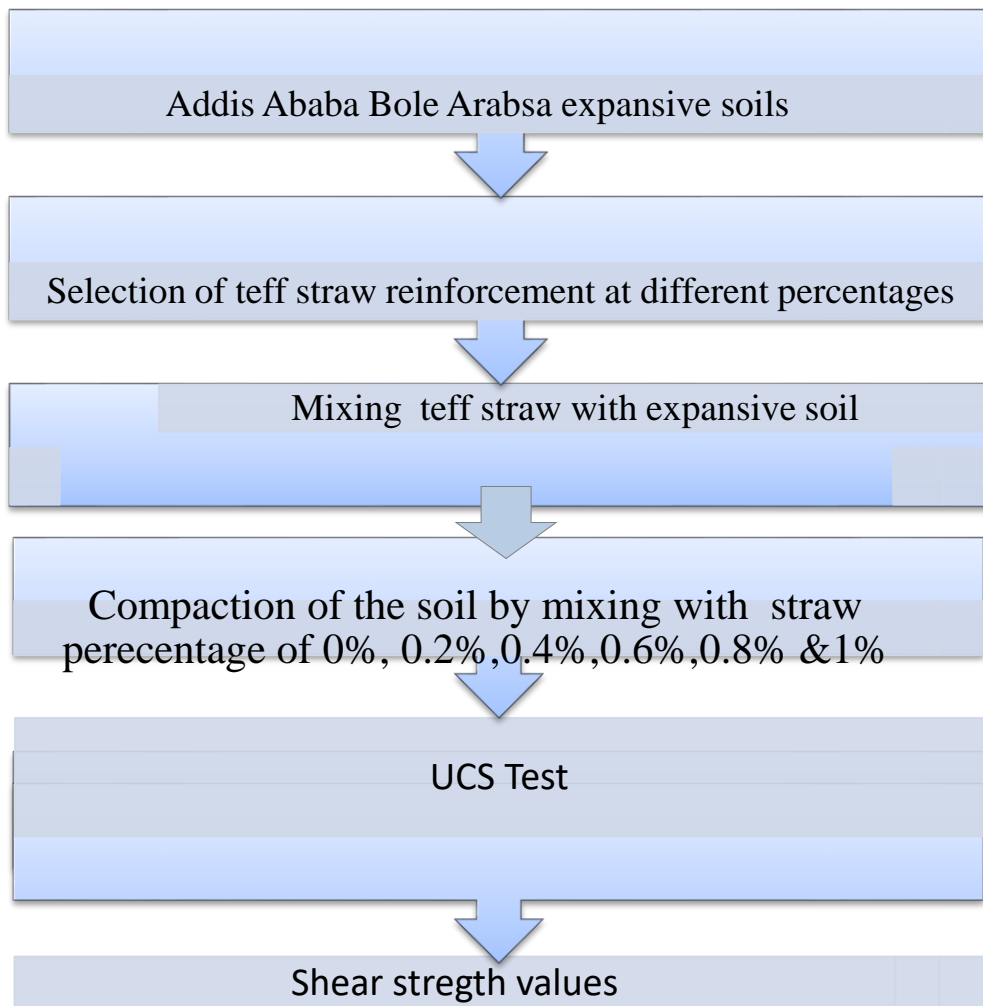


Figure 3-3 Flow Chart

## 3.5 Laboratory Works

The laboratory testing on expansive soil sample included determination of compaction characteristics of the soils. Additionally, the testing program consists of testing of the randomly mixed soil with teff straw at different percentages. Compaction tests, Unconfined Compressive Strength tests, unsoaked CBR test, free swell tests and Atterberg limit tests were conducted.

### 3.5.1. Atterberg Limit Tests

Atterberg limits can be defined as water contents at certain limiting or critical stages in soil behavior.

They used to determine the plastic and liquid limits of fine grained soils. They are advantageous because they correlate with the engineering properties and engineering behavior of fine grained soils (Holtz and Kovacs, 1981).

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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### a. The Liquid Limit (LL)

The liquid limit is that the moisture content that designates where the soil changes from a plastic to a viscous fluid state. Soil sample for liquid limit was air dried and 200g of the soil passing through sieve No. 40 was obtained and thoroughly mixed on a flat glass plate with water to make a uniform paste. The liquid limit could be defined as the water content in percent at which part of soil in Casagrande's cup cut by groove of standard dimensions will flow together at the base of the groove for a distance of thirteen millimeter when lay open to to 25 blows from the cup being dropped 10mm in a standard liquid limit apparatus worked at a speed of two blows per second. The values of moisture content determined and the corresponding number of blows is plotted on a semi-log graph. The moisture content corresponding to 25 blows from the graph is determined as liquid limit. Similar procedures are repeated to determine the liquid limit of the straw treated soil.

### b. Plastic Limit (PL)

The Plastic Limit represents the moisture content at which transition between the plastic and semisolid state of a soil occurs. The PL is defined as the moisture content at which a thread of soil just crumbles when it is carefully rolled out by hand to a diameter of 1/8-inch (3mm).

### c. Shrinkage Limit (SL)

Shrinkage limit represents the moisture content corresponding to the change between the semisolid to solid state of soil. It is also defined as the moisture content at which any additional decrease in moisture content will not result in a decrease in the volume of soil.

Burmister (1947) classified plastic properties of soils based on their plasticity index as follows:

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Table 3-3 Plasticity Characteristics (Burmister 1947)

Plasticity Index	Plasticity
0	Nonplastic
1 to 5	Slight
5 to 10	Low
10 to 20	Medium
20-40	High
>40	Very high

### 3.5.2. Particle Size Distribution

Grain size analysis is an attempt to determine the relative sizes of different grain particles which makes up a soil mass. The soil sample under investigation is almost fine grained that the amount of particles retained on No200 (0.075mm) sieve was insignificant.

Table 3-4 Grain size analysis laboratory test result of the natural soil

Sieve No	Sieve Opening (mm)	Mass of Sieve (g)	Mass of sieve +Retained soil (g)	Mass of Retained soil (g)	Percentage (%)	Cum. Percentage (%)	Perc. (%)
3"	75.0	1057.0	1057.0	0.0	0.0	0.0	<b>100.0</b>
2"	50.0	1199.0	1199.0	0.0	0.0	0.0	<b>100.0</b>
1.5"	37.5	1084.0	1084.0	0.0	0.0	0.0	<b>100.0</b>
1"	25.0	1248.0	1248.0	0.0	0.0	0.0	<b>100.0</b>
3/4"	19.0	1443.0	1445.6	2.6	0.2	0.2	<b>99.8</b>
1/2"	12.5	1242.0	1244.5	2.5	0.2	0.5	<b>99.5</b>
3.8"	9.5	1211.0	1213.8	2.8	0.3	0.8	<b>99.2</b>
No 4	4.75	431.0	894.2	3.2	0.3	1.1	<b>98.9</b>
No 8	2.36	389.0	393.0	4.0	0.4	1.4	<b>98.6</b>
No 10	2	378.0	378.0	0.0	0.0	1.4	<b>98.6</b>
No 16	1.18	355.0	356.1	1.2	0.1	1.6	<b>98.4</b>
No 30	0.6	312.0	313.5	1.5	0.1	1.7	<b>98.3</b>
No 40	0.425	291.0	291.9	10.6	1.0	2.7	<b>97.3</b>
No 50	0.3	287.0	288.1	2.8	0.3	3.0	<b>97.0</b>
No 100	0.15	268.0	270.8	2.8	0.3	3.3	<b>96.7</b>
No 200	0.075	258.0	260.9	8.4	0.8	4.1	<b>95.9</b>
Pan	-----	240.0	240.0	1002.1	95.9	100.0	<b>0.0</b>

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

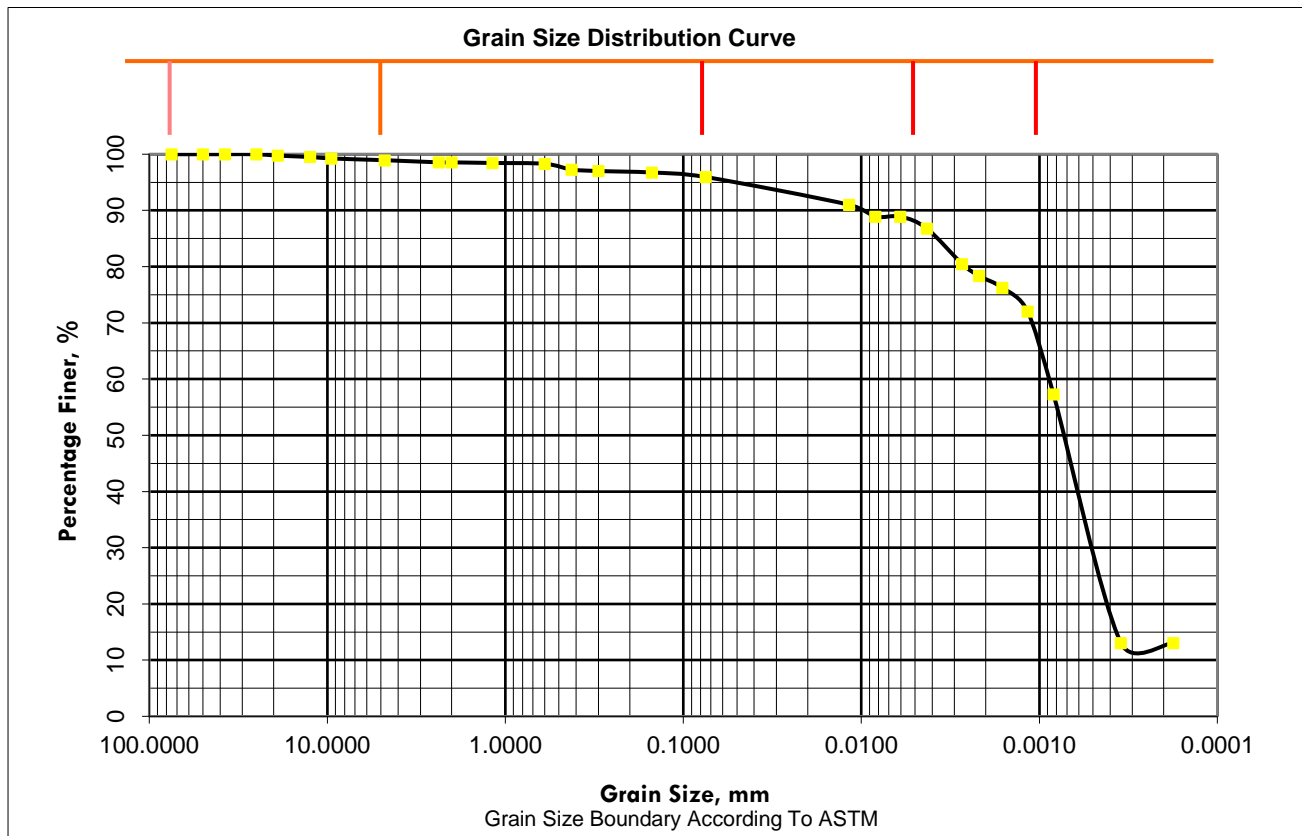


Figure 3-4 Particle size distribution curve for the natural soil tested

### 3.5.3. Compaction Tests

Soil compaction consists of close packing, packing the soil grains together the soil particles so as to increase the dry unit weight. Compaction reduces the air void in the soil. The maximum dry density (MDD) and Optimum moisture content (OMC) of the soils were determined in accordance with ASTM D 1557.

The soils with teff straw reinforcements were thoroughly mixed with various moisture contents. The first series of compaction tests were planned to determine compaction properties of the unreinforced soils. Secondly, tests were carried out to determine the proctor compaction properties of the soil randomly mixed with teff straw at different percentages and different straw lengths.

### 3.5.4. California Bearing Ratio Tests

California Bearing Ratio test measures the shearing resistance of a soil within controlled moisture and density conditions. CBR value is the ratio of load required to effect a certain depth of penetration into a soil specimen compacted at given moisture content and dry density to the load required to get an equivalent depth of penetration

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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on a typical sample of crushed stone. This test indirectly measures the shearing resistance of a soil under controlled moisture and density conditions. CBR tests were conducted in accordance with AASHTO T193.

### 3.5.5. Moisture Content Test

The moisture content test is one of the simplest and least expensive laboratory tests to perform. Moisture content could be defined as the ratio of the weight of the water within a soil specimen to the dry weight of the specimen. The natural soil was taken to the laboratory and oven dried at 105 °c for 24 hour.

### 3.5.6. Specific Gravity Test

The specific gravity of the soil solid matter in a soil particle may be defined as the ratio of the unit weight of solid matter to the unit weight of water. The specific gravity was determined in the laboratory according to ASTM D854-92. Based on ASTM D854-92, specific gravity of soils is determined by means of pycnometer. The representative values of specific gravity (Gs) of most soils lie within the narrow range of  $G_s = 2.7 \pm 0.1$ . Exceptions include soils with appreciable organics (e.g., peat), ores (e.g., mine tailings), or calcareous (high calcium carbonate content) constituents (e.g., caliche).

### 3.5.7. Free Swell Test

In this test approximation of the degree of expansiveness of a given soil sample is obtained.

- Pouring very slowly 10cc of dry soil passing No 40 sieve into 100cc of distilled water
- allowing the content stand for 24hours until all the sample completely settles on the bottom of the cilinder
- record the final volume

$$FS(\%) = [ ( V_f - V_i ) / V_i ] * 100 \quad (3.1)$$

where  $FS(\%)$  = free swell

$V_f$  = soil volume after 24 hoursswelling, mm

$V_i$  = initial volume of dry soil which is commonly considered, mm

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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### 3.5.8. Unconfined Compression Test

The unconfined compression test is a quick, relatively cheap means to get an estimation of the undrained shear strength of cohesive specimens. In this test a cylindrical specimen of the soil is loaded axially with none lateral confinement to the specimen, at a sufficiently high rate to stop drainage. The shear stresses induced within the specimen by the axial load end in a shear failure. The amount of the shear stress at the moment of failure represents the shear strength of the soil under these circumstances of loading and drainage. Consequently, the shear strength obtained from this test is called the undrained shear strength. In most cases the values of undrained shear strength obtained from an unconfined compression test is conservative. The maximum axial compressive stress measured at failure represents the compressive strength of the soil under the conditions of loading, drainage, and confinement. The undrained shear strength is equal 0.5 times the unconfined compressive strength.

The test is carried out in cylindrical specimen with dimensions of 40mm in diameter and 80mm in length. The test is conducted in accordance with AASHTO T-208. The unconfined compressive strength test is quick test and usually taken as a special form of triaxial compression test. The UCS test was conducted for both natural and straw (teff) reinforced soil. The test result of the untreated soil sample revealed that the UCS of the soil as 198.2kPa.

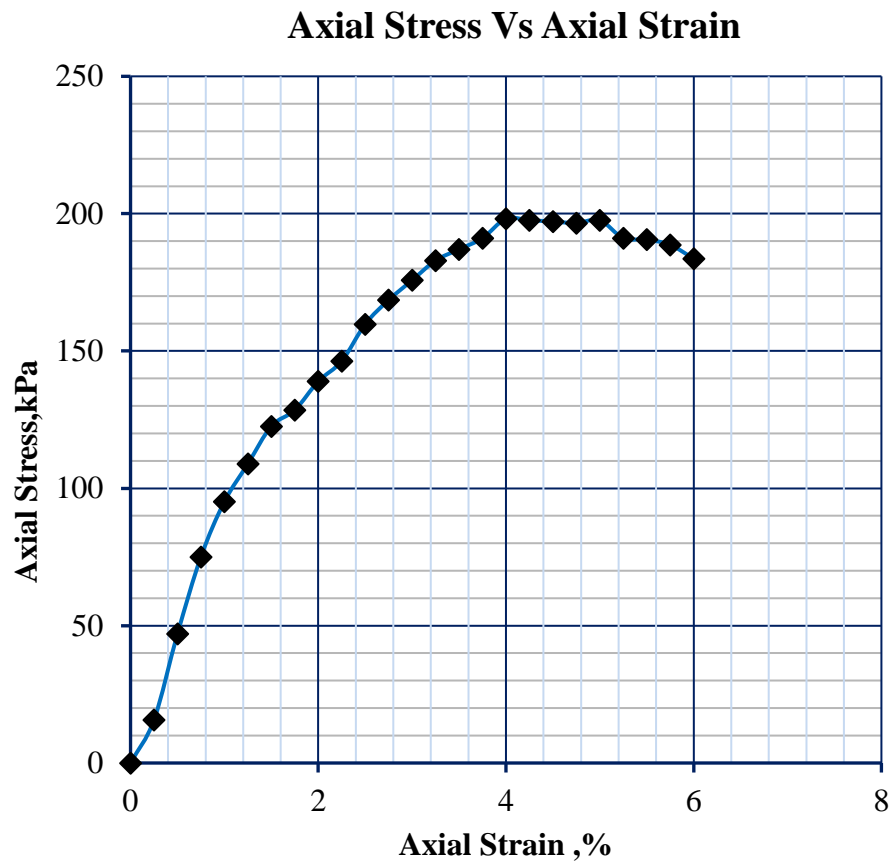


Figure 3-5 unconfined compressive strength of the natural soil

## CHAPTER FOUR

### 4. RESULT AND DISCUSSION

#### 4.1 Introduction

This chapter deals with laboratory test results and their analysis is briefly discussed. The relevant engineering properties of the soil were evaluated both for natural and reinforced soil samples separately. The tests include specific gravity, moisture content, grain size analysis, hydrometer, compaction, unconfined compression, free swell and Atterberg limit tests. All the tests were conducted on black cotton soil collected from Bole Arabsa condominium site.

Comparisons were made and thoroughly discussed in reference to the corresponding natural soil shear strength characteristics and within each reinforced soil.

#### 4.2 Laboratory Test Results of the Natural Soil

The following laboratory tests were carried out for the natural soil and the results are summarized in Table 4.1.

- Natural moisture content
- Specific gravity
- Grain size distribution/Particle size analysis
- Atterberg limits/Liquid limit, plastic limit & Plasticity index
- Compaction tests
- California Bearing Ratio test (CBR)
- Unconfined compression test

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Table 4-1 Laboratory Test Results of the natural soil

Property	Values
Specific Gravity	2.71
% passing Sieve #200	95.9%
Liquid Limit(%)	101
Plastic Limit(%)	39
Plasticity Index(%)	62
Natural Moisture Content (%)	32
Free Swell(%)	105
Compaction Characteristics	OMC= 26%, MDD= 1.41g/cc
UnsoakedCBR	16%
UCS	Unconfined compressive strength, $q_u = 198\text{kPa}$ , Cohesion $C = 99\text{kPa}$
AASHTO Classification	A -7-5
Color	Black

From Table 4.1 summary of test results, the natural soil can be characterized as highly expansive and of high plasticity. From the particle size distribution curve 95.9% of the soil passing sieve No.200. The natural soil exhibits a liquid limit of 101%, plastic limit of 39% and plasticity index of 62%. These values clearly indicate that the soil is highly plastic clay and it falls under A-7-5 soil classification based on AASHTO soil classification and CH according to USCS soil classification system.

From the compaction test, the soil has maximum dry density of 1.41g/cc and optimum moisture content of 26%. The cohesion of the natural soil was found as 99kPa obtained from Unconfined Compression test. The soil has unsoaked CBR value of 16%.

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

## 4.3 Test Results of Straw Reinforced Soils

### 4.3.1 Effects of Teff Straw on Maximum Dry Density

Figure 4.1 shows the variation of maximum dry density of expansive soil with the addition of different percentages of teff straw. Although the straw content increases, the MDD goes on decreasing. When the straw content increases from 0% to 1%, the MDD decreases by 13%.

Fibers have very low specific gravity whereas the natural soil particles have a value of 2.71g/cc. As the straw content increased, the low density of fibers replaces the high density soil grains, resulting in a lower density of teff straw reinforced soil.

Thus it can be concluded that the maximum reduction in dry density of the stabilized soil can be attributed to the lower density of straw compared to that of soil.

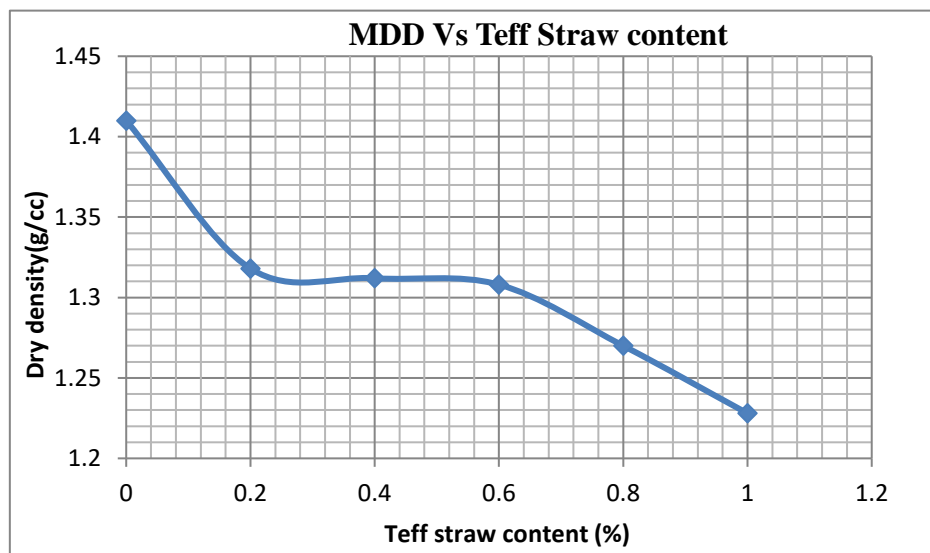


Figure 4-1 Variation of MDD with teffstraw content

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

### 4.3.2 Effects of Teff Straw on Optimum Moisture Content

The variation of OMC in the expansive soil with addition of different percentages of teff straw was shown in Table 4.2. The OMC increases from 26% for the natural soil to 36% for 1% straw reinforced soil. With the addition of fibers, more water is required to lubricate the soil grains during compaction, resulting in higher optimal moisture contents. Investigators (Abdi, et al., 2008) have also reported that an increase in moisture content reduces the contribution of fibers to the strength and ductility of composite materials. This was attributed to the lubricating effects of water in decreasing the load transfer between the clay and straw. Although, there is fluctuation in moisture content with increase of straw content, the graph shows an increase in moisture content with increase fiber content.

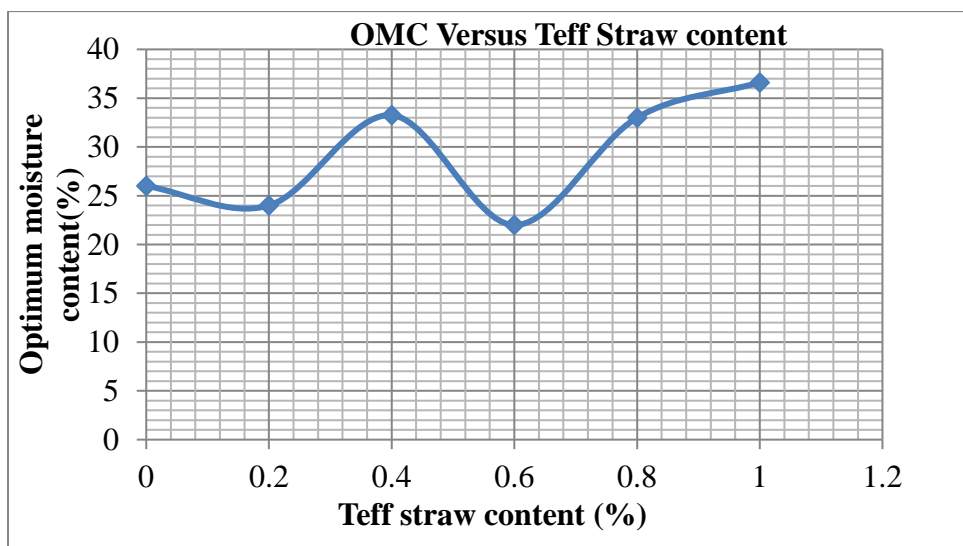


Figure 4-2 Variation of OMC with straw content

### 4.3.3 Effect of Straw on Cohesion

Figure 4.3 and Table 4.2 showed that there is an increase in cohesion with increase in fiber content. The maximum value of cohesion was increased by a factor of 1.22 (22%) compared to the untreated soil cohesion value. This increase shows that the maximum bondage between the soil and the reinforcement was attained at low straw content. The optimum fiber content which cause maximum increase in cohesion (120kPa) is 0.6%. However, further increase in fiber content decreases the cohesion of the reinforced soil.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Generally it can be concluded that the cohesion value of the soil increases as the percentage of teff straw increases for intermediate percentages. For straw contents of 0.8% and 1%, the cohesion decreases probably due to lack of lubrication effect. Thus, the effect of varying the amount of teff straw on the shear strength parameter (cohesion) of the soil is summarized in Table 4.2.

Table 4-2 Cohesion of the soil

Strawcontent (%)	Cohesion(C) in kPa
0	99.1
0.2	100.85
0.4	116.15
0.6	120.695
0.8	119
1	102

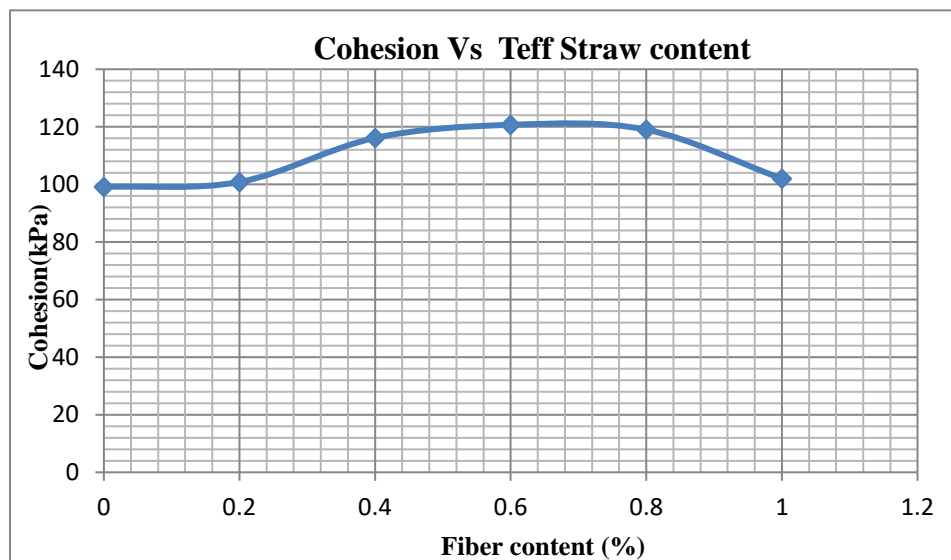


Figure 4-3 Variation of Cohesion with respect to fiber content

### 4.3.4 Effects of Teff Straw on Unconfined Compressive Strength of the Soil

The variation between Unconfined Compressive Strength (UCS) values at different percentages of straw was shown in Table 4.3. The UCS of the reinforced soil increases with increases of teff straw content. As the cohesion is half of the UCS, it proportionally increases with increase in straw content. The optimum value of straw that gives maximum strength is 0.6%. The peak shear strength value is found to be 241.39kPa. With an increase in straw content, it forms a protective coat on the soil

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

particles and serves as reinforcement material that ultimately increases the strength. However, for higher straw content, the lubrication effect decreases and the unconfined compressive strength values drop.

Table 4-3 Unconfined Compressive Strength

Teff straw content	UCS(kPa)
0	198.2
0.2	201.7
0.4	232.3
0.6	241.39
0.8	238
1	204

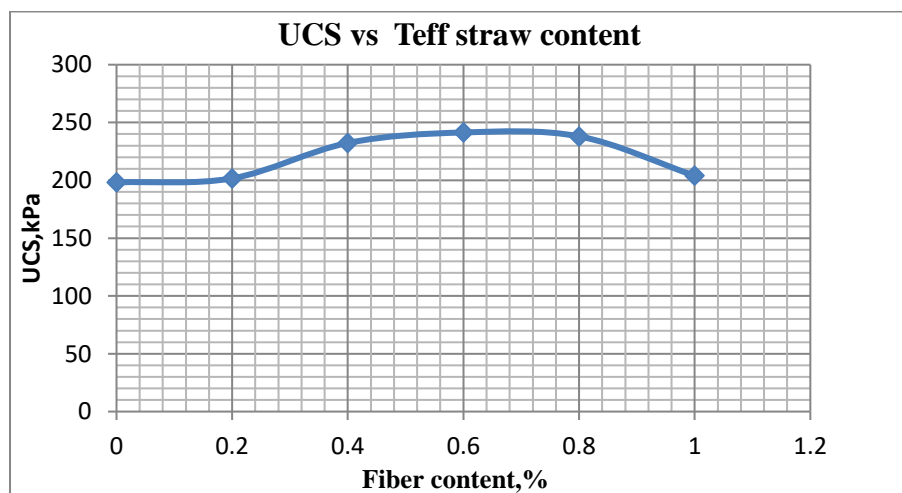


Figure 4-4 Variation of UCS with respect to straw content

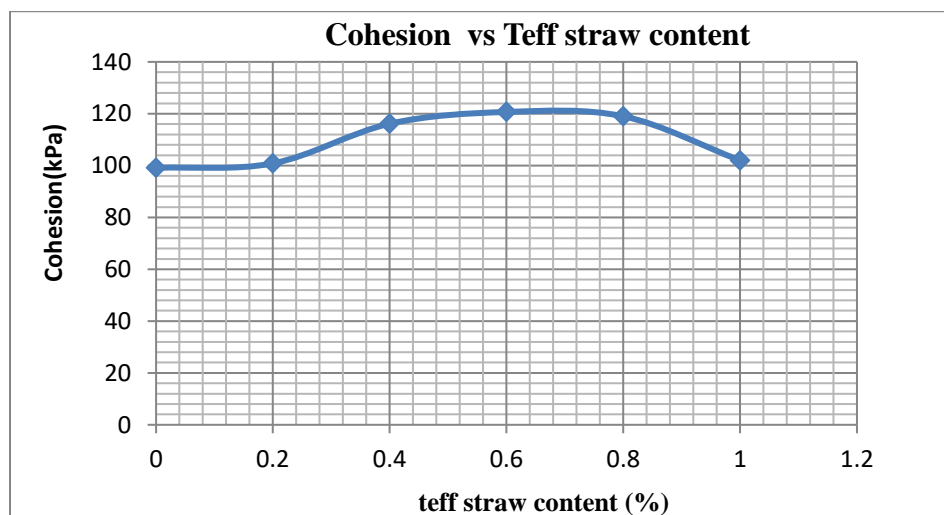


Figure 4-5 Variation of UCS with respect to fiber content

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Table 4-4 UCS & Cohesion versus straw content

Fiber content	UCS(kPa)	C(kPa)
0	198.2	99.1
0.2	201.7	100.85
0.4	232.3	116.5
0.6	241.39	120.695
0.8	238	119
1	204	102

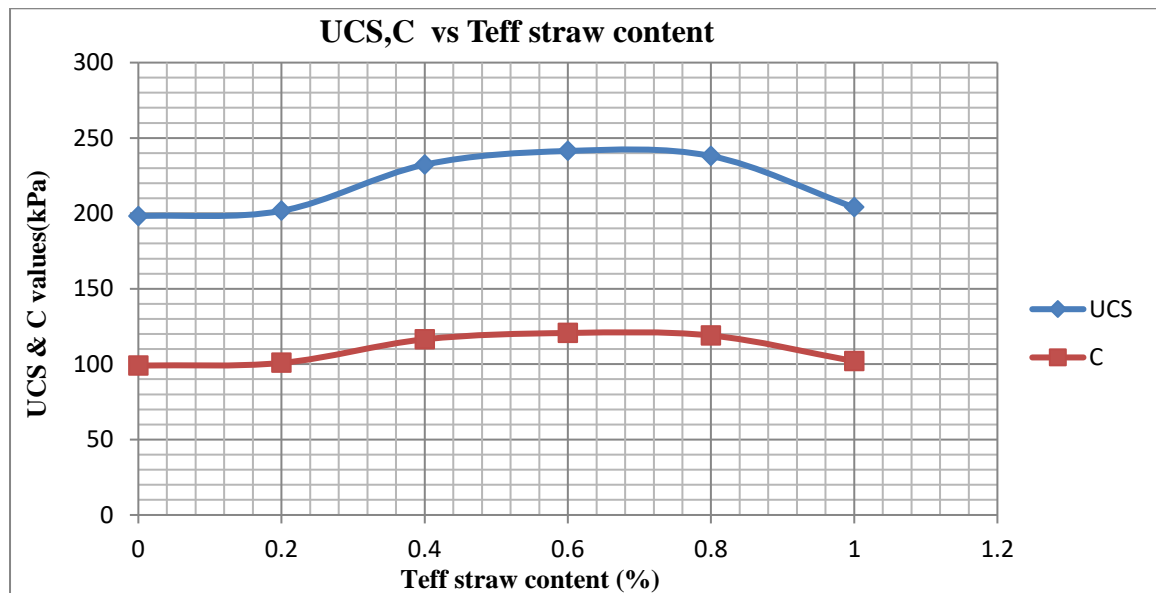


Figure 4-6 Variation of UCS, C with teff straw content

### 4.3.5 Effects of Straw on Atterberg Limit Tests

The nature and response of soils up on change to moisture content is determined by Atterberg limit tests. This parameter is based on the AASHTO and USCS soil classification systems. Atterberg limits depend on clay type and clay content predominated available in the soil mass.

The natural soil had liquid limit of 101, plastic limit of 39 and plasticity index of 62, which makes it a highly plastic soil according to the plasticity categories proposed by Bermister (1947). After being mixed with teff straw, the Atterberg limits of the soil changed.

The effect of addition of straw in varying proportions with soil was studied and the variation in consistency limits for various mixes is presented Table 4.5. Soil was reinforced with varying amount of teff straw from 0.2 % to 1% by dry weight of soil.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

The liquid limit, Plastic limit and Plasticity Index of soil reinforced with teff straw were determined and plotted against teff straw content.(Table 4.5 and Figures 4.7-4.9)

As the percentage of straw increases, the liquid limit and plasticity index are reduced. The maximum decrease in liquid limit is attained at straw content of 0.4%, which is found to be 19.8%. This might be due to the fact that the clay fraction, which is responsible for the plasticity of the soil, is reduced by the addition of teff straw.

Table 4-5 Summary of Atterberg Limit Test Results

% of teff straw( by dry weight of soil)	LL(%)	PL(%)	PI(%)	% decrease of PI
0	101	39	62	0
0.2	83	30	53	14.52
0.4	81	30	51	17.74
0.6	84	35	49	20.97
0.8	84	33.6	50.4	18.71
1	85	30	55	11.29

$$\text{Percent decrease in plasticity index} = \left( \frac{PI_f - PI_0}{PI_0} \right) * 100 \quad (4.1)$$

$PI_f$  = value of PI of the soil for respective percentage of straw

$PI_0$  = value of PI of the natural soil

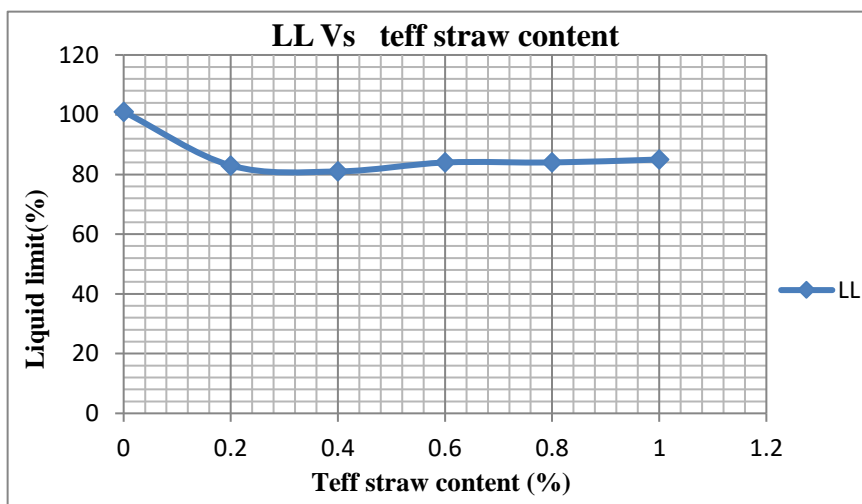


Figure 4-7 Variation of LL with respect to fiber content

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

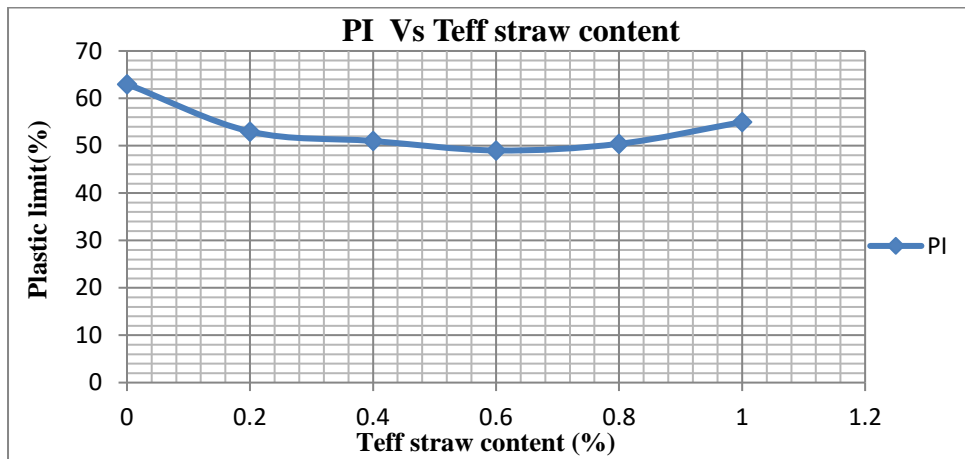


Figure 4-8 Variation of PI with respect to fiber content

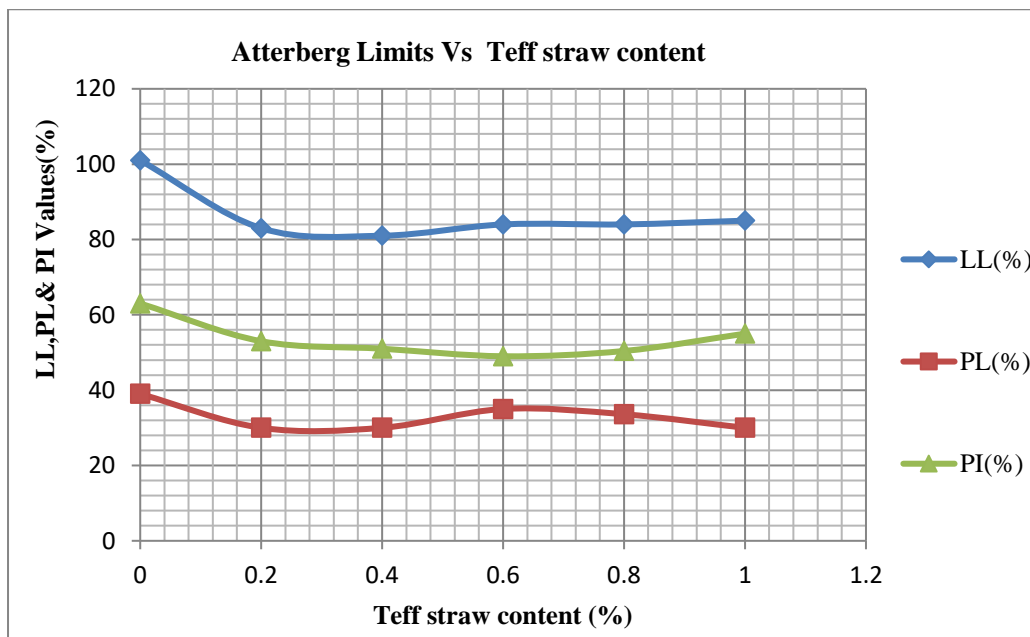


Figure 4-9 Effects of straw on Atterberg limits

In general, the plasticity of the soil is decreased by the addition of teff straw content. This is clearly shown by the fact that plasticity index of reinforced soil decreased with increasing the reinforcement materials. These effects are due to partial replacement of plastic soil particles with straw which is non-plastic material.

The maximum decrease in PI is 20.97%, which is attained at straw content of 0.6%. The plastic limit decreases initially as the straw content increases. However, there is inconsistency, at higher percentages of straw content.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

### 4.4 Discussion on CBR Test Results

The effect of teff straw on unsoaked CBR values of straw teff mixture is shown in Table 4.6. The CBR value is highest at 0.6% straw content for all the cases of the fiber content. At this straw content value, the CBR was increased by 35.8% compared to that of the CBR value of the natural soil

Table 4-6 Summary of unsoaked CBR test results

Teff Straw content (%)	CBR (%)	% increase in CBR
0	16.11	0
0.2	18.58	15.33
0.4	18.80	16.72
0.6	21.88	35.79
0.8	19.85	23.23
1	21.35	32.54

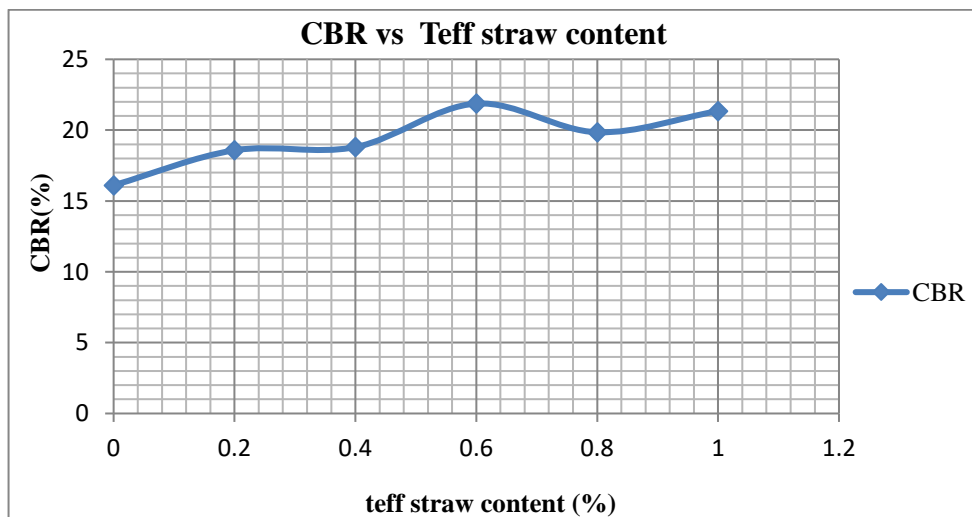


Figure 4-10 Variation of unsoaked CBR with teff straw contents

## CHAPTER FIVE

### 5. CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusion

The following conclusions can be drawn from the results and investigations of the research.

- Unconfined compressive strength of the soil increases with increase in teff straw content up to optimum value. The optimum teff straw which gives maximum strength is 0.6% of teff straw by dry weight of soil.
- Unsoaked CBR value of teff straw reinforced soil was increased to a maximum by 35.8% of the natural soil CBR value at optimum straw content.
- The decrease in maximum dry density is associated with increase of teff straw amount.
- The plasticity index and the liquid limits of the straw reinforced soil reduced with increase in straw content. The decrease in liquid limit and plasticity index were respectively 16.83% and 20.97% for the optimum straw content of 0.6% compared to the natural soil.
- As straw is biodegradable material, the reinforcement of soil with teff straw is taken to be more effective for temporary reinforcement.

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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## 5.2. Recommendation

From the results of the study, it is observed that random inclusion of teff straw improves the strength characteristics of expansive soils. For further applications the following recommendations are forwarded

- In reinforcing of expansive soils, in addition to using teff straws a third material such as lime should be introduced and the combined effect have to be studied.
- Further studies are required in protecting teff straw fibers so as to increase the durability as it is biodegradable material.
- Further mixing methods in the site with expansive soil and teff straw should be studied. Moreover, laboratory tests should be validated with the field tests.
- Versatile laboratory tests like triaxial compression tests are recommended to get more reliable result

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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## REFERENCES

- Braja M. Das(2008), Advanced Soil Mechanics, New York.
- Bell, F.G(1993) Engineering treatment of soils,Luton, Taylor & Francis.
- DR.K.R. Arora(2004). Soil Mechanics and Foundation engineering, Delhi.
- Jones,CJ.F.P(1996), Earth reinforcement and soil structures.
- Alemayehu Tefera and MesfinLeikun (1999), Soil Mechanics, Faculty of Technology, Addis Ababa University.
- Li, C. (2005), Mechanical Response of Fiber-Reinforced Soil, Ph.D. Dissertation, the University of Texas at Austin.
- Robert D. Holtz and William D. Kovacs (1981) An Introduction to Geotechnical engineering, University of Washington and University of Rhode Island.
- Ayeneu Zewdie (2004), Investigation into Shear Strength Characteristics of expansive soils of Ethiopia,MSc Thesis School of Graduate studies Addis Ababa University.
- Abdullah Ekinci (2016), The mechanical Properties of compacted clay from the Lambeth Group using Fiber Reinforcement, PhD Dissertation,UCL
- Lambe,T.W.;Whitman,R.V.(1979).SoilMechanics,SIversion.USA:JohnWiley&Sons.
- Santhi Krishna K. and Sayida M.K (2009), Behavior of Black Cotton Soil Reinforced with Sisal Fiber, 10<sup>th</sup> National Conference on Technological Trends, College of Engineering Trivandrum,Kerala.
- Jili Qu, ChencaiLi,BaoshiLiu,XinxingChen,MingLi,Zhaowei Yao,2013, Effect of Random Inclusion of Wheat Straw Fibers on Shear Strength Characteristics of Shanghai Cohesive Soil, Journal of Geotech and Geoleng.
- Alemayehu Tefera and Solomon Yohanese,Investigation expansive soils of Addis Ababa.
- Mehdi Mirzababaei (2012) Reinforcement of clay soils using waste carpet fibers, PhD thesis, University of Bolton.

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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V.N.S Murthy Geotechnical Engineering Principles and Practices of soil Mechanics and Foundation Engineering, New York

Dhiraj Kumar, Gourav, Akash Priyadarshie (2015), Performance of Different forms of Soil Reinforcement, Civil engineering, Dr. B. R. National Institute of Technology, Jalandhar

Moradi M., Hamid A. and Tavakoli Mehrjardi Gh. (2017) Journal of Engineering geology, vol. 10 No. 4

J. Prabhakar & R. S. Sridhar (2012), effect of sisal fiber on strength behavior of soil, Journal of construction & building materials, India.

Pratiika, Malvia, Vikash Kumar (2011) Millennium institute of technology, Bhopal, India.

Guyer, J. P., Introduction to soil stabilization in pavements, New York, 2011.

Department of the Army, the Navy, and the Air Force, Technical Manual Soil Stabilization for pavements, 1994.

P. K. Pradhan, R. K. Kar., A. Naik (2011), Effect of Random Inclusion of Polypropylene Fibers on Strength Characteristics of Cohesive Soil, Journal of Geotech Geological engineering, India

Maher, M. H. and Ho, Y. C. (1994) Mechanical properties of kaolinite fiber composite soil, Journal of Geotechnical Engineering Division, ASCE. Vol. 120(8)

Abdi, M. R., Parsapajouh, A., Arjomand, M. A., 2008, Effects of Random Fiber Inclusion on Consolidation, Hydraulic Conductivity, Swelling, Shrinkage Limit and Desiccation Cracking of Clays, International Journal of Civil Engineering.

## APPENDIX A

### **ATTERBERG LIMIT TESTS AND SPECIFIC GRAVITY TESTS**

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

**Sample type disturbed**

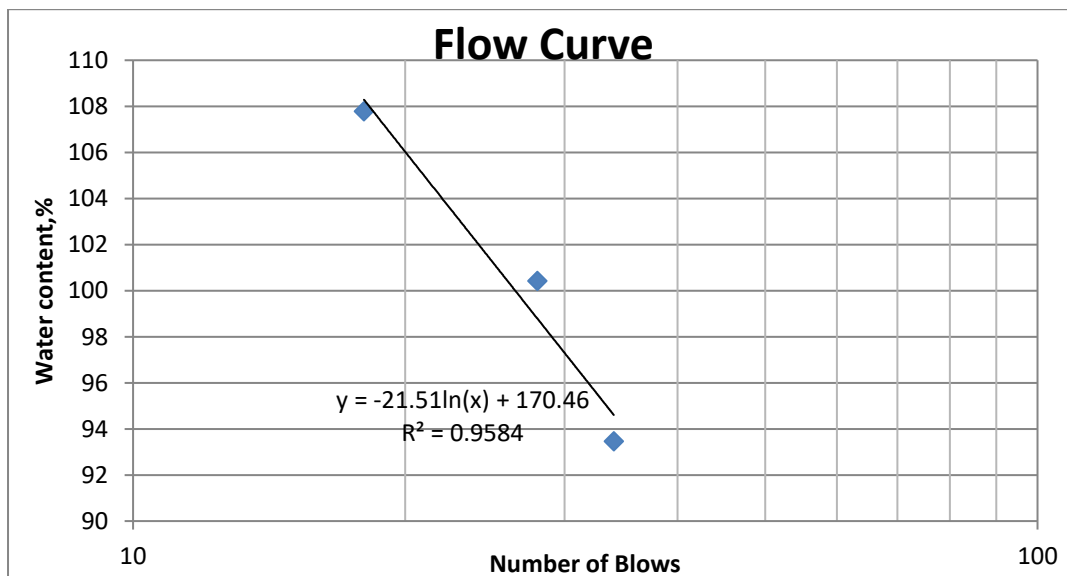
**i) Atterberg limit tests for the natural soil**

can number	Liquid Limit			Plastic Limit	
	B1	P7	I	7	G7
number of blows	34	28	18		
weight of container + wet soil in gm	43.364	43.577	43.767	16.666	16.8
weight of container + dry soil in gram	32.913	32.743	32.412	15.976	16.029
weight of water in gm	10.451	10.834	11.355	0.69	0.771
weight of container in gm	21.731	21.955	21.877	14.154	14.068
weight of dry soil in gm	11.182	10.788	10.535	1.822	1.961
water content	93.4627	100.426	107.784	37.8705	39.3167

Liquid Limit,% = 101

Plastic Limit,% = 39

Plasticity Index,% = 62



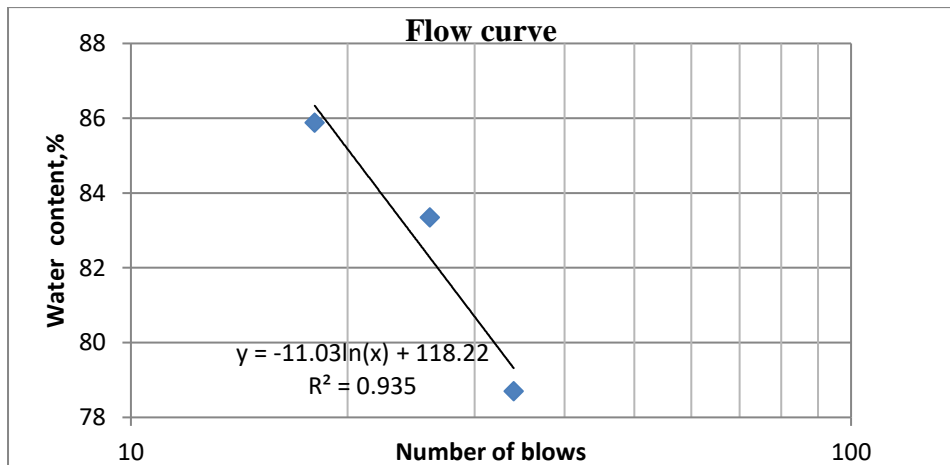
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

ii) Atterberg limit tests for the reinforced soil

Atterberg limit test at 0.2% straw content

can number	Liquid Limit			Plastic Limit	
	N3	I	JK	L4	B2
number of blows	34	26	18		
weight of container + wet soil in gm	45.012	45	45.638	16.412	16.496
weight of container + dry soil in gram	34.822	35	34.572	15.884	15.98
weight of water in gm	10.19	11	11.066	0.528	0.516
weight of container in gm	21.874	22	21.687	14.14	14.28
weight of dry soil in gm	12.948	13	12.885	1.744	1.7
water content	78.699413	83	85.883	30.27523	30.35294

LL	83.09
PL	30.3140853
PI	52.7759147

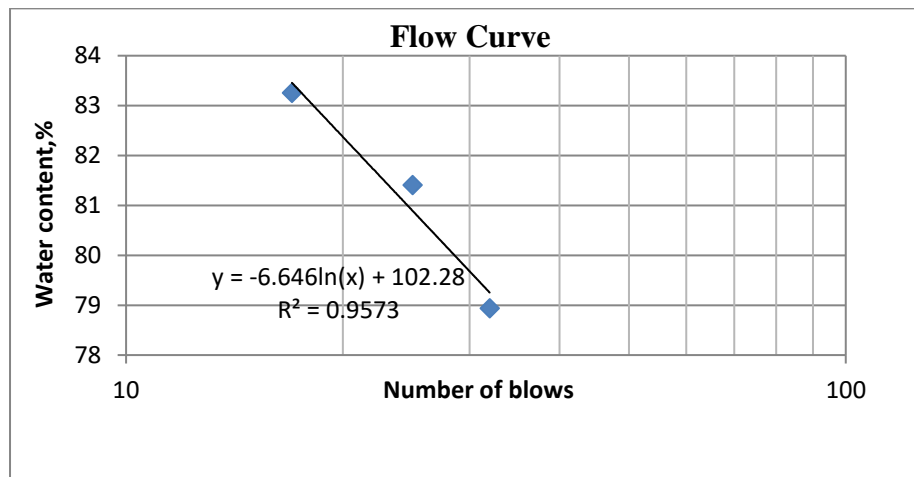


## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Atterberg limit tests at 0.4% straw content

	Liquid Limit			Plastic Limit	
	R7	LM	100	P2	OP
can number					
number of blows	32	25	17		
weight of container + wet soil in gm	43.993	44.265	44.45	16.684	16.552
weight of container +dry soil in gram	34.157	34.042	34.152	16.094	15.982
weight of water in gm	9.836	10.223	10.298	0.59	0.57
weight of container in gm	21.697	21.484	21.783	14.109	14.093
weight of dry soil in gm	12.46	12.558	12.369	1.985	1.889
water content	78.94061	81.4063	83.2565	29.7229	30.1747

LL	81.105
PL	29.94881
PI	51.15619

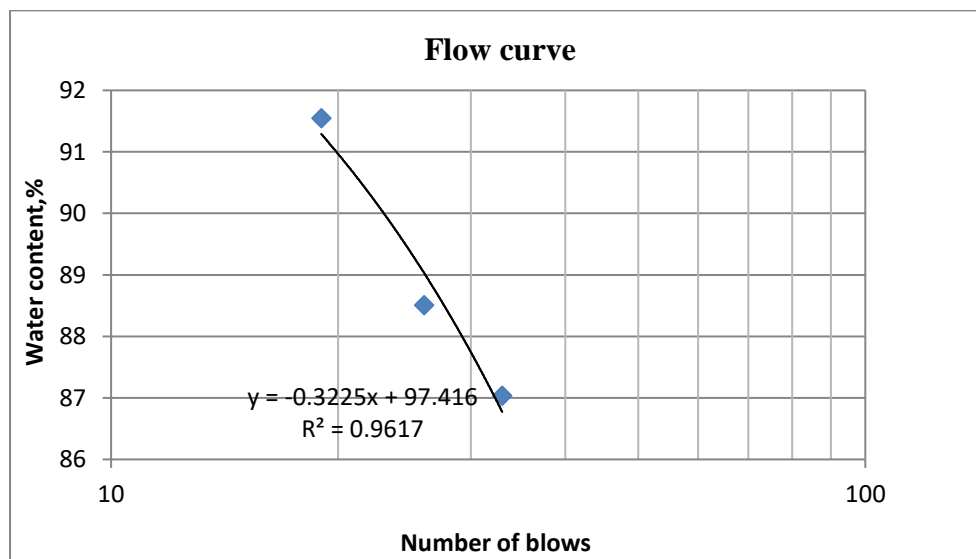


## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Atterberg limit test at 0.6% straw content

can number	Liquid Limit			Plastic Limit	
	KJ	F6	Y7	L4	3F
number of blows	33	26	19		
weight of container + wet soil in gm	43.455	43.676	43.752	16.761	16.807
weight of container +dry soil in gram	33.413	33.352	33.331	16.075	16.085
weight of water in gm	10.042	10.324	10.421	0.686	0.722
weight of container in gm	21.875	21.688	21.948	14.139	14.011
weight of dry soil in gm	11.538	11.664	11.383	1.936	2.074
water content	87.03415	88.51165981	91.5488	35.4339	34.812

LL	89.3535
PL	35.12292
PI	54.23058

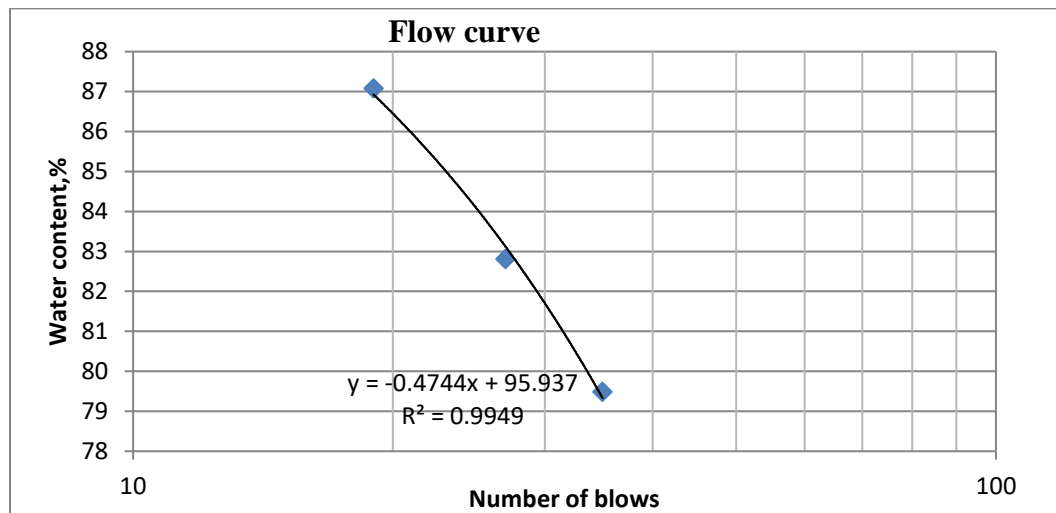


## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Atterberg limit test at 0.8% straw content

can number	Liquid Limit			Plastic Limit	
	XX	YY	J4	II	M6
number of blows	35	27	19		
weight of container + wet soil in gm	45.465	45.742	45.93	16.697	16.569
weight of container +dry soil in gram	35.05	34.982	34.639	15.968	15.954
weight of water in gm	10.415	10.76	11.291	0.729	0.615
weight of container in gm	21.948	21.989	21.673	13.743	14.169
weight of dry soil in gm	13.102	12.993	12.966	2.225	1.785
water content	79.4916807	82.8138228	87.0816	32.764	34.4538

LL	84.077
PL	33.60891
PI	50.46809

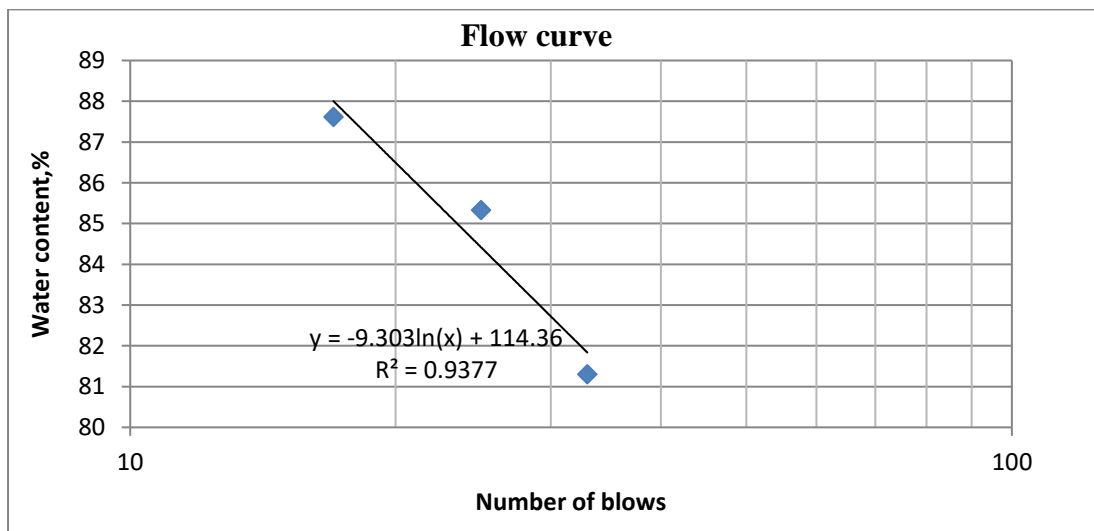


## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Atterberg limit test at 1% straw content

can number	Liquid Limit			Plastic Limit	
	P7	C10	D1	G7	A3
number of blows	33	25	17		
weight of container + wet soil in gm	46	46.484	46.781	16.937	16.842
weight of container +dry soil in gram	35.187	35.026	34.975	16.29	16.274
weight of water in gm	10.813	11.458	11.806	0.647	0.568
weight of container in gm	21.887	21.599	21.501	14.164	14.383
weight of dry soil in gm	13.3	13.427	13.474	2.126	1.891
water content	81.30075188	85.3355	87.6206	30.4327	30.037

LL	84.4148
PL	30.23488
PI	54.17992



The Effect of Random Inclusion of Teff Straw on Shear Strength  
Characteristics of Addis Ababa Expansive Soil

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Specific gravity Test  
Testing Method: ASHTO T-100

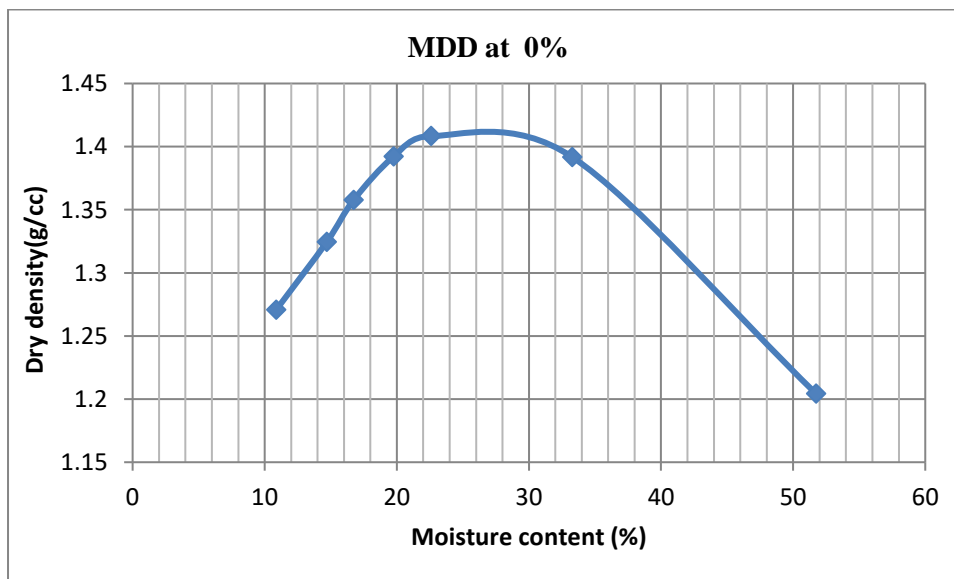
SN	Bottle No	1
1	Mass of bottle+soil+water(m3)	143.78
2	Mass of bottle+soil(m2)	48.56
3	Mass of bottle full of water only(m4)	137.85
4	Mass of bottle(m1)	39.18
5	Mass of water used(m3-m2),gm	95.22
6	Mass of soil used(m2-m1),gm	9.38
7	Volume of soil(m4-m1)-(m3-m2),gm	3.45
8	Specific gravity of soil particle $G_s = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)}$	2.71

APPENDIX B.

**COMPACTION TESTS**

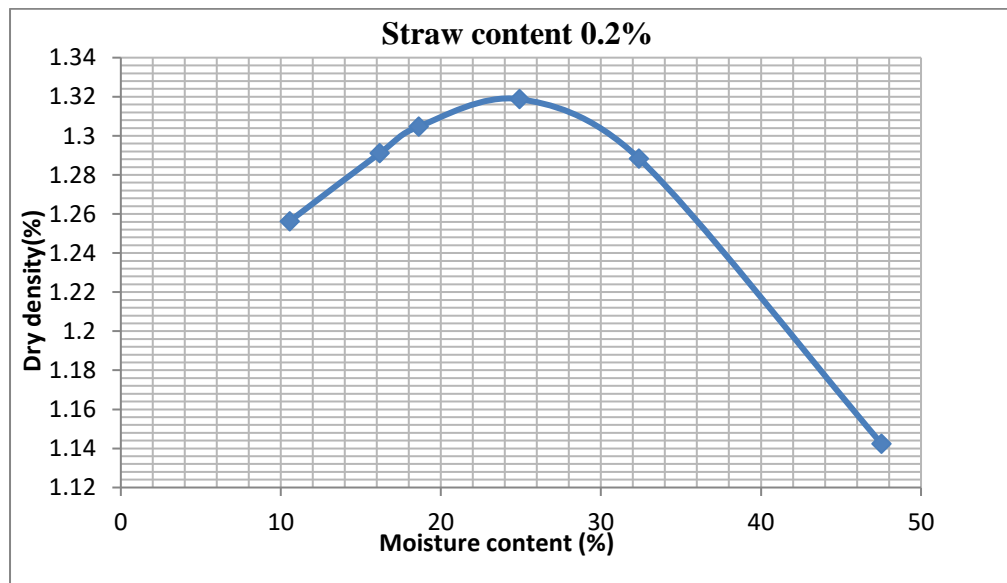
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Standard compaction test							
Straw content 0%							
Location BoleArabasa							
Moisture -density relationship							
Trial	1	2	3	4	5	6	7
weight of mold	5489	5489	5489	5489	5489	5489	5489
weight of wet soil +mold	6819	6923	6985	7063	7119	7240	7214
weight of soil	1330	1434	1496	1574	1630	1751	1725
Volume of mold	944	944	944	944	944	944	944
bulk density,g/cc	1.4089	1.51907	1.58475	1.66737	1.72669	1.85487	1.82733
Moisture content determination							
can No	B1	N7	Y7	Y11	F6	Y5	D6
weight of can	21.7	21.7	22	21.7	21.6	21.4	25.1
weight of wet soil +can	134.9	125.5	119	113.2	113.8	105.1	161.2
weight of dry soil+can	123.8	112.2	105.1	98.1	96.8	84.2	114.8
moisture content in percent	10.8717	14.6961	16.7268	19.7644	22.6064	33.2803	51.728
dry density in g/cm <sup>3</sup>	1.27075	1.32443	1.35765	1.39221	1.40832	1.39171	1.20435
weight of water	11.1	13.3	13.9	15.1	17	20.9	46.4
weight of wt. soil	113.2	103.8	97	91.5	92.2	83.7	136.1
weight of dry soil	102.1	90.5	83.1	76.4	75.2	62.8	89.7



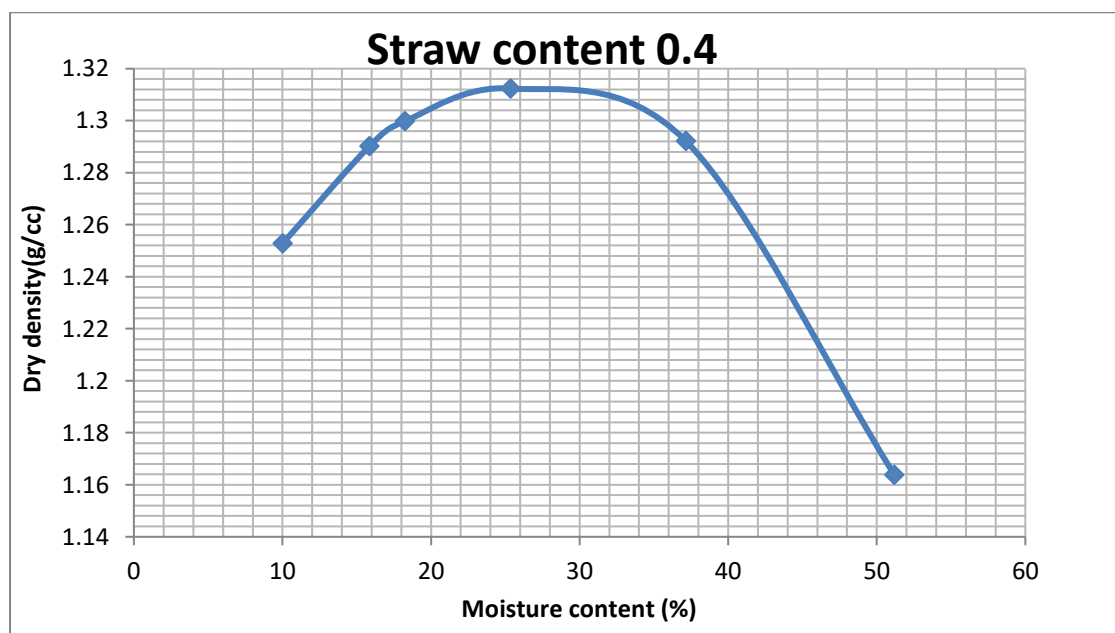
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Standard compaction test						
Straw content 0.2%						
Location BoleArabsa						
Trial	1	2	3	4	5	6
weight of mold	5489	5489	5489	5489	5489	5489
weight of wet soil +mold	6800	6905	6950	7085	7104	7080
weight of soil	1311	1416	1461	1555	1610	1591
Volume of mold	944	944	944	944	944	944
bulk density,g/cc	1.38877	1.5	1.54767	1.64725	1.70551	1.68538
Moisture content determination						
can No	I7	WA	K7	L8	D1	N7
weight of can	21.8	21.8	21.8	21.5	21.5	21.8
weight of wet soil +can	137.1	144.6	123.1	123.3	113.9	129.5
weight of dry soil+can	126.1	127.5	107.2	103	91.3	94.8
moisture content in percent	10.5465	16.1779	18.6183	24.908	32.3782	47.5342
dry density in g/cm <sup>3</sup>	1.25628	1.29112	1.30475	1.31877	1.28836	1.14237
weight of water	11	17.1	15.9	20.3	22.6	34.7
weight of wt. soil	115.3	122.8	101.3	101.8	92.4	107.7
weight of dry soil	104.3	105.7	85.4	81.5	69.8	73



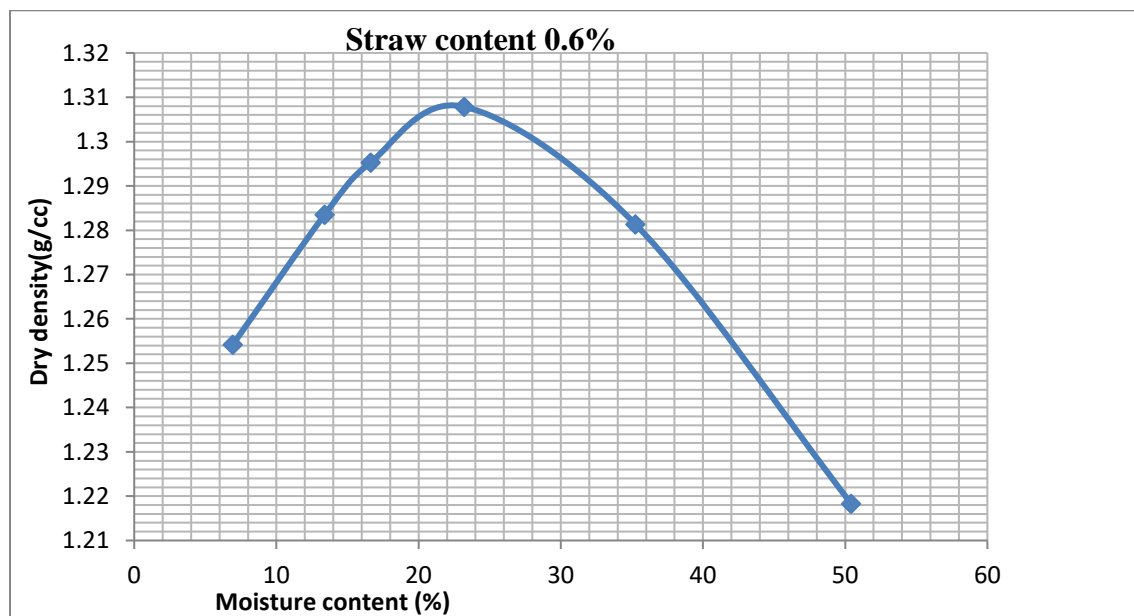
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Standard compaction test						
Straw content 0.4%						
Location: BoleArabsa						
Moisture -density relationship						
Trial	1	2	3	5	6	7
weight of mold	5489	5489	5489	5489	5489	5489
weight of wet soil +mold	6790	6900	6940	7042	7162	7150
weight of soil	1301	1411	1451	1553	1673	1661
Volume of mold	944	944	944	944	944	944
bulk density,g/cc	1.37818	1.4947	1.53708	1.64513	1.77225	1.75953
Moisture content determination						
can No	Y5	XY	D6	Y11	B1	100
weight of can	22.1	21.5	25.1	21.7	21.9	21.8
weight of wet soil +can	143	116.5	148.2	118.6	105.7	149.4
weight of dry soil+can	132	103.5	129.2	99	83	106.2
moisture content in percent	10.0091	15.8537	18.2517	25.3558	37.1522	51.1848
dry density in g/cm <sup>3</sup>	1.25279	1.29017	1.29983	1.31237	1.29217	1.16383
weight of water	11	13	19	19.6	22.7	43.2
weight of wt soil	120.9	95	123.1	96.9	83.8	127.6
weight of dry soil	109.9	82	104.1	77.3	61.1	84.4



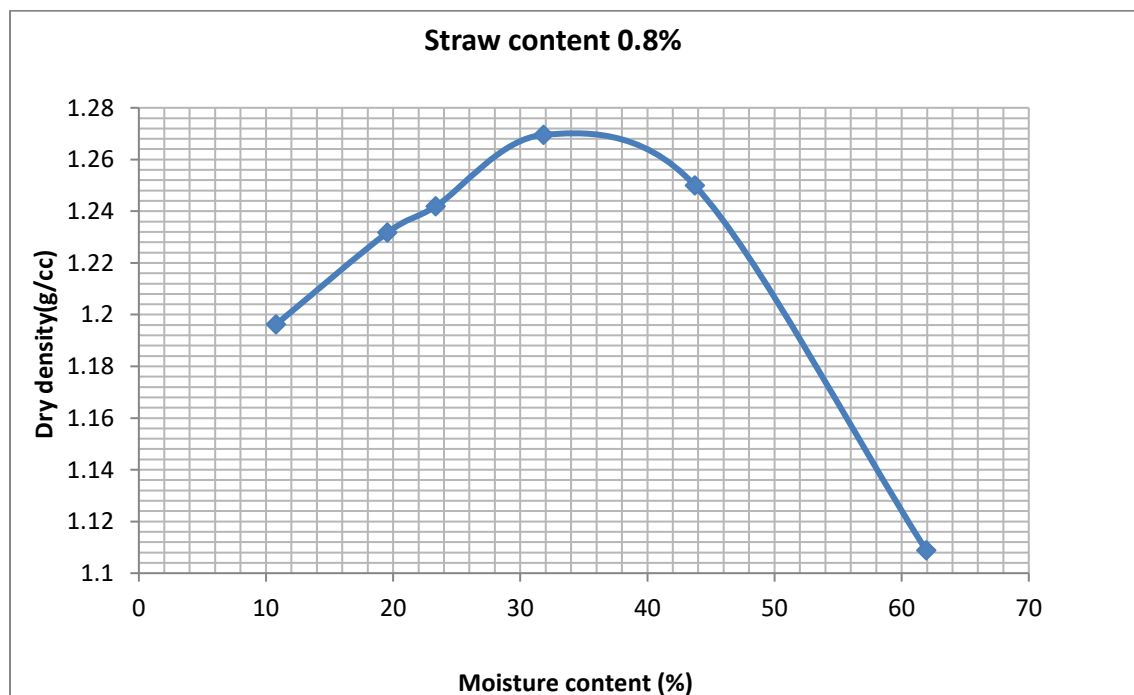
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Standard compaction test						
Straw content 0.6%						
Location:BoleArabsa						
Moisture -density relationship						
Trial	1	2	3	4	5	6
weight of mold	5489	5489	5489	5489	5489	5489
weight of wet soil +mold	6755	6863	6915	7010	7125	7219
weight of soil	1266	1374	1426	1521	1636	1730
Volume of mold	944	944	944	944	944	944
bulk density,g/cc	1.3411	1.4555	1.5105	1.6112	1.733	1.8326
		1	9	3	1	3
Moisture content determination						
Can No	MN	B7	U4	27	OI	Y11
weight of can	21.8	22.1	24.7	22.1	23.9	24.8
weight of wet soil +can	122.1	102.5	113.8	102.3	122.5	167.1
weight of dry soil+can	115.6	93	101.1	87.2	96.8	119.4
moisture content in percent	6.9296	13.399		23.195	35.25	50.422
	4	2	16.623	1	4	8
dry density in g/cm3	1.2541	1.2835	1.2952	1.3078	1.281	1.2183
	9	3	8	7	3	2
weight of water	6.5	9.5	12.7	15.1	25.7	47.7
weight of wt soil	100.3	80.4	89.1	80.2	98.6	142.3
weight of dry soil	93.8	70.9	76.4	65.1	72.9	94.6



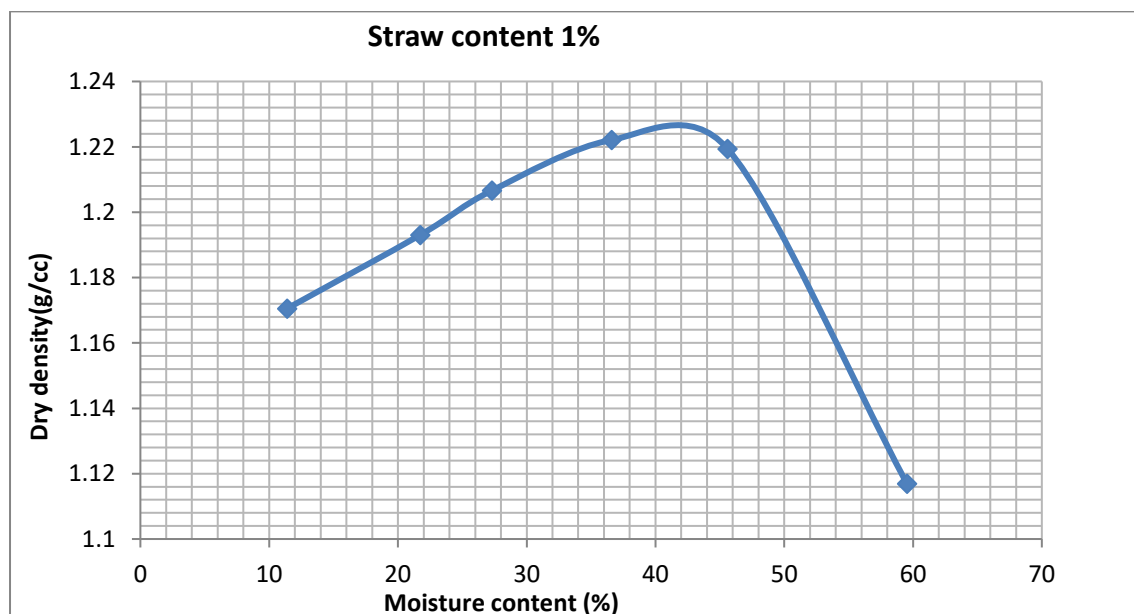
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Standard compaction test						
Straw content 0.8%						
Location:BoleArabsa						
Trial	Moisture -density relationship					
weight of mold	5489	5489	5489	5489	5489	5489
weight of wet soil +mold	6740	6879	6935	7069	7185	7184
weight of soil	1251	1390	1446	1580	1696	1695
Volume of mold	944	944	944	944	944	944
bulk density,g/cc	1.32521	1.47246	1.53178	1.67373	1.79661	1.79555
Moisture content determination						
Can No	D1	E1	I	J7	LM	Y3
weight of can	21.8	22.8	21.6	21.7	21.5	22
weight of wet soil +can	131.7	139	103.5	115.7	123.7	156.4
weight of dry soil+can	121	120	88	93	92.6	105
moisture content in percent	10.7863	19.5473	23.3434	31.8373	43.7412	61.9277
dry density in g/cm <sup>3</sup>	1.19619	1.23169	1.24188	1.26954	1.24989	1.10886
weight of water	10.7	19	15.5	22.7	31.1	51.4
weight of wt. soil	109.9	116.2	81.9	94	102.2	134.4
weight of dry soil	99.2	97.2	66.4	71.3	71.1	83



## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Standard compaction test						
Straw content 1%						
Location: BoleArabasa						
Moisture -density relationship						
Trial	1	2	3	4	5	6
weight of mold	5489	5489	5489	5489	5489	5489
weight of wet soil +mold	6720	6860	6939	7065	7165	7171
weight of soil	1231	1371	1450	1576	1676	1682
Volume of mold	944	944	944	944	944	944
bulk density,g/cc	1.304025	1.452331	1.536017	1.669492	1.77542	1.78178
Moisture content determination						
Can No	F	X1	HA	M4	C6	0
weight of can	21.9	21.9	21.8	23.3	24.6	25
weight of wet soil +can	132.3	116	111.8	124.8	142.1	152.3
weight of dry soil+can	121	99.2	92.5	97.6	105.3	104.8
moisture content in percent	11.40262	21.73351	27.29844	36.60834	45.601	59.5238
dry density in g/cm <sup>3</sup>	1.170552	1.193041	1.206627	1.222101	1.21938	1.11694
weight of water	11.3	16.8	19.3	27.2	36.8	47.5
weight of wet soil	110.4	94.1	90	101.5	117.5	127.3
weight of dry soil	99.1	77.3	70.7	74.3	80.7	79.8



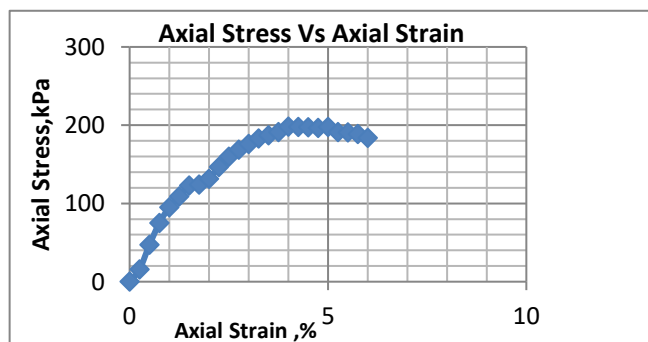
## APPENDIX C

### **UNCONFINED COMPRESSIVE STRENGTH TESTS**



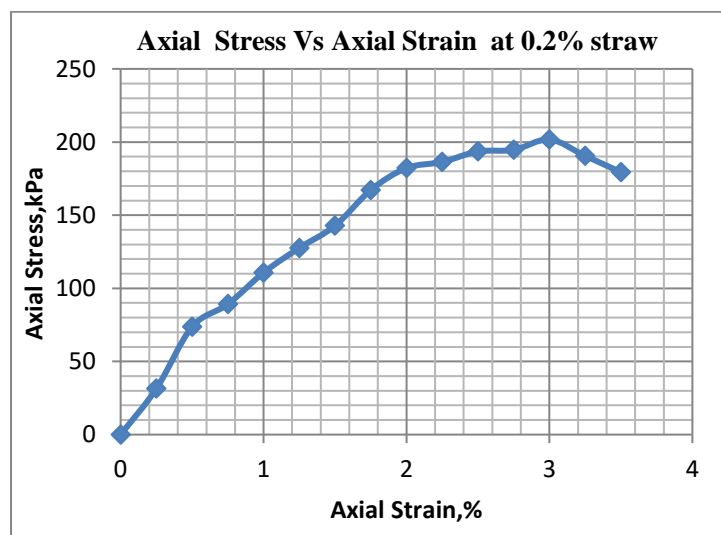
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

0% reinforcement		Cross- Sectional Area , m <sup>2</sup>			0.001257
Depth, m	1.50	Ring Calibration Factor, kN/div			0.00198
Sampling	Remolded	Moisture content, %			33.14
Diameter of sample , mm	40	Wet unit weight, kN/m <sup>3</sup>			15.37
Length of sample , mm	80	Dry Unit Weight, kN/m <sup>3</sup>			11.64
Rate of Strain, mm/min					1.70
Axial Deformation	Axial Strain	Proving Ring Reading	Axial Load	Corrected Area	Axial Stress
[mm]	[%]	[div]	[kN]	[m <sup>2</sup> ]	[kPa]
0.00	0.00	0	0.0000	0.001257	0
0.20	0.25	10	0.0198	0.001260	15.72
0.40	0.50	30	0.0594	0.001263	47.03
0.60	0.75	48	0.0950	0.001266	75.06
0.80	1.00	61	0.1208	0.001269	95.15
1.00	1.25	70	0.1386	0.001273	108.92
1.20	1.50	79	0.1564	0.001276	122.61
1.40	1.75	80	0.1584	0.001279	123.84
1.60	2.00	85	0.1683	0.001282	131.25
1.80	2.25	95	0.1881	0.001286	146.32
2.00	2.50	104	0.2059	0.001289	159.77
2.20	2.75	110	0.2178	0.001292	168.55
2.40	3.00	115	0.2277	0.001296	175.76
2.60	3.25	120	0.2376	0.001299	182.93
2.80	3.50	123	0.2435	0.001302	187.02
3.00	3.75	126	0.2495	0.001306	191.09
3.20	4.00	131	0.2594	0.001309	198.15
3.40	4.25	131	0.2594	0.001312	197.64
3.60	4.50	131	0.2594	0.001316	197.12
3.80	4.75	131	0.2594	0.001319	196.60
4.00	5.00	132	0.2614	0.001323	197.58
4.20	5.25	128	0.2534	0.001326	191.09
4.40	5.50	128	0.2534	0.001330	190.59
4.60	5.75	127	0.2515	0.001333	188.60
4.80	6.00	124	0.2455	0.001337	183.66



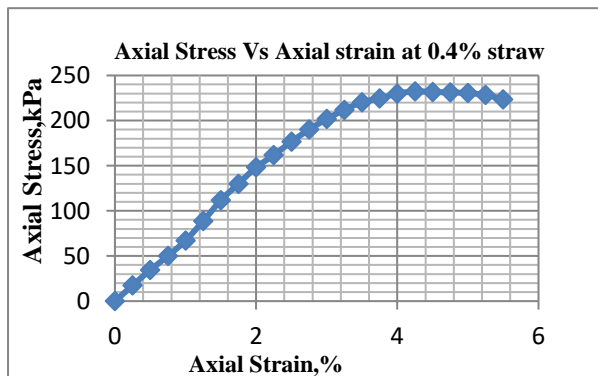
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content ,0.2%					
Cross- Sectional Area , m <sup>2</sup>		0.001257			
Depth, m	1.5	Ring Calibration Factor, kN/div	0.00198		
Sampling	Remolded	Moisture content, %	33.14		
Diameter of sample , mm	40	Wet unit weight, kN/m <sup>3</sup>	14.50		
Length of sample , mm	80	Dry Unit Weight, kN/m <sup>3</sup>	11.22		
Rate of Strain, mm/min		1.70			
Axial Deformation [mm]	Axial Strain [%]	Proving Ring Reading [div]	Axial Load [kN]	Corrected Area [m <sup>2</sup> ]	Axial Stress [kPa]
0.00	0.00	0	0.0000	0.001257	0
0.20	0.25	20	0.0396	0.001260	31.43
0.40	0.50	47	0.0931	0.001263	73.68
0.60	0.75	57	0.1129	0.001266	89.14
0.80	1.00	71	0.1406	0.001269	110.75
1.00	1.25	82	0.1624	0.001273	127.59
1.20	1.50	92	0.1822	0.001276	142.78
1.40	1.75	108	0.2138	0.001279	167.19
1.60	2.00	118	0.2336	0.001282	182.21
1.80	2.25	121	0.2396	0.001286	186.36
2.00	2.50	126	0.2495	0.001289	193.57
2.20	2.75	127	0.2515	0.001292	194.60
2.40	3.00	132	0.2614	0.001296	201.74
2.60	3.25	125	0.2475	0.001299	190.55
2.80	3.50	118	0.2336	0.001302	179.42



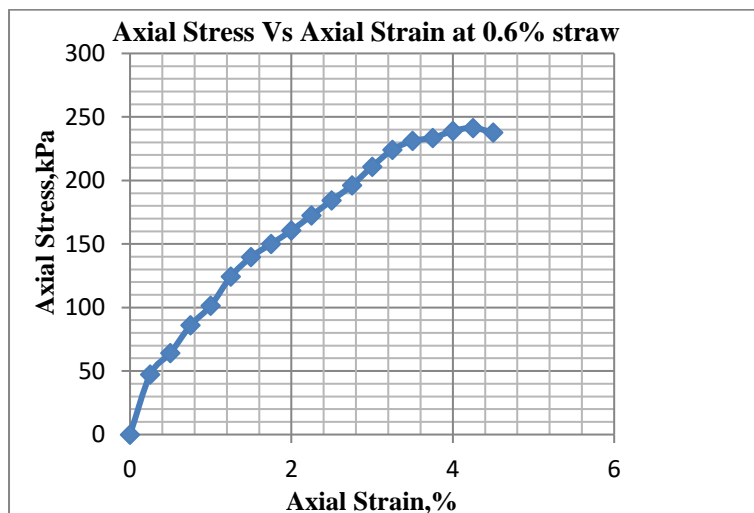
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content 0.4%					
Pit No:			Cross- Sectional Area , m <sup>2</sup>	0.001257	
Depth, m :		1.50	Ring Calibration Factor, kN/div	0.00198	
Sampling		Remolded	Moisture content, %	33.14	
Diameter of sample , mm		40	Wet unit weight, kN/m <sup>3</sup>	14.55	
Length of sample , mm		80	Dry Unit Weight, kN/m <sup>3</sup>	10.92	
			Rate of Strain, mm/min	1.70	
Axial Deformation	Axial Strain	Proving Ring Reading	Axial Load	Corrected Area	Axial Stress
[mm]	[%]	[div]	[kN]	[m <sup>2</sup> ]	[kPa]
0.00	0.00	0	0.0000	0.001257	0
0.20	0.25	11	0.0218	0.001260	17.29
0.40	0.50	22	0.0436	0.001263	34.49
0.60	0.75	32	0.0634	0.001266	50.04
0.80	1.00	43	0.0851	0.001269	67.07
1.00	1.25	57	0.1129	0.001273	88.69
1.20	1.50	72	0.1426	0.001276	111.74
1.40	1.75	84	0.1663	0.001279	130.04
1.60	2.00	96	0.1901	0.001282	148.24
1.80	2.25	105	0.2079	0.001286	161.72
2.00	2.50	115	0.2277	0.001289	176.67
2.20	2.75	124	0.2455	0.001292	190.01
2.40	3.00	132	0.2614	0.001296	201.74
2.60	3.25	139	0.2752	0.001299	211.90
2.80	3.50	145	0.2871	0.001302	220.47
3.00	3.75	148	0.2930	0.001306	224.45
3.20	4.00	152	0.3010	0.001309	229.92
3.40	4.25	154	0.3049	0.001312	232.34
3.60	4.50	154	0.3049	0.001316	231.73
3.80	4.75	154	0.3049	0.001319	231.12
4.00	5.00	154	0.3049	0.001323	230.52
4.20	5.25	153	0.3029	0.001326	228.42
4.40	5.50	150	0.2970	0.001330	223.35



## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content 0.6%					
Cross- Sectional Area , m <sup>2</sup>					0.001257
Depth, m :	1.5		Ring Calibration Factor, kN/div		0.00198
Sampling	Remolded		Moisture content, %		33.14
Diameter of sample , mm	40		Wet unit weight, kN/m <sup>3</sup>		14.50
Length of sample , mm	80		Dry Unit Weight, kN/m <sup>3</sup>		10.14
			Rate of Strain, mm/min		1.70
Axial Deformation	Axial Strain	Proving Ring Reading	Axial Load	Corrected Area	Axial Stress
[mm]	[%]	[div]	[kN]	[m <sup>2</sup> ]	[kPa]
0.00	0.00	0	0.0000	0.001257	0
0.20	0.25	30	0.0594	0.001260	47.15
0.40	0.50	41	0.0812	0.001263	64.28
0.60	0.75	55	0.1089	0.001266	86.01
0.80	1.00	65	0.1287	0.001269	101.39
1.00	1.25	80	0.1584	0.001273	124.48
1.20	1.50	90	0.1782	0.001276	139.68
1.40	1.75	97	0.1921	0.001279	150.16
1.60	2.00	104	0.2059	0.001282	160.59
1.80	2.25	112	0.2218	0.001286	172.50
2.00	2.50	120	0.2376	0.001289	184.35
2.20	2.75	128	0.2534	0.001292	196.13
2.40	3.00	138	0.2732	0.001296	210.91
2.60	3.25	147	0.2911	0.001299	224.09
2.80	3.50	152	0.3010	0.001302	231.11
3.00	3.75	154	0.3049	0.001306	233.55
3.20	4.00	158	0.3128	0.001309	238.99
3.40	4.25	160	0.3168	0.001312	241.39
3.60	4.50	158	0.3128	0.001316	237.75

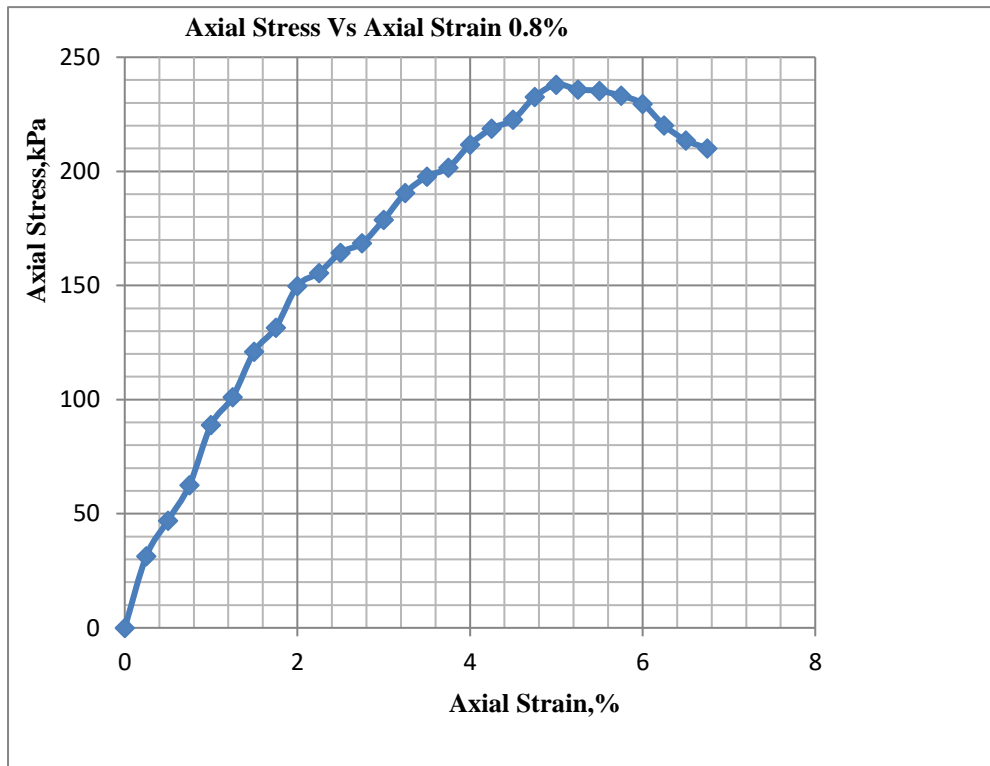


## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content 0.8%					
Cross- Sectional Area , m <sup>2</sup>					0.001257
Depth, m	1.50		Ring Calibration Factor, kN/div	0.00198	
Sampling	Remolded		Moisture content, %	33.14	
Diameter of sample , mm	40		Wet unit weight, kN/m <sup>3</sup>	14.50	
Length of sample , mm	80		Dry Unit Weight, kN/m <sup>3</sup>	10.15	
			Rate of Strain, mm/min	1.70	
Axial Deformation	Axial Strain	Proving Ring Reading	Axial Load	Corrected Area	Axial Stress
[mm]	[%]	[div]	[kN]	[m <sup>2</sup> ]	[kPa]
0.00	0.00	0	0.0000	0.001257	0
0.20	0.25	20	0.0396	0.001260	31.43
0.40	0.50	30	0.0594	0.001263	47.03
0.60	0.75	40	0.0792	0.001266	62.55
0.80	1.00	57	0.1129	0.001269	88.91
1.00	1.25	65	0.1287	0.001273	101.14
1.20	1.50	78	0.1544	0.001276	121.06
1.40	1.75	85	0.1683	0.001279	131.59
1.60	2.00	97	0.1921	0.001282	149.78
1.80	2.25	101	0.2000	0.001286	155.56
2.00	2.50	107	0.2119	0.001289	164.38
2.20	2.75	110	0.2178	0.001292	168.55
2.40	3.00	117	0.2317	0.001296	178.82
2.60	3.25	125	0.2475	0.001299	190.55
2.80	3.50	130	0.2574	0.001302	197.66
3.00	3.75	133	0.2633	0.001306	201.70
3.20	4.00	140	0.2772	0.001309	211.77
3.40	4.25	145	0.2871	0.001312	218.76
3.60	4.50	148	0.2930	0.001316	222.70
3.80	4.75	155	0.3069	0.001319	232.62
4.00	5.00	159	0.3148	0.001323	238.00
4.20	5.25	158	0.3128	0.001326	235.88
4.40	5.50	158	0.3128	0.001330	235.26
4.60	5.75	157	0.3109	0.001333	233.15
4.80	6.00	155	0.3069	0.001337	229.57
5.00	6.25	149	0.2950	0.001340	220.10
5.20	6.50	145	0.2871	0.001344	213.62
5.40	6.75	143	0.2831	0.001348	210.11

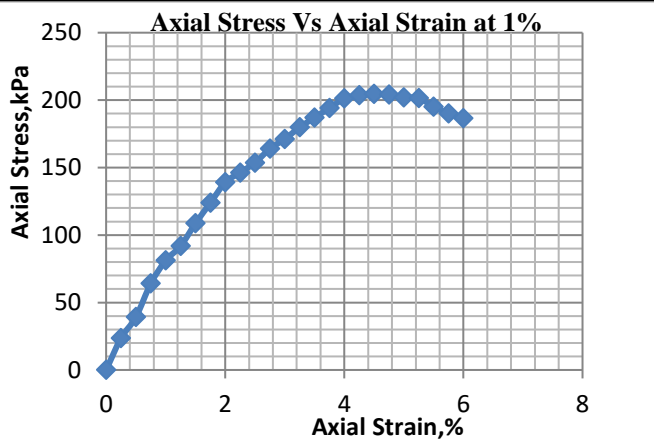
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content 1%						
					Cross- Sectional Area , m <sup>2</sup>	0.001257
Depth, m :		1.50	Ring Calibration Factor, kN/div		0.00198	
Sampling		Remolded	Moisture content, %		33.14	
Diameter of sample , mm		40	Wet unit weight, kN/m <sup>3</sup>		14.28	
Length of sample , mm		80	Dry Unit Weight, kN/m <sup>3</sup>		9.74	
Rate of Strain, mm/min					1.70	
Axial Deformation	Axial Strain	Proving Ring Reading	Axial Load	Corrected Area	Axial Stress	
[mm]	[%]	[div]	[kN]	[m <sup>2</sup> ]	[kPa]	
0.00	0.00	0	0.0000	0.001257	0	
0.20	0.25	15	0.0297	0.001260	23.58	
0.40	0.50	25	0.0495	0.001263	39.19	
0.60	0.75	41	0.0812	0.001266	64.12	
0.80	1.00	52	0.1030	0.001269	81.11	
1.00	1.25	59	0.1168	0.001273	91.80	
1.20	1.50	70	0.1386	0.001276	108.64	
1.40	1.75	80	0.1584	0.001279	123.84	
1.60	2.00	90	0.1782	0.001282	138.97	
1.80	2.25	95	0.1881	0.001286	146.32	
2.00	2.50	100	0.1980	0.001289	153.62	
2.20	2.75	107	0.2119	0.001292	163.96	
2.40	3.00	112	0.2218	0.001296	171.18	
2.60	3.25	118	0.2336	0.001299	179.88	
2.80	3.50	123	0.2435	0.001302	187.02	
3.00	3.75	128	0.2534	0.001306	194.12	
3.20	4.00	133	0.2633	0.001309	201.18	
3.40	4.25	135	0.2673	0.001312	203.67	
3.60	4.50	136	0.2693	0.001316	204.64	
3.80	4.75	136	0.2693	0.001319	204.11	
4.00	5.00	135	0.2673	0.001323	202.08	
4.20	5.25	135	0.2673	0.001326	201.54	
4.40	5.50	131	0.2594	0.001330	195.06	
4.60	5.75	128	0.2534	0.001333	190.08	
4.80	6.00	126	0.2495	0.001337	186.62	



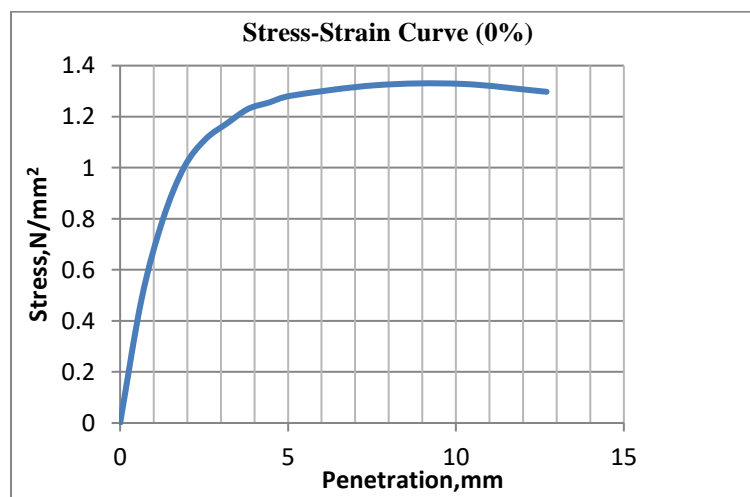
APPENDIX D

**UNSOAKED CBR TESTS**

## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

CBR for unreinforced soil

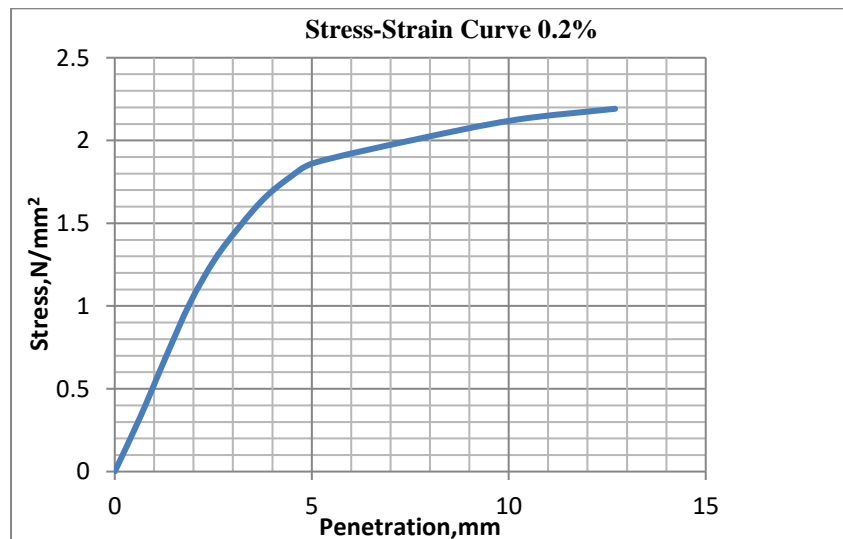
Depth, cm :		Ring Calibration Factor, N/Div	25.709
Test Pit (sample) No.		Plunger Area, mm <sup>2</sup>	1934.5
Material Desc.	Remolded	Rate of strain, mm/min	1.27
Station:	Bole Arabsa	Hammer wt. (kg)	2.5
<i>CBR Computation Table</i>			
Blow/ Layer	56/3	NMC	40.69
Swell, %	1.66	Optimum Moisture Content	37.50
CBR Value, %	16.11	Max. Dry Density	1.38
<i>Penet.</i>	Load	Stress	Standard stress
<i>(mm)</i>	(N)	(N/mm <sup>2</sup> )	(N/mm <sup>2</sup> )
0	0	0	
0.6	940	0.48591	
1.27	1540	0.79607	
1.91	1940	1.00284	
2.54	2150	1.11140	6.9
3.18	2270	1.17343	
3.81	2380	1.23029	
4.45	2430	1.25614	
5.08	2480	1.28199	10.3
7.62	2560	1.32334	
10.16	2570	1.32851	
12.70	2510	1.29749	
			16.11
			12.45



## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

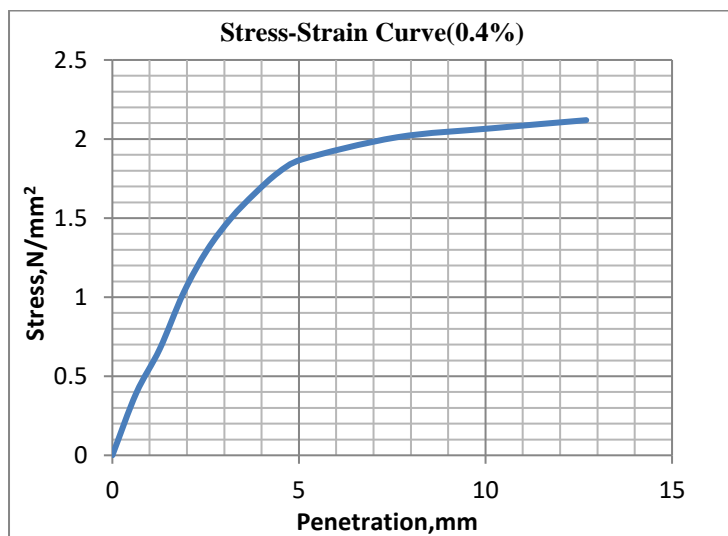
### CBR for Reinforced soil

Percent of straw		0.2%		
Depth, cm :		Ring Calibration Factor, N/Div		25.709
Test Pit (sample) No.		Plunger Area, mm <sup>2</sup>		1934.5
Material Desc.	Remolded	Rate of strain, mm/min		1.27
Station:	Bole Arabsa	Hammer wt. (kg)		2.5
CBR Computation Table				
Blow/ Layer	56/3	NMC		0
Swell, %	1.66087	Optimum Moisture Content		37.5
CBR Value, %	18.5795	Max. Dry Density		1.38
Penetration (mm)	Load (N)	Stress (N/mm <sup>2</sup> )	Standard stress (N/mm <sup>2</sup> )	CBR (%)
0	0	0		
0.64	630	0.325666		
1.27	1310	0.677178		
1.91	1970	1.018351		
2.54	2480	1.281985	6.9	18.579493
3.18	2870	1.483587		
3.81	3200	1.654174		
4.45	3440	1.778237		
5.08	3610	1.866115	10.3	18.117624
7.62	3880	2.005686		
10.16	4110	2.12458		
12.7	4240	2.191781		



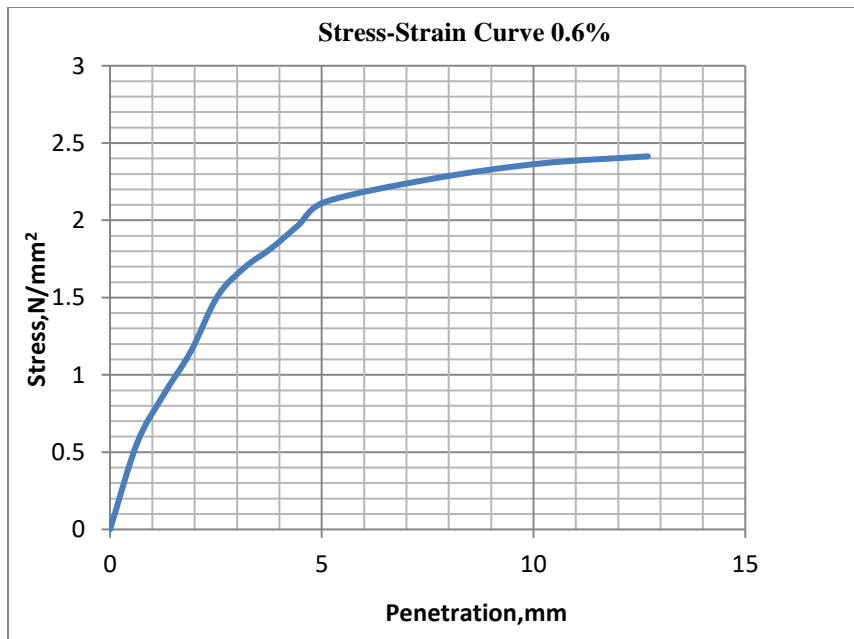
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content	0.40%			
Depth, cm :	Ring Calibration Factor, N/Div		25.709	
Plunger Area, mm <sup>2</sup>			1934.5	
Material Desc.	Remolded	Rate of strain, mm/min		1.27
Station:	Bole Arabsa	Hammer wt. (kg)		2.5
CBR Computation Table				
Blow/ Layer	56/3	NMC		22
Swell, %	1.6608	Optimum Moisture Content		37.5
CBR Value, %	18.804	Max. Dry Density		1.38
Penetration (mm)	Load (N)	Stress (N/mm <sup>2</sup> )	Standard stress (N/mm <sup>2</sup> )	CBR (%)
0	0	0		
0.64	760	0.392866		
1.27	1300	0.672008		
1.91	1990	1.02869		
2.54	2510	1.297493	6.9	18.804245
3.18	2900	1.499095		
3.81	3200	1.654174		
4.45	3460	1.788576		
5.08	3620	1.871285	10.3	18.167811
7.62	3890	2.010856		
10.16	4000	2.067718		
12.7	4100	2.119411		



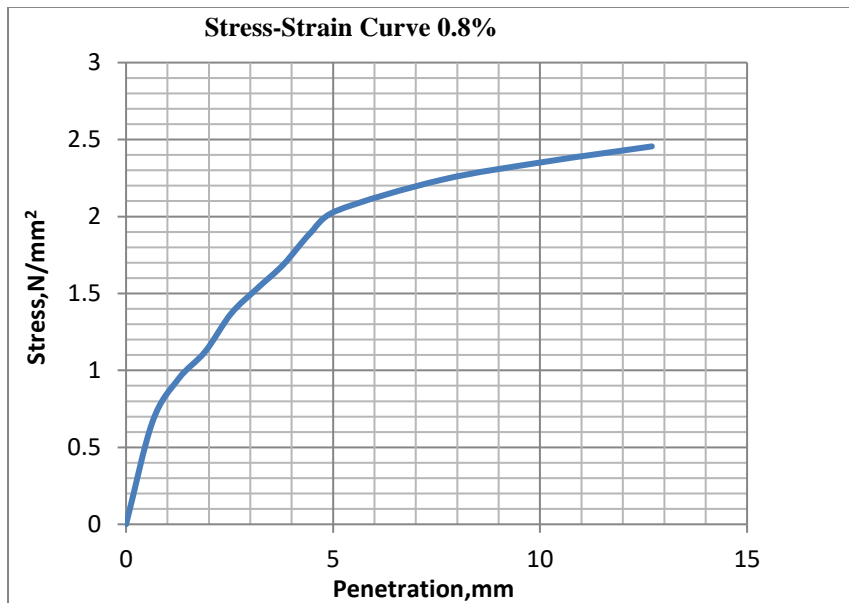
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content		0.60%		
Depth, cm :		Ring Calibration Factor, N/Div	25.709	
Test Pit (sample) No.		Plunger Area, mm <sup>2</sup>	1934.5	
Material Desc.	Remolded	Rate of strain, mm/min	1.27	
Station:	Bole Arabsa	Hammer wt. (kg)	2.5	
CBR Computation Table				
Blow/ Layer	56/3		NMC	0
Swell, %	1.66087		Optimum Moisture Content	37.5
CBR Value, %	21.87585	Density	Max. Dry	1.38
Penetration (mm)	Load (N)	Stress (N/mm <sup>2</sup> )	Standard stress (N/mm <sup>2</sup> )	CBR (%)
0	0	0		
0.64	1080	0.558283794		
1.27	1690	0.873610752		
1.91	2230	1.152752649		
2.54	2920	1.509433962	6.9	21.8758545
3.18	3280	1.69552856		
3.81	3520	1.819591626		
4.45	3810	1.969501163		
5.08	4100	2.1194107	10.3	20.5768029
7.62	4390	2.269320238		
10.16	4580	2.367536831		
12.7	4670	2.414060481		



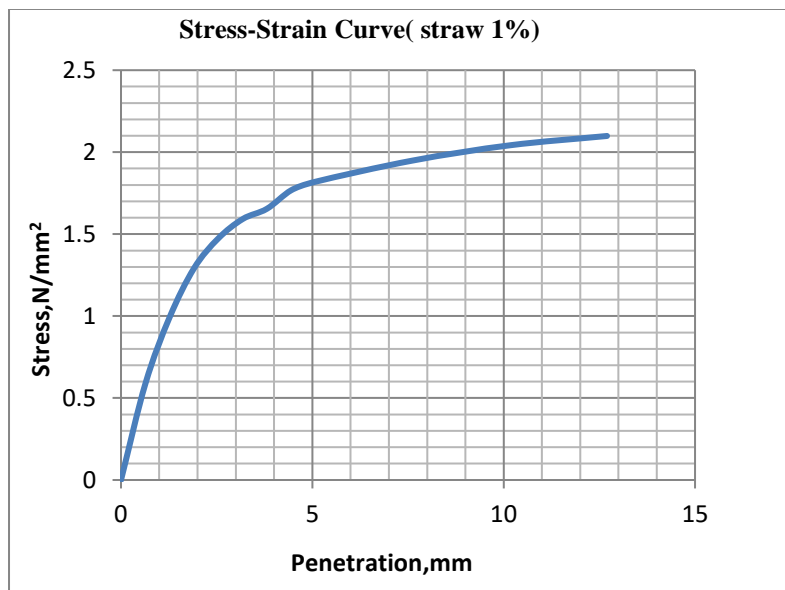
## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content	0.80%			
Depth, cm :		Ring Calibration Factor, N/Div	25.709	
Test Pit (sample) No.		Plunger Area, mm <sup>2</sup>	1934.5	
Material Desc.	Remolded	Rate of strain, mm/min	1.27	
Station:	Bole Arabsa	Hammer wt. (kg)	2.5	
<b>CBR Computation Table</b>				
Blow/ Layer	56/3	NMC	28	
Swell, %	1.66087	Optimum Moisture Content	37.5	
CBR Value, %	19.85309	Max. Dry Density	1.38	
Penetration (mm)	Load (N)	Stress (N/mm <sup>2</sup> )	Standard stress (N/mm <sup>2</sup> )	CBR (%)
0	0	0		
0.64	1290	0.66683898		
1.27	1830	0.94598087		
1.91	2170	1.12173688		
2.54	2650	1.36986301	6.9	19.8530872
3.18	2970	1.53528043		
3.81	3270	1.69035927		
4.45	3660	1.89196175		
5.08	3940	2.03670199	10.3	19.7738057
7.62	4330	2.23830447		
10.16	4560	2.35719824		
12.7	4750	2.45541484		



## The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

Straw content	1%			
Depth, cm :		Ring Calibration Factor, N/Div	25.709	
Test Pit (sample) No.		Plunger Area, mm <sup>2</sup>	1934.5	
Material Desc.	Remolded	Rate of strain, mm/min	1.27	
Station:	Bole Arabsa	Hammer wt. (kg)	2.5	
<b>CBR Computation Table</b>				
Blow/ Layer	56/3	NMC	0	
Swell, %	1.66087	Optimum Moisture Content	37.5	
CBR Value, %	21.35143	Max. Dry Density	1.38	
Penet. (mm)	Load (N)	Stress (N/mm <sup>2</sup> )	Standard stress (N/mm <sup>2</sup> )	CBR (%)
0	0	0		
0.64	1140	0.589299561		
1.27	1920	0.992504523		
1.91	2500	1.292323598		
2.54	2850	1.473248902	6.9	21.3514334
3.18	3080	1.592142673		
3.81	3200	1.654174205		
4.45	3420	1.767898682		
5.08	3520	1.819591626	10.3	17.6659381
7.62	3770	1.948823986		
10.16	3950	2.041871285		
12.7	4060	2.098733523		



APPENDIX E  
**LABORATORY PHOTOS**

# The Effect of Random Inclusion of Teff Straw on Shear Strength Characteristics of Addis Ababa Expansive Soil

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