JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FUCULTYOF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTEMENT OF CIVIL ENGINEERING

HIGHWAY ENGINEERING STREAM

Improvement of Engineering Properties of Weak Subgrade Soil by Ensete Ventricosum Fiber Reinforcement. (A case in Jimma Town)

A Research Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By: Zeginet Zerihun

Oct, 2019

Jimma, Ethiopia

JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FUCULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTEMENT OF CIVIL ENGINEERING

HIGHWAY ENGINEERING STREAM

Improvement of Engineering Properties of Weak Subgrade Soil by Ensete Ventricosum Fiber Reinforcement. (A case in Jimma Town)

A Research Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering (Highway Engineering)

By: Zeginet Zerihun

Main Advisor: Dr.-Ing.Tamene Adugna (PhD)

Co-Advisor: Mr. Bushirelkerim Oumer (MSc)

Oct, 2019

Jimma, Ethiopia

Declaration

This research which is entitled as improvement of engineering properties of weak subgrade soil by ensete ventricosum fiber reinforcement (a case in Jimma town) is my original work and has not been presented in any other university.

Zeginet Zerihun

Signature_________________________ Date_____________________

JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FUCULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

DEPARTEMENT OF CIVIL ENGINEERING

HIGHWAY ENGINEERING STREAM

Improvement of Engineering Properties of Weak Subgrade Soil by Ensete Ventricosum Fiber Reinforcement. (A case in Jimma Town)

By

Zeginet Zerihun

Approved by board of examiners:

External Examiner	Signature	Date
Prof. Emer T. Quezon	______________	______________
Internal Examiner	Signature	Date
Mr. Mesfin Dinku(MSc)	______________	______________
Chairman	Signature	Date
Mr. Oluma Gudina(MSc)	______________	______________
Advisor	Signature	Date
Dr.-Ing. Tamene Adugna (PhD)	______________	______________
Co. Advisor	Signature	Date
Mr. Bushirelkerim Oumer (MSc)	______________	______________

Abstract

Weak and unsuitable soil conditions have always caused problems for civil engineers during the construction of structures. To avoid problems in a cost- effective manner, proper and reliable solutions need to be developed. Therefore, development of effective stabilization techniques for these environmentally sensitive lands and soils has been called for. In Jimma town most of roads are deteriorated. For this deterioration one of the reasons behind is weakness of subgrade soil. Therefore modification or improvement of such soil is required to get stable subgrade soil. Over centuries the Ensete ventricosum fibers have been extracted from the stems as major material for the weaving, ropes and cord production, as well as for baskets production. To use this material as a fiber for soil reinforcement, this study investigated properties and strength on reinforced soil.

The objective of this study was to use ensete ventricosum fiber in improvement of weak subgrade soil by examining its effect on engineering properties.

The disturbed samples were collected at desired amount from dippo and koshe at adequate depth. And ensete ventricosum fiber sample were collected based on desired content from local market of Jimma zone Shebe. From sieve analysis tests, percentage of passing through sieve No. 200 (0.075mm sieve size) of koshe and dippo is 93.16% and 95.07 % respectively. While from the Atterberg's limit test results, natural soil sample contains a liquid limit of 82.9and 80.53%, a plastic limit of 36.11% and 35.1%, and plasticity index of 46.8% and 45.43%, koshe and dippo samples respectively. This result shows that both samples are clay soil. Both natural sample soils were classified as A-7-5 according to AASHTO soil classification system and CH according to USCS.

As observed from CBR test result, when fiber content increases, CBR value also increases until 0.75% fiber content is added and then decreases for both samples. So this 0.75% fiber content can be taken as optimum content to produce best mix of soil and reinforcement fiber which improve weak subgrade soil. From compaction test, it is observed that fiber content increases, MDD decreases and OMC increases for both samples. MDD decreases from 1.35 $g/cm^3$of natural sample to 1.28 $g/cm^3$of 1% fiber reinforced sample and from 1.47g/cm^3 of natural sample to 1.39$g/cm^3$of 1% fiber reinforced sample for koshe and dippo samples respectively. Again OMC increases from 30.16% of natural sample to 36.65% of 1%fiber reinforced sample for koshe sample and from 20.21 of natural sample to 27.05% of 1%fiber reinforced sample for dippo sample.

UCS value increased by 91.7% at 25mm ,121.97% at 50mm, 229.9% at 75mm length from natural soil for dippo sample and 57.1% at 25mm,80.5% at 50mm,176.8% at 75mm for koshe sample for constant content of 0.75% of fiber is added . It is observed that the UCS value of fiber reinforced soil increases with increase in fiber length.

Key Words: *CBR, ensete ventricosum fiber, soil reinforcement, UCS, weak soil*

Acknowledgement

First of all, my special thanks go to the Almighty God. Then, I would like to express my deepest gratitude to Jimma University, Institute of Technology for allowing me to pursue post graduate studies for my professional advancement.

As well, I want to present my deepest gratitude to my Main Advisor Dr.-Ing.Tamene Adugna (PhD) and my Co- advisor Mr. Bushirelkerim Oumer (MSc) who had guided me in this research work.

Also I would like to acknowledge and heartfelt thanks to my best families, friends and my love Emebet Abera for their continuous support to prepare this research.

Table of Contents

Contents

List of Tables

List of Figures

Acronyms

AASHTO	American Association of State Highway and Transportation Organization
ASTM	American Society for Testing Materials
CBR	Californian Bearing Ratio
CH	High Plastic Clay
ERA	Ethiopian Road Authority
EV	Ensete Ventricosum
LL	Liquid Limit
MDD	Maximum Dry Density
Mpa	Mega Pascal
OMC	Optimum Moisture Content
PL	Plastic limit
PI	Plasticity Index
RDFS	Randomly Distributed Fiber Reinforced Soil
UCS	Unconfined Compressive Strength
USCS	Unified Soil Classification System
USD	United State Dollar

Chapter One

Introduction

1.1 Background

Soil properties are very important for every construction work, because we can change the material if it hasn't good quality, but it is very difficult to replace the soil. So it needs improvement or modification of existing soil. Method of using low cost material and admixture to improve the property of soil is called soil stabilization. [1].

In the past, there were numerous soil improvement techniques that have been proposed and implemented to stabilize the weaker soil prior to the constructions. The recommended improvement methods can be mainly categorized into two types: (i) mechanical methods of stabilization and (ii) chemical methods of stabilization. Mechanical techniques are displacement and replacement, stage constructions, preloading, stone columns method, soil nailing and reinforcement applications. The chemical methods of stabilizing consist of deep in-situ mixing and surface stabilizations by using cement, fly ash, bottom ash, bentonite, gypsum, silica fume and blast furnace slag [2]. Also, the chemical stabilization techniques were widely incorporated with the ashes of several organic materials derived from burning process [3]. However, the above usual stabilization techniques (mechanical and chemical) are coupled with severe environmental issues such as global warming via large carbon-dioxide emissions, high energy cost, environmental (air, land and water) pollutions, depletion of non-renewable resources and influx of heavy and dangerous substances to the geo-environment [4]. Thus, the current intentions of Engineers are targeting on modifying the existing weaker ground and soils using ground improvement techniques by ensuring sustainability in land use [5]. Jimma town roads are mostly deteriorated and this may as result of weakness of subgrade soil. Therefore, ecofriendly applications are highly preferred from us to make long lasting roads. This study implies reinforcing soil by ensete ventricosum fiber which is local abundant resource.

1.2 Statement of Problem

Subgrades are usually consisted of locally available soil deposits that sometimes might be very weak or very wet with low strength /stiffness to support the pavements traffic loading. The replacement of weak in situ soil better quality of borrow soil is not always an economical option due to the associated extra cost of excavation and hauling. In many cases, weak subgrade soils are treated/ stabilized with cementitious materials (i,e , cement,lime, fly ash) to achieve a certain strength/stiffness to support the construction and pavement loading. But this cementitious material is not cost effective. So there is a need to concentrate on improving properties of subgrade soils using cost-effective practices like treating it with low cost and readily available material. From these cost effective practices, one is that using ensete ventricosum fiber which is locally produced and abundantly available. This is a reason why this research is considered to improve weak subgrade soil of Jimma town by available ensete ventricosum fiber reinforcement.

1.3 Research questions

1. What are the engineering properties of existing subgrade soil sample?
2. What is the optimum content of ensete ventricosum fiber to improve engineering properties weak subgrade soil?
3. What is the effect of ensete ventricosum fiber soil reinforcement on engineering properties of weak subgrade soil?

1.4 Objectives

1.4.1 The general objective of this study is to improve engineering properties of weak subgrade soil by using ensete ventricosum fiber reinforcement

1.4.2 Specific Objectives

- To determine the engineering properties of existing subgrade soil sample.
- To determine the optimum content of ensete ventricosum fiber to be as reinforcement fiber for improving weak subgrade soil.
- To examine the effect of ensete ventricosum fiber soil reinforcement on engineering properties of weak subgrade soil.

1.5 Scope and Limitation of Study

The finding of the research was limited on selected weak subgrade soil in Jimma town. It was supported by different sources of literatures and a series of laboratory experiments. The relevant laboratory tests were Californian Bearing Ratio (CBR) test, compaction test and unconfined compressive strength test on reinforced sample. Atterburg limit test, grain size analysis, free swell, natural moisture content and specific gravity tests were conducted only on natural soil sample. Because fiber reinforced soil is not suitable for these tests. The ensete ventricosum reinforcement fiber was randomly distributed and untreated by any chemicals.

1.6 Significance of the study

This study is to improve engineering properties of selected subgrade soil of Jimma town. It will be to benefit the construction industry by utilizing the natural resources in a cost effective way. Most of studies indicate that natural fiber can be utilized for soil reinforcement. From this natural fiber, ensete ventricosum fiber is one of available fiber. Therefore, this study provided findings on reinforcement of ensete ventricosum fiber to improve engineering properties weak subgrade soil.

Chapter Two

Literature Review

2.1 Introduction

One of the most important aspects of the study of the soil mechanics is the prediction of load carrying capacity. Different types of infrastructures like roads, building, bridges, stadium, ports, harbor, etc. are being constructed on the ground. Road structures are constructed for the movement of various transports like buses, trucks, car, auto rickshaws, rickshaw, bullock carts etc. Load from these traffics is ultimately distributed on the ground.

The load carrying capacity of soil is measured by various methods like Unconfined Compression test, California Bearing Ratio (CBR) test, Direct Shear test, Vane Shear test, Plate Load test etc. [10]

Engineering properties of soil depend on the combined effects of several interacting and/or inter-related factors. These factors may be divided into two groups i.e. compositional and environmental. Compositional factors consist of type and amount of mineral, shape and size distribution of particles, type of adsorbed cations, pore water composition etc. Environmental factors include water content, density, confining pressure, temperature etc. [10] Load carrying capacity of different type of soil is different. The principal factors affecting the load carrying capacity are soil texture, moisture content and density. Consolidation characteristics also affect load carrying capacity of a particular soil. [10]

2.2 Road Pavement

The word Pavement implies to a hard surface of flat stones or a mixture of aggregate, sand and soil or without soil to support the load of traffic plying on it as well as to facilitate the movement of traffic. The pavement consists of a few layers of pavement materials over a prepared sub grade soil to serve as a carriage way. The pavement carries the traffic loads and transfers the load through a wider area on the soil subgrade below. The surface of the pavement should be stable and non-yielding under heaviest road traffic. This property of the pavement makes the road traffic to move with least possible rolling resistance. The pavement also keeps its temporary elastic deformation within the permissible limits so that it can sustain a large number of repeated load applications during the design life. [10]

2.2.1 Types of pavement

For design purpose, pavements fall under two categories, namely Rigid and Flexible.

Rigid pavement: as the name entail is a cement concrete slab acting as wearing surface of the road. Rigid pavement contains high rigidity and modulus of elasticity and is able to bridge over any localized failures. It provides a good riding surface and lasts long with very little maintenance.

Flexible pavement: All other types of pavement other than rigid can traditionally be classified as flexible pavement. The commonly accepted characterization of a flexible pavement is that, a flexible pavement is a uniform or composite structure that maintains an intimate contact with and distributes loads to the subgrade soil by mechanical interlocking of aggregates, particle friction and cohesion for developing stability. Thus, the classical flexible pavement includes primarily those pavements which are composed of series granular layers (bituminous or non-bituminous) with a relatively thin layer of wearing surface made of high quality materials. A flexible pavement can be composed of a single layer or a series of layers depending mainly on traffic volume. Sometimes, multiple bituminous layers are provided for heavy duty pavements.[10]

2.2.2 Pavement structure

Followings are the main component layers of Flexible pavement:- Sub-grade, Sub-base, Base course and Wearing course or surface course.

The general structure of a flexible pavement is given below:

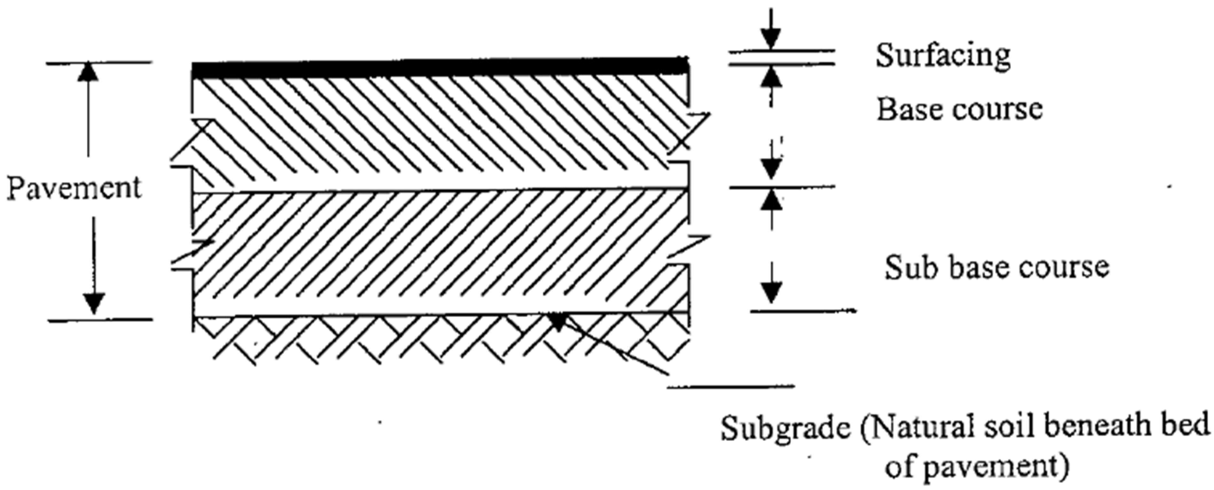

Fig 2.1 Structure of Flexible pavement [12]

Pavement structure may be having all these elements or some of them may have been eliminated and some new have been added depending upon the actual site and traffic conditions. Improved subgrade is provided underneath sub base course where sub grade soil strength is poor. [12]

2.3 Road Subgrade

The upper layer of the embankment or natural ground in cut or fill is termed as subgrade. Load from the traffic is ultimately distributed on sub grade through other component layers. So the strength of the sub grade is a basic factor in determining the thickness of pavement. Sometimes, selected or imported materials is used for sub grade preparation either mixing with the available natural or embankment materials. [10]

The design of the pavement layers laid over the subgrade soil starts with the determination of subgrade strength and the traffic volume which is to be carried. The design of pavement is extremely dependent on the subgrade strength of soil. Design criteria mainly needs thickness of layers. Weaker subgrade soil needs thicker layers whereas stronger subgrade soil needs thinner pavement layers. [10]

The strength of road subgrade is commonly assessed in terms of the California Bearing Ratio

(CBR) of the sub grade soil and this is dependent on the type of soil, its density and its moisture content. Due to the heterogeneous nature of the plain soils, changes in subgrade California Bearing Ratio (CBR) values are frequent and large. The soil type is largely determined by the location of the road, but where the soils within the possible corridor for the road vary significantly in strength from place to place, it is obviously desirable to locate the pavement on the stronger soils, if this does not clash with other constraints. The density of the sub grade soil can be controlled by compaction at suitable moisture content at the time of construction. The moisture content of the sub grade soil is governed by the local climate and the depth of the ground water table below the road surface. [10]

A subgrade characteristic essentially depends on the following three factors such as:-

Load bearing capacity: Subgrade soil resists loads which are transmitted from the pavement structure. Different factors such as degree of compaction, moisture content, and nature of soil affect the load bearing capacity of soil. A subgrade soil without excessive deformation maintains heavy loading is considered as high-quality. [11]

Moisture content: Characteristics such as load bearing capacity, shrinkage and swelling etc. are typically affected by the variation of moisture content. Various factors such as drainage, groundwater table elevation, infiltration, pavement porosity etc. influence the moisture content. Highly wet subgrades deform more under loading. [11]

Shrinkage or swelling: Shrinkage or swelling largely depends on moisture content. Also in frost conditions (in northern climate) soils with excessive fine content may be susceptible to frost heave. Shrinkage, swelling and frost heave are the factors whose tendency is to deform and crack any pavement structure constructed over them. [11]

Table 2.1 Suitability of Soils for Subgrade Applications : [13]

Subgrade Soils for Design	Unified Soil Classifications	Load Support and Drainage Characteristics	Modulus of Subgrade Reaction (k), psi/inch	Resilient Modulus (MR), psi	CBR Range
Crushed Stone	GW, GP, and GU	Excellent support and drainage characteristics with no frost potential	220 to 250	Greater than 5,700	30 to 80
Gravel	GW, GP, and GU	Excellent support and drainage characteristics with very slight frost potential	200 to 220	4,500 to 5,700	30 to 80
Silty gravel	GW-GM, GP-GM, and GM	Good support and fair drainage, characteristics with moderate frost potential	150 to 200	4,000 to 5,700	20 to 60
Sand	SW, SP, GP-GM, and GM	Good support and excellent drainage characteristics with very slight frost potential	150 to 200	4,000 to 5,700	10 to 40
Silty sand	SM, non-plastic (NP), and >35% silt (minus #200)	Poor support and poor drainage with very high frost potential	100 to 150	2,700 to 4,000	5 to 30
Silty sand	SM, Plasticity Index (PI) <10, and <35 % silt	Poor support and fair to poor drainage with moderate to high frost potential	100 to 150	2,700 to 4,000	5 to 20
Silt	ML, >50% silt, liquid limit <40, and PI <10	Poor support and impervious drainage with very high frost value	50 to 100	1,000 to 2,700	1 to 15
Clay	CL, liquid limit >40 and PI >10	Very poor support and impervious drainage with high frost potential	50 to 100	1,000 to 2,700	1 to 15

Sub grade moisture conditions under impermeable road pavements can be classified into the following three main categories [12]:

I) Subgrade where the water table is sufficiently close to the ground surface to control subgrade moisture content. This type of subgrade soil governs the depth below the road surface at which a water table becomes the dominant influence on the subgrade moisture content. In non-plastic soils the water table dominates the subgrade moisture content when it rises to within 0.9m of the road surface, in sandy clay (Ip>20 percent) the water table dominates when it rises to within 3m of the road surface, and in heavy clays (Ip>40 percent) the water table dominates when it tries to within 7m of the road surface. In addition to areas where the water table is maintained by rainfall, this category includes coastal strips and floodplains where the water table is maintained by the sea, by lake or by a river.

II) Subgrade with deep water tables and where rainfall is sufficient to produce significant seasonal changes in moisture conditions under the road. These conditions occur where rainfall exceeds evapo transpiration for at least two months of the year. The rainfall in such areas is usually greater than 250 mm per year is often seasonal.

III) Subgrade in areas with no permanent water table near the ground surface and where the climate is arid throughout the year. Such areas have an annual rainfall of 250mm or less.

Considering road pavement virtually impermeable, moisture content of sub grade changes only with the change of ground water level. If permeable base and sub base materials are used rain water shed from the road surface can also penetrate to the sub grade and may saturate it. In these cases the strength of sub grade with moisture condition in category (I) and category (II) areas should be assessed on the basis of saturated CBR i.e. soaked CBR. Sub grade with moisture conditions in category (III) are unlikely to become saturated when covered by a permeable base and sub base and the sub grade moisture content; in such situations unsoaked CBR value can be taken for estimating the sub grade strength. [12]

2.3. Determining the Subgrade Strength

Having estimated the ultimate subgrade moisture content it is then possible to determine the appropriate design CBR value at the specified density for the subgrade [10]. During construction it is recommended that all sub grades should be compacted to a relative density of at least 95% of the MDD achieved in Standard /Modified Proctor Density test. Compaction not only improves the subgrade bearing strength but also reduces permeability and subsequent compaction by traffic. As a first step it is necessary to determine the compaction properties of the sub grade soil by carrying out a standard laboratory compaction test. Samples of the sub grade soil at the estimated subgrade moisture content can then be compacted in CBR molds to the specified density and penetrated to determine the design CBR value. This value is then used to determine the required pavement thickness from the design chart. CBR values and the quality of subgrades in pavement design are explained in the table 2.2 below.

Table 2.2 CBR range Subgrade quality [14]

Serial Number	CBR (%) Range	Subgrade Quality
1	0-3	Very poor subgrade
2	3-7	Poor to fair subgrade
3	7-20	Fair subgrade
4	20-50	Good subgrade
5	50+	Excellent subgrde

2.4 Types of fibers used as reinforcement

Fibers can be classified in two classes: Synthetic fiber and natural fiber. Some commonly used fibers are coconut fiber, Ensete ventricosum fiber, Sisal fiber, jute fiber, Cotton fiber, wool fiber, Asbestos fiber, metallic fiber and Glass fiber…etc. [15]

2.4.1 Synthetic Fibers

Different types of synthetic fiber are polypropylene, nylon, plastic, glass asbestos etc. Polyimide has inherent defect of getting affected by the ultraviolet rays from sun but as the fiber embedded they are not affected. Synthetic fibers also show a great biological resistance. Polypropylene fibers are prone to fire and sun light which practically cannot reach inside the soil. The important characteristics of polypropylene are; its versatility, excellent chemical resistance, low density, high melting point and moderate cost. These characteristics make it an important fiber in construction applications. So far as fiber structure of polypropylene is concerned, fibers are composed of crystalline and non- crystalline regions. Fiber spinning and rawing may cause the orientation of both crystalline and amorphous regions. The degree of crystallinity of polypropylene fiber is generally between 50-60%, depending on processing conditions. Crystallization occurs between glass transition temperature and equilibrium melting point. Polypropylene fibers are being used extensively throughout the USA and Canada in all types of concrete construction, and they have proven to be an effective method of controlling un-using and troublesome shrinkage cracking in concrete. Polypropylene fibers were tested in eight different media (distilled water, iron, bacteria culture, seawater and soil) for seventeen months. Results showed that there was no change in tensile strength. Plastic fibers show loss in strength with temperature. Nylon is comparable with polypropylene as for as strength, chemical innerness and durability is concerned. Steel fibers are prone to rust and acids. Glass fibers although costly but they can bear temperature up to 1500 ^{o}F. Asbestos, glass, carbon fiber has been found to be resistant to alkaloids and other chemicals attack. But long exposure to adverse environment, asbestos fibers has been found to lead to corrosion damage.[15]

2.4.2 Natural Fibers

The various types of natural fiber are: coir, sisal, jute, hemp, ensete ventricosum, bamboo and banana etc. In order to minimize the cost of ply soil, locally available fibers should be considered in design. But stability and life of structure should be given prime importance. Most of these fibers have been tested and found to lose their strength when subjected to alternate wetting and drying environment. In view of low strength and lack of durability, natural fibers are not in wide use for reinforcements but are preferred for erosion control due to their environment friendliness and biodegradability. However, some natural fibers like coir are strong and durable. They can be prepared sustainable with proper treatment for reinforcement function in cohesion less soils and also as filter fabric in cohesive soils. Coir fibers are even resistant to biodegradation over long period of time. It has been shown that breaking strengths of coir fiber after 15 years of storage in a hanger comes down from 176 MPa to 160 MPa and elongation from 29% to 21%. It shows that coir becomes slightly brittle with time but best among all natural fibers.[15]

2.4.2.1 Ensete ventricosum fiber

Ensete ventricosum plant (Fig2.1), commonly known as Ensete, belongs to the order Scitamineae, the family Musaceae, and the genus Ensete [16]. Morphologically it resembles a banana plant, but bananas belong to the related genus Musa. Genetically, ensete is diploid (with chromosome number n=9), while the species of Musa have different ploidy levels (with n = 10, 11 or 14). As a common feature, both Ensete and Musa have a large underground corm, a bundle of leaf sheaths (pseudo stem), and large paddle-shaped leaves. Although ensete is thicker and larger than banana (often reaching up to 3m in height and more than 1 m in diameter) both ensete and banana are herbaceous perennial monocarpic crops. They produce flowers only once at the end of their life cycle [18]. At the end of the life cycle of ensete(9-14 years), the true stem emerges through the leaf sheaths, and forms multiple flowers, fruits and seeds. In fact, the ensete plant is usually harvested before it reaches maturity (from 3 years depending on altitude and genotype), before or just at flowering, for the carbohydrate-rich false stem (pseudo stem) and underground corm. The fruits of ensete, unlike that of banana, are seldom edible and therefore ensete is often called false-banana [16]. Ensete plant grows in domestic as well as in wild forms. The cultivated ensete is mainly propagated vegetatively from suckers whereas most wild plants are produced from seeds, and the species appears to have an outcrossing reproductive system [16]. This plant occurs in sub-Saharan Africa and grows wild in many countries in Central and Eastern Africa including Ethiopia, Congo, Mozambique, Uganda, Tanzania and Zambia. In Ethiopia, wild ensete occurs in the highlands in the southwestern part whereas the cultivated ensete grows in a wider area comprising the central, southern and southwestern parts of Ethiopia. Ensete is presently the main crop of a sustainable indigenous African system, which ensures food security [16] and it is well known for its drought resistance. In Ethiopia alone, more than 20 percent of the total population, concentrated in the highlands of southern Ethiopia, depends upon ensete [16]. Ensete production and productivity have shown remarkable growth during the last two decades. It has revealed that the area under ensete production has increased from 270,000 hectares to 312,171.98 hectares and is taking up to about 2.30% land area covered by all crops at country level and yielding about 7,288,686.96 quintals of produce by the peasant holders, and contributing about 2.68% to the total country level crop production.[17]

Ensete ventricosum fiber is a plant fiber extracted from the pseudostem and leaf parts of the ensete plant. Decortication of the pseudostem (leaf sheaths) of Ensete ventricosum provides starchy pulp which along with the corm is processed and used as a food product, and a fiber as a byproduct. The extracted fibers are then sun dried and used, in rural areas, to make sacks, bags, ropes, cordage, mats, sieves and tying materials for construction (in place of nails). These fibers are very long, often cut to 1-2m during extraction but can be extended to 6m or more depending upon the height of pseudostem, the method of extraction and the intended end use. It is also strong and flexible enough to be used for many applications. Additionally, there is enormous potential to extract and utilize fibers from the leafstalk (midrib) and fallen-sheath parts of this plant which are commonly used for animal feed,compost,fuel(firewood)andlandfills.[19]

Fig2. 1 Ensete ventricosum plant [16]

Table 2.3 Physical and tensile properties of EV fibers [19]

Fiber property	Average	Std. Dev.
Diameter (μ)	127.87	36.32
Linea density (tex)	8.75	1.31
Tensile strength (MPa)	351.67	130.30
Elongation at break (%	3.16	0.66
Moisture content (MC)	12.15	0.016
Moisture regain (MR)	13.84	0.021

Table 2.4Comparison of chemical composition and tensile properties of EV fiber with other natural plant fibers [19-21]

Fiber	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Tensile strength (MPa)	Elongation (%)
Abaca	56-70.2	17.5-25	7-15.1	12-980	3-10
Bamboo	26-43	20.5-30	21-31	140-230	-
Banana	57.6-62.5	19-29.1	5-13.3	180-914	5.9
Coir	32-46	0.15-0.3	40-45	106-175	30
Cotton	82-96	2-6.3	0.5-1	300-700	7
Flax	71-75.2	8.6-20.6	2.2-4.8	345–1500	2.7-3.2
Hemp	68-81	2.0-22.4	3.5-10	690	1.6
Jute	61-71	14-20	12-13	393-773	1.5-1.8
Kenaf	53.5-72	21-20.3	9-17	930	1.6
Pineapple	80.5	17.5	8.3	1020	14.5
Ramie	68.6-76.2	13-16	< 0.7	560	2.5
Sisal	47.6-78	10-17	10-14	317.5	3-7
Enset	64.46	22.47	6.88	351.7	3.2

Table 2.5Mechanical properties of Ensete fiber under different temperature [22]

T (°C)	σ(MPa)	ΔL(mm)	E
-20	452 ± 54	0.62 ± 0.14	0.031 ± 682* 10-5
0	483 ± 68	0.44 ± 0.08	0.022 ± 418* 10-5
25	526 ± 63	0.50 ± 0.13	0.025 ± 650* 10-5
40	474 ± 90	0.42 ± 0.11	0.021± 525* 10-5
60	498 ± 85	0.54 ± 0.12	0.027 ± 621* 10-5
80	477 ± 105	0.66 ± 0.12	0.033 ± 594 *10-5
100	485 ± 68	0.52 ± 0.11	0.026 ± 572 *10-5
140	378 ± 64	0.40 ± 0.11	0.020 ± 540* 10-5
180	339 ± 75	0.66 ± 0.20	0.033 ± 1023 *10-5
220	252 ± 48	0.74 ± 0.13	0.037 ± 666* 10-5

Table 2.6 Mechanical properties of Ensete fiber under different moisture content [22]

Mc (%)	σ(MPa)	ΔL(mm)	E
10	492 ± 59	0.44 ± 0.07	0.022 ± 374* 10-5
20	525 ± 84	1.06 ± 0.16	0.053 ± 795* 10-5
40	540 ± 65	1.42 ± 0.23	0.071 ± 1 136* 10-5
60	590 ± 100	1.78 ± 0.39	0.089 ± 1 958* 10-5
80	497 ± 85	2.68 ± 0.38	0.134 ± 1 876* 10-5
90	468 ± 103	2.78 ± 0.67	0.139 ± 3 336* 10-5

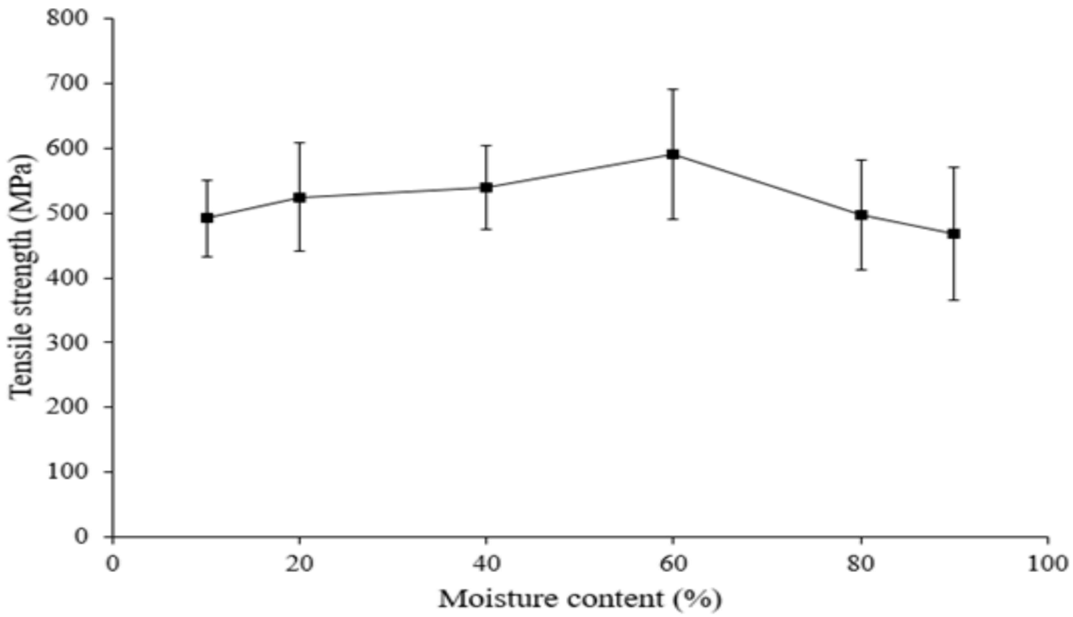

Fig 2.2Tensile strength of Ensete fibers under different moisture content[22]

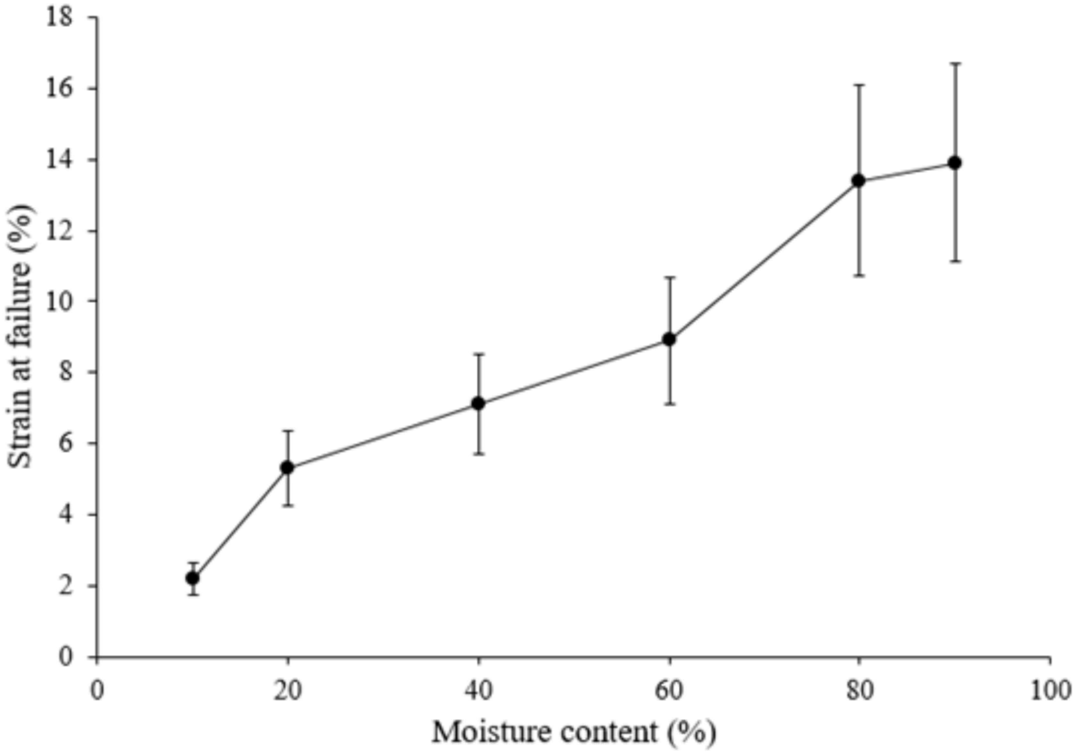

Fig 2.3 Strain at failure of Ensete fibers under different moisture content [22]

2.5 Advantages of Fiber-Reinforced Soil [15]

Randomly distributed fiber reinforced soil (RDFS) presents many advantages as listed below:

- ✓ Increased shear strength with maintenance of strength isotropy.
- ✓ Beneficial for all type of soils (i.e. sand, silt and clay).
- ✓ Reduce post peak strength loss.
- ✓ Increase ductility.
- ✓ Increase seismic performance.
- ✓ No catastrophic failure.
- ✓ Great potential to use natural or waste material such as coir fibers, shredded tire and recycled waste plastic strips and fibers.
- ✓ Provide erosion control and facilitate vegetation development.
- ✓ Reduce shrinkage and swell pressure of expansion soil.
- ✓ No appreciable change in permeability.
- ✓ Unlike lime, cement and other chemical stabilization methods, the construction using fiber reinforcement is not significantly affected by weather conditions.
- ✓ Fiber reinforcement has been reported to be helpful in eliminating the shallow failure on the slope face and thus reducing the cost of maintenance.

2.6 Different procedures of soil reinforcement

Reinforced soil is a set of theories, principles and application methods and it is one of the branches of geotechnical science to stabilize and improve soil engineering properties such as strength, hardness and deformability. Reinforced soils can be attained by either incorporating continuous reinforcement inclusions (e.g., sheet, strip or bar) within a soil mass in a defined pattern (i.e., systematically reinforced soils) or mixing discrete fibers varyingly within a soil fill (i.e., randomly reinforced soils). In systematically reinforced soil, the reinforcement in the form of sheets etc. is laid horizontally at specific intervals, whereas in RDFS, the fibers are mixed randomly in soil, thus making a homogeneous mass and maintain the isotropy in strength. In comparison with systematically reinforced soils, randomly distributed fibers reinforced soils exhibit some advantages that they can be easily prepared by simply adding the fibers much like cement, lime or other additives. Also the randomly distributed fibers offer strength isotropy and limit the potential planes of weakness that can develop parallel to oriented reinforcement. The main advantages of using natural fibers as reinforcing elements are they are locally available and are very cheap. They are biodegradable and hence do not create disposal problem in environment. Processing of these materials into a usable form is an employment generation activity in rural areas. [23]

The concept and principle of reinforcement of soil using fibers was pioneered by Vidal, who found that adding reinforcing elements in a soil mass increases the shear resistance. To date, nearly 4000 applications have been undertaken in more than 37 countries using the concept of soil reinforcement, after the invention by Vidal in 1969 [24]. Past research reflects an array of reinforcement materials ranging from low-modulus polymeric materials to high tensile strength metallic sheets, which were used as geosynthetics to enable the fiber-reinforcement of soil [25]. These usual synthetic fibers were mostly the by-products of petroleum which is a non-renewable limited resource of the earth. Geosynthetic products have gained popularity due to their flexibility during processing, high specific stiffness and low cost [26]. Universal capacity of such plastic composites exhibit a huge increase from 0.36 million metric tons in 2007 to 2.33 million metric tons by 2013 and is expected to increase to 3.45 million metric tons by 2020 [1]. In addition, incorporating steel bars as soil reinforcement has been reported as a non-ecofriendly approach due to detrimental impacts to the environment at the end of its useful life as the corroded steel is very toxic to the environment [27]. Recently, natural fiber-soil reinforcement has gained momentum as one of the evolving sustainable soil strengthening techniques in geotechnical engineering due to its unique advantages such as environmental friendliness, resource abundance, minimum energy consumption, cost effectiveness and high potential over other established materials [28]. The rewards of these options are illustrated in Table 1.1 by comparing the energy content and cost between conventional synthetic materials and natural fibers [28].

Table 2. 7 Comparison of specific properties and cost of conventional synthetic fiber and natural plant fiber materials[28]

Fiber Material		Cost (USD/Ton)	Energy Content (GJ/Ton)
Carbon Fiber	Conventional synthetic Fibers	12,500	130
Kevlar Fiber		75,000	25
Glass Fiber		1200–1800	30
Plant Fiber	Sustainable Alternation	200–1000	4

Several reinforcement methods are available for stabilizing problematic soils. Therefore, the techniques of soil reinforcement can be classified into a number of categories with different points of view.

The up–down arrows in this figure illustrate some unconventional methods of soil reinforcement achieved by the combination of randomly distributed fiber with chemical admixtures such as cement, lime and/or chemical resins. [15]

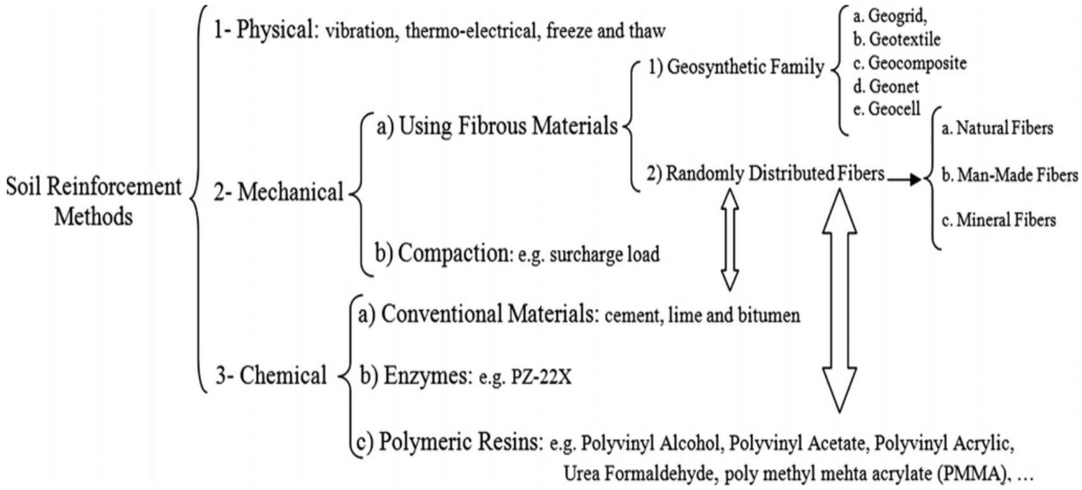

Fig 2.4 procedures of soil reinforcement [15]

2.7 Engineering properties of fiber reinforced soils

Limited studies reported on unconfined compression tests, CBR tests, tensile strength tests and flexural strength tests reveal that unconfined compressive strength, CBR values and tensile strength of silty/clayey soils increase due to addition of discrete fibers. The addition of fibers to soil offers resistance to compaction in case of synthetic fibers, causing a decrease in maximum dry density. However, natural coir fiber reinforced soils do not exhibit any reduction in maximum dry density. A very limited laboratory-field model test results reported in the literature indicate that in general, the strength of sands, in terms of either ultimate bearing capacity or c and φ values, increases due to fiber inclusion. [29] Reported the results of laboratory compression and CBR tests on a sandy gravel reinforced with very small amounts (less than 2% by weight) of random fibers. Compaction tests showed that the fibers increased the resistance to densification. When a constant compactive effort was applied to a range of samples with increasing fiber content, the strength either increased hardly at all or actually decreased. This was caused by the related increase in porosity or void ratio, which would tend to negate any increase in strength from fiber reinforcement. Triaxial compression tests were run on dry sand reinforced with randomly distributed, discrete fiber sand oriented continuous fabric layers by [30]. Test results showed that both types of reinforcement systems increased strength and modified the stress-deformation behavior of sand in a significant manner. The following main conclusions emerged from the study of [30] and are given as

1. Continuous, oriented fabric inclusions markedly increased the ultimate strength, increased the axial strain at failure, and in most cases limited reductions in post-peak loss of strength.
2. At very low strains less than 1% fabric inclusions produced a loss in compressive stiffness of triaxial specimens. The loss in stiffness was more pronounced when the number of layers or the tensile modulus of the fabric was greater.
3. Fabric reinforcements placed at spacing/diameter ratios greater than one had little effect on strength.
4. Discrete, randomly distributed fiber increased both the ultimate strength and the stiffness of reinforced sand. The decrease in stiffness at low strains, observed with fabric inclusions, did not occur with the fiber. The increase in strength with fiber content varied linearly up to a fiber content of 2 % by weight, and thereafter approached an asymptotic upper limit. The rate of increase was roughly proportional to the fiber aspect ratio.

6. At the same aspect ratio, confining stress, and weight fraction, rougher (not stiffer) fiber tended to be more effective in increasing strength.

The presence of reinforcement changes the stress filed giving a restraint typically in the form of friction or adhesion so that less strains are induced and tension is avoided. Inclusions like discrete shot fibers placed random or in different layers will also impart additional resistance by way of cohesion and friction.[31]

The use of reinforcement in improving the strength parameters of geo-materials has taken momentum due to the availability of variety of synthetic materials commercially at cheaper rates. The essential principles involved in soil reinforcement techniques are simple and have been used by mankind for centuries. One of the necessary characteristics of reinforced soil is that it is made with two types of elements, soil grains and reinforcements. The fundamental mechanism of reinforced soil involves the generation of frictional forces between the soil and reinforcement. By way of friction the soil transfers the forces developed in earth mass to the reinforcement thus developing tension. The soil develops pseudo cohesion in the direction in which reinforcement is placed and the cohesion is proportional to tension developed in reinforcement[32]. [23] Studied on Strength and Durability Study on Banana Fiber Reinforced Lime Stabilized Kuttanad Soil concluded that the unconfined compressive strength of soil reinforced with 0.5% untreated and rubber coated fibers of random length shows an increase of 1.59 and 1.86 times respectively with respect to that of unreinforced soil. [15] Used the Jute Geotextile sheets to improve the laboratory CBR value of fly ash. Based on the experimental results they found that stress-strain behavior of soil is improved by inclusion of coir-fiber into the soil and Jute Geotextile sheets improves the California Bearing Ratio (CBR) value of fly ash significantly. They also concluded that the deviator stress at failure is increased up to 3.5 times over the plain soil. They further observed that stiffness modulus of reinforced soil increases considerably which can reduce the immediate settlement of soil significantly. [31] Conducted studies on clayey silty soil, silty sand, clay sandy soil using barley straw as reinforcement. The barley straw fibers were added in length of 1 cm , 2 cm, 4 cm and 6 cm and they were added at different percentages of 1, 1.5, 2, 2.5, 3 and 3.5. It was observed that the compressive strength increased up to 1.5 % after which it was shown to decrease. The effect of reinforcement was more pronounced in clayey soil. [32] Conducted studies on silty sand using palm fibers as reinforcement. The palm fibers were added in length of 2cm and 4 cm and they were added at different percentages of .25, .5, .75, 1, 1.5, 2 and 2.5. It was observed that the CBR value increased as the percentage and length of reinforcement increased. [6] Studied on soil reinforced with jute fiber for improvement of CBR. In their study, soil samples were prepared at its optimum moisture content in CBR mold with and without reinforcement. Jute fiber added by content of 0.25%, 0.5%,0.75% and 1% and length of 30mm,60mm and 90mm and also by diameter of 1mm and 2mm. They concluded that CBR value of soil increases with increase in fiber content. And also they observed that increasing the length and diameter of fiber further increases the CBR value of reinforced soil and this increases is substantial at fiber content of 1% for 90mm fiber length having diameter of 2mm. [33] Studied on effect of Natural coir fibers on CBR strength of soil subgrade and used coir fibers of varying length from 0.5 to 3cm and varying percentage from 2 to 8% of total weight of soil. He conducted CBR test and concluded that CBR strength using coir reinforcement was improved and optimum fiber content and length obtained are 5% and 1.5cm respectively. [22] Studied on effects of marine clay stabilized with banana fiber. They concluded that addition of banana fiber improved the properties of marine clay. The optimum value for marine clay stabilized with banana fiber was obtained at 0.75%.It was seen that OMC value increased with the addition of banana fiber and dry density decrease. The shear strength increased from 8.5KN/m^2 to 32.91KN/m^2 with the addition of 0.75% of banana fiber and CBR value increased from 2.79 -13.2% which makes it suitable for subgrade soil for road pavements.

Chapter Three

Methodology

3.1 Study Area

The study was conducted in Jimma town, southwestern part of Ethiopia which is located 335km from Addis Ababa. Its geographical coordinates are between 7° 13'- 8° 56N latitude and 35°49'-38°38'E longitude with an estimated area of 19,506.24 ha. The town is found in an area of average altitude, of about 5400 ft. (1780 m) above sea level. It lies in the climatic zone locally known as WoynāDegā which is considered ideal for agriculture as well as human settlement. It is mostly covered with black, gray and red colored plastic clay soils.

Fig 3.1Study area

Source: Map data Imagery, CNES / Airbus, DigitalGlobe, Landsat/ Copernicus at June 12, 2019 at 10:00 am.

3.2Study design

To meet the objectives of this study, the study design are divided into 4 main stages.

1. Organizing literature review of related materials

2. Sampling and data collection

3. Laboratory tests and analyzing the results from tests.

4. Conclusion and recommendation based on result obtained.

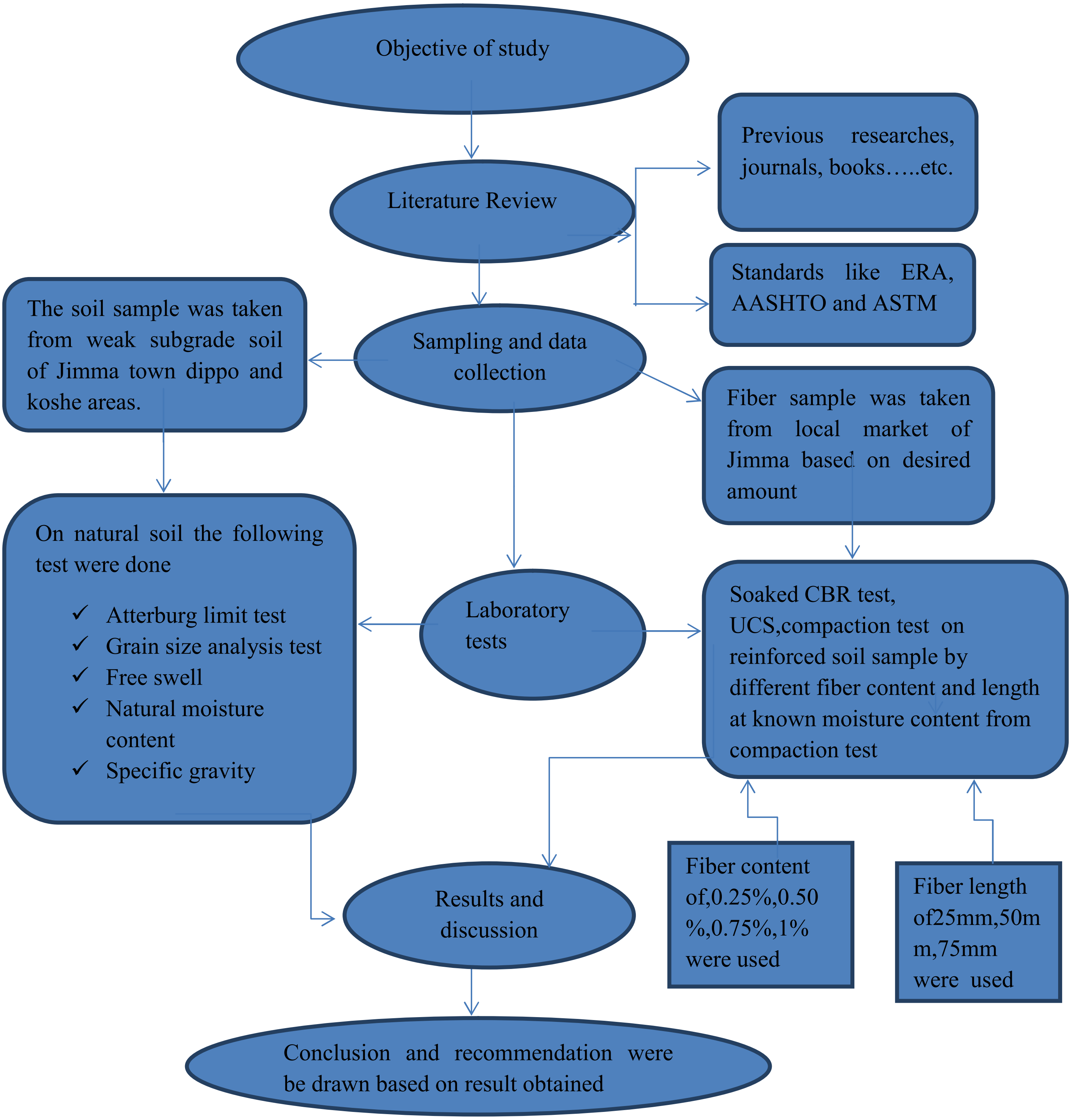

Fig 3.2 Study design flow chart

3.3 Study variables

3.3.1. Dependent Variable

The dependent variable is;

- ✓ Improved engineering properties of subgrade soil

3.3.2. Independent Variables

The independent variables are: -

- ✓ Ensete ventricosum fiber content
- ✓ Ensete ventricosum fiber length
- ✓ Engineering properties of soil
- ✓ Moisture content

3.4 Data Sources

Data were composed from both primary and secondary sources. Primary data were obtained by laboratory tests. Secondary data are literature, related materials, journals…etc.

3.5 Sampling Technique and Sample size

The samples were collected by following purposive sampling technique. Two test pits were taken depending upon the value of their CBR tests which has value of less than three. This disturbed sample was collected at desired amount at adequate depth from subgrade level to avoid the inclusion of organic matter. Ensete ventricosum fiber sample were collected based on desired content from local market of Jimma zone Shebe.

3.6 Laboratory Tests

3.6.1Natural Moisture content

Natural moisture content test was conducted for natural subgrade soil according to the standard test procedure of AASHTO T265.

3.6.2 Free Swell Test

The method was suggested to measure the expansive potential of cohesive soils. The free swell test gives a fair approximation of the degree of the expansiveness of the soil sample. The procedure consists of pouring very slowly of 10 cubic centimeters of that part of the dry soil passing No. 40 sieve into a 100 cubic centimeters graduated measuring cylinder and letting the content stand for approximately 24 hours until all the soil ultimately settles on the bottom of the graduating cylinder. Then the final volume of the soil is noted. [36]

Finally, the free swell value is calculated using Equation (3.1).

Free swell (%) = $\frac{Vf-Vi}{Vi}$x100…….equation 3.1

Where vi= initial reading and vf= final reading after 24 hours

Fig 3. 3 Recording of free swell test result

3.6.3 California Bearing Ratio (CBR)

The CBR test taken in this research is socked CBR test. CBR tests are usually made on test specimens at the optimum moisture value for the soil as determined by AASHTO T193.

Fig 3. 4 Mixing of fiber and soil sample for CBR test (sep17,2018)

3.6.4 Textural classification

In general, texture of soil refers to its surface appearance. Soil texture is affected by the size of the individual particles present in it. Natural soils are combinations of particles from several size groups. In the textural classification system, the soils are named after their principal components, such as sandy, clay, silty clay, and so forth [37].

3.6.4.1 Wet sieve analysis

Wet sieve analysis test was carried for natural soil sample, and the test is conducted by the following procedure of Test Method- ASTM D 422

Fig 3. 5Washing of soil sample for wet sieve analysis test(sep 18,2018)

3.6.5 Atterburg Limit

When clay minerals are there in fine-grained soil, the soil can be remolded in the presence of some moisture without crumbling. This cohesive character is caused by the adsorbed water surrounding the clay particles. In the early 1900s, a Swedish scientist Atterburg developed a method to describe the consistency of fine-grained soils with varying moisture contents.

At very low moisture content, soil act as more like a solid. When the moisture content is extremely high, the soil and water may flow like a liquid. Hence, depending on the moisture content, the behavior of soil can be divided into four basic states solid, semisolid, plastic and liquid. The moisture content, in percent, at which the transition from solid to semisolid state takes place, is defined as the shrinkage limit. The moisture content at the position of transition from semisolid to plastic state is the plastic limit, and from plastic to liquid state is the liquid limit. These parameters are also known as Atterburg limits.
This limit describes the plasticity and consistency of fine grained soils with varying degrees of water content. For the portion of soil passing 425mm (no 40) sieve, the moisture content is

varied to determine the three stages of soil behavior in terms of consistency. These stages are generally known as liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) of soils.[22]

3.6.5.1 Liquid Limit

The liquid limit (LL) is the water content, expressed in percent, at which the soil changes from a liquid state to a plastic state and principally it is defined as the water content at which the soil pat cut using standard groove closes for about a distance of 13mm at 25 blows of the liquid limit machine (Casagrande Apparatus). The liquid limit of a soil greatly depends upon the clay mineral present. The conventional liquid limit test is carried out in accordance of test procedures of AASHTO T 89-96 . A soil has high water content is in liquid state and it offers no shearing resistance.

Fig 3. 6 Grooving of samples for LL test(sep 25,2018)

3.6.5.2 Plastic Limit

The moisture at which soil has the smallest plasticity is known as the plastic limit. Which the soil stops behaving as a plastic material just after plastic limit the soil displays the properties of a semi-solid. For determination purpose, the plastic limit is defined as the water content at which soil will just begin to crumble when rolled into a thread of 3mm in diameter.
Test is conducted by the following procedure of AASHTO T90-96 Test Method.

Fig 3. 7 PL test(sep 25,2018)

3.6.5.3 Plastic Index

The amount of water which must be added to change a soil from its plastic limit to liquid limit is an indication of the plasticity of the soil. The degree of plasticity is measured by the plasticity index (PI), which is the numerical difference between liquid limit and plastic limit (PI=LL–PL). The greater the plasticity index means that the soil is more plastic, compressible and the greater volume change characteristic of the soil.

3.6.6 Moisture Density Relationship (Compaction Test)

It is the process of densification of soils. Compaction is the use of mechanical energy to a soil so as to rearrange its particles. It is applied to improve the engineering properties. That means it increases the shear strength of the soil and hence, the bearing capacity. It increases the stiffness and thus, reduces future settlement, void ratio and permeability of an existing soil or in the process of placing fill such as in the construction of embankments, road bases, earth dams and reinforced earth walls. Compaction is also used to prepare a level surface during construction of buildings. [38] The test was carried for natural and reinforced soil; the test is conducted by AASHTO T99-95 testing procedures.

The values of the dry densities as gained from equation above are plotted against their respective moisture contents and the dry densities; MDD is deduced as the maximum point on the resulting curves, and the corresponding value of moisture contents at maximum dry densities from the graph of dry density against moisture content gives optimum moisture content

Fig 3. 8 compacting of sample(sep 26,2018)

Fig 3. 9 extruding of samples (sep 26,2018)

3.6.7 Unconfined compression test

Unconfined compression test is a simple laboratory testing method to assess the mechanical properties of soils. It provides a measures of the undrained strength and the stress-strain characteristics of the soil. The unconfined compression test is regularly included in the laboratory testing program of geotechnical investigations. Unconfined compression test is popular method of soil shear testing. Since it is one of the fastest and cheapest methods of measuring shear strength. The specimens were prepared based on the maximum dry unit weight and optimum water content.[39] The test was carried out by AASHTO T208-92.

3.6.8 Specific gravity

In general, the term specific gravity is defined as the ratio of the mass of a given volume of a material to the mass of an equal volume of water. In effect, it tells us how much the material is heavier than (or lighter) than water. The particular specific gravity of a soil actually denotes the specific gravity of the solid matter of the soil and refers to the ratio of the mass of solid matter of a given soil sample to the mass of an equal volume i.e. equal to the volume of the solid matter) of water. Specific gravity test was carried for natural soil sample; the test is conducted by Test method- ASTM D 854-83 testing procedure.

Chapter Four

Results and Discussion

4.1. Introduction

This chapter presents; the result of laboratory tests on natural soil sample as well as stabilized soil sample and discussion to the result of the laboratory tests. Laboratory tests are included natural moisture content, specific gravity, Atterberg's limit tests(liquid limit, plastic limit, and plastic index), free swell and wet sieve analysis on natural soil sample and California bearing ratio(CBR), standard Proctor(compaction) test and unconfined compressive strength(UCS) on reinforced sample.

4.2 Properties of Material Used in the Study

4.2.1 Natural soil

The results of the tests conducted for determination of properties of the natural soil sample are shown. The soil sample used in this study were identified and taken from two pits, koshe and dippo samples.

Table 4. 1 Free swell

Sample	Initial volume	Final volume	Free swell index
Koshe	10	14.6	46%
Dippo	10	16.3	63%

Table 4. 2 Grain size analysis dippo sample

Location	sieve no.	Opening	mass retained	%retained	cumulative % retained	% passing
Dippo	4	4.75	1.21	0.121	0.121	99.879
	10	2	7.43	0.743	0.864	99.136
	20	0.85	9.25	0.925	1.789	98.211
	40	0.425	13.62	1.362	3.151	96.849
	60	0.25	8.14	0.814	3.965	96.035
	100	0.15	5.02	0.502	4.467	95.533
	200	0.075	4.62	0.462	4.929	95.071

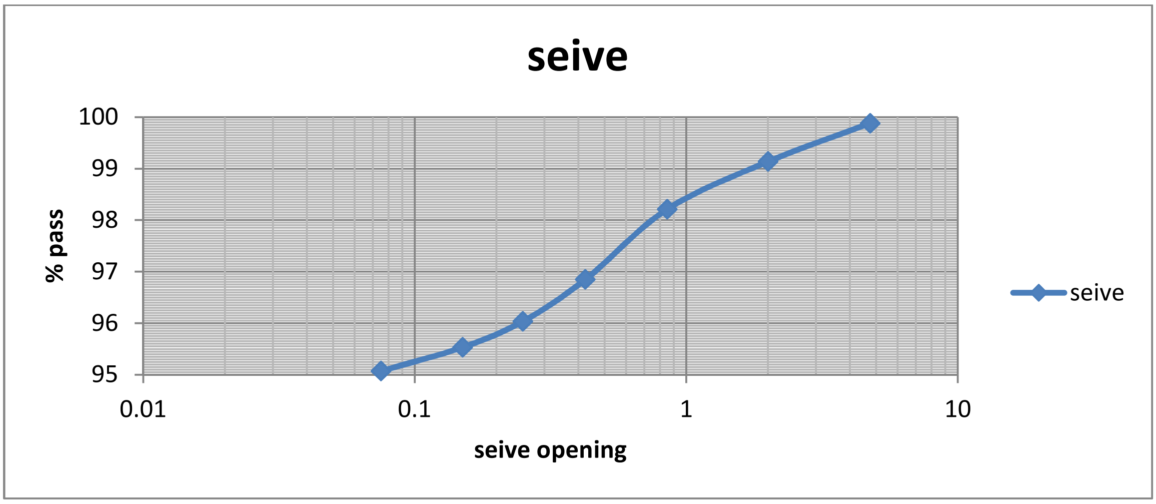

Fig 4. 1Grain size analysis, dippo sample

Table 4. 3 Grain size analysis, koshe sample

location	sieve no.	Opening	mass retained	%retained	cumulative % retained	% passing
koshe	4	4.75	0.84	0.084	0.084	99.916
	10	2	3.96	0.396	0.48	99.52
	20	0.85	8.82	0.882	1.362	98.638
	40	0.425	11.58	1.158	2.52	97.48
	60	0.25	14.63	1.463	3.983	96.017
	100	0.15	17.53	1.753	5.736	94.264
	200	0.075	10.97	1.097	6.833	93.167

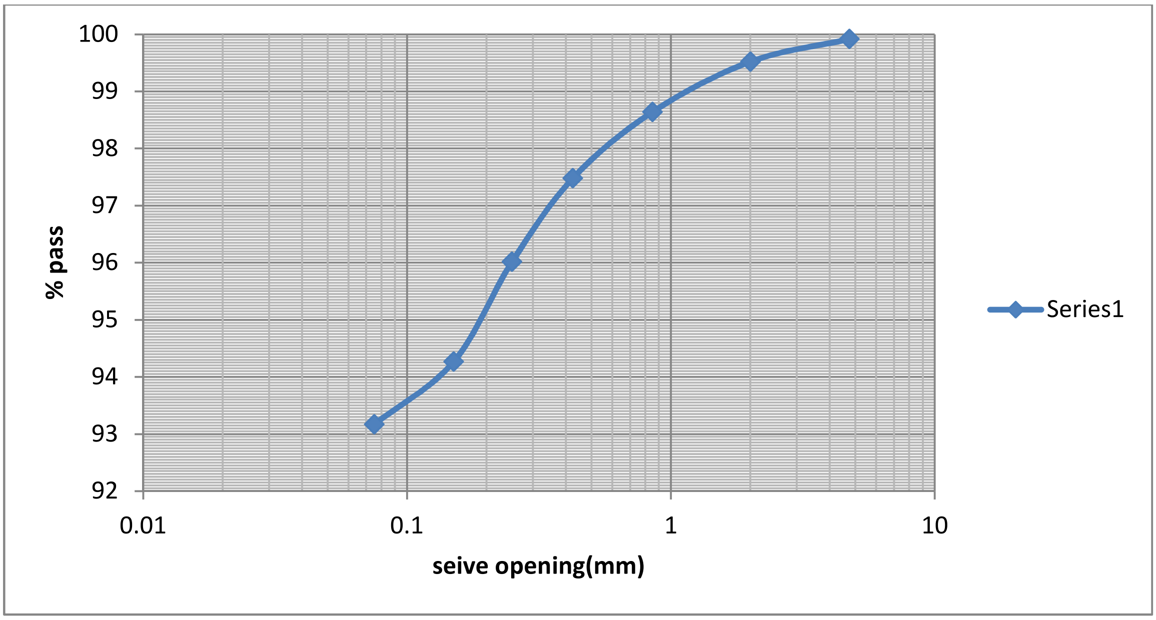

Fig 4. 2 Grain size analysis, dippo sample

Table 4. 4 Specific gravity of koshe sample

Location	Weights	determination number		
Koshe		1	2	3
	weight of bottle	15.69	18.58	16.54
	bottle + dry soil	25.45	32.54	28.35
	bottle + dry soil+water	46.62	49.9	48.03
	bottle+water	40.16	41.74	40.89
	dry soil	9.76	13.96	10.98
	temperature of water	24	24	24
	density of water	0.99732	0.99732	0.99732
	Temprature of soil.	25	25	25
	density of water	0.99731	0.99731	0.99731
	corrected mass of water	40.15975464	41.73976778	40.88975585
	correction factor	0.9991	0.9991	0.9991
	v.of water equal to soil	3.299754642	5.799767778	3.839755846
	specific gravity	2.96	2.41	2.86
	av.specific gravity	2.74		

Table 4. 5 Specific gravity of dippo sample

Location	Weights	determination number		
Dippo		1	2	3
	weight of bottle	25.65	28.5	26.36
	bottle + dry soil	36.54	39.06	36.46
	bottle + dry soil+water	87.54	83.93	85.28
	bottle+water	80.74	77.39	78.8
	dry soil	10.89	10.56	10.1
	temperature of water	24	24	24
	density of water	0.99732	0.99732	0.99732
	Temprature of soil	25	25	25
	density of water	0.99707	0.99707	0.99707
	corrected mass of water	80.71976076	77.3706	78.78025
	correction factor	0.9991	0.9991	0.9991
	v. of water equal to soil	4.069760759	4.000601	3.600247
	specific gravity	2.68	2.64	2.81
	av.specific gravity	2.71		

Table 4. 6 Natural moisture content

location	weight of can	can+ wet soil	can+ dry soil	weight of water	weight of soil	moisture content	average moisture
Koshe	15.4	32.6	22.1	10.5	6.7	47.51	46.09%
	16.9	35.3	24.4	10.9	7.5	44.67	
Dippo	17.5	68.7	51.4	17.3	33.9	33.66	41.99%
	16.5	71.4	47.5	23.9	31	50.32	

Table 4. 7 Atterburg limit test of dippo sample

		liquid limit			plastic limit	
dippo	Trial	1	2	3	1	2
	number of blows	33	26	20		
	can no.	G8	C16	J1	A4	G2
	weight of can	15.41	16.45	17.88	4.93	6.54
	weight of can+ soil	32.06	26.13	29.92	11.93	12.56
	weight of can+ dry soil	25.01	21.85	24.32	10.13	10.98
	weight of water	7.05	4.28	5.6	1.8	1.58
	weight of dry soil	9.6	5.4	6.44	5.195	4.442
	water content	73.44	79.26	86.96	34.65	35.57
	LL	80.5			PL=35.11	

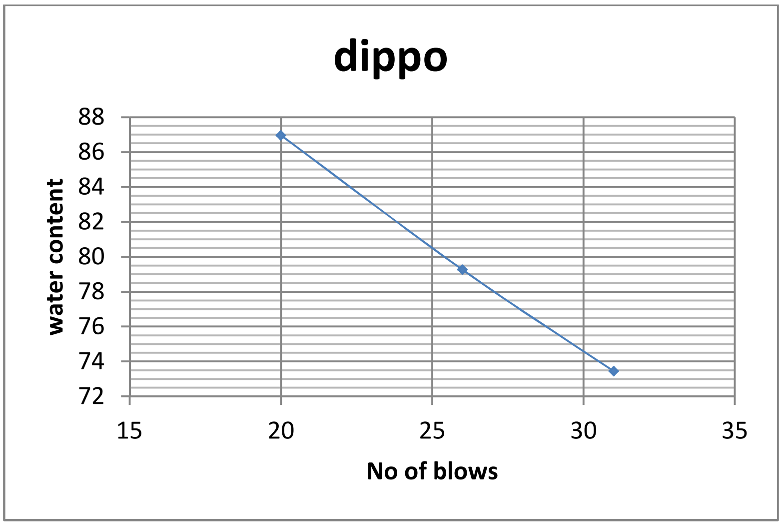

Fig 4. 3 liquid limit test of dippo sample

Table 4. 8 Atterburg test of koshe sample

		liquid limit			plastic limit	
	Trial	1	2	3	1	2
	number of blows	34	27	18		
	can no.	L4	N2	K5	C	M
	weight of can	14.69	15.4	16.34	5.71	5.344
koshe	weight of can+ soil	34.65	30.02	32.52	12.25	11.5
	weight of can+ dry soil	25.98	23.45	24.99	10.49	9.89
	weight of water	8.67	6.57	7.53	1.76	1.61
	weight of dry soil	11.29	8.05	8.65	4.78	4.546
	water content	76.79	81.61	87.05	36.82	35.41
	LL	82.9			PL=36.11	

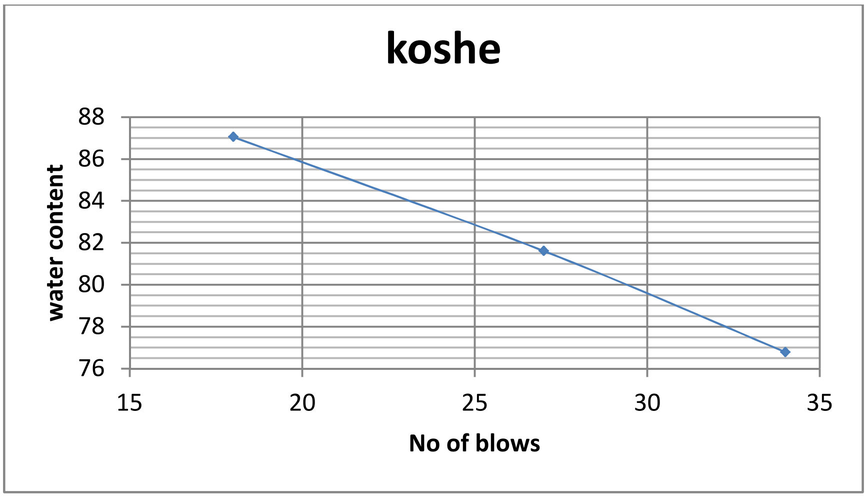

Fig 4. 4 Atterburg limit test of koshe sample

From sieve analysis tests, percentage of passing through sieve No. 200 (0.075mm sieve size) of koshe and dippo is 93.16% and 95.07 % respectively. While from the Atterberg's limit test results, the soil sample contains a liquid limit of 82.9and 80.5%, a plastic limit of 36.1% and 35.11%, and plasticity index of 46.8% and 45.39%,koshe and dippo samples respectively. This result showed that fine grained soil of high plastic clay which is under requirement subgrade soil.

Table 4.9 Summary of Laboratory results of samples

Sample	Dippo	Koshe
Percentage passing through no.200	95.07%	93.16%
Liquid limit	80.5	82.9
Plastic limit	35.11	36.1
Plastic index	46.8	45.39
AASHTO classification	A-7-5	A-7-5
Specific gravity	2.71	2.74
Free swell	46%	63%
Natural moisture content	41.99%	46.09%
Maximum dry density, g/cm^3	1.47	1.36
Optimum moisture content	20.21/%	30.16%
CBR value	2.08	1.6
UCS, Kn/m^2	81	63

AASHTO soil classification system are classify soil based on; percentage of passing through sieve no 200, liquid limit and plasticity index. According to this classification system both soil samples falls under the A-7-5 soil.

USCS are classifying soil based on liquid limit and plasticity index, according to USCS, natural soil sample lies under CH (high plasticity clay soil).

ERA manual classify subgrade soil based on CBR values, according to ERA subgrade soil classification , a material with CBR value less than three are challenging to work and subgrade would lead to uneconomical pavement structures, it is recommended to cover with selected material or treating it with other stabilizing material. This sample soil which is initially fall under S1 which is not recommended to use as subgrade materials was shifted to S3 after stabilization, which can be used for the designing of flexible pavement for light and medium traffic.

4.2.2 Ensete Ventricosum Fiber

The required Ensete ventricosum fiber collected from local market from study area and dried under room temperature at the same time with clay soil. It is minimum 1m and maximum of 2m long as shown in Figure 4.5. In order to mix it with soil, the fiber was chopped in 25mm, 50mm and 75mm long. The chopped fiber weighted according to mass ratio of the soil and ranges from 0.25 - 1%. The following physical and tensile properties were taken from previous study on Bonga. Since Bonga and Shebe are nearest areas, property of ensete ventricosum should be same.

Fig 4.5 Ensete ventricosum fiber(sep 15,2018)

4.3 Effect of Reinforcement on Compaction

Compaction tests were carried out on different proportions of fiber and soil to study their moisture density relationship.

Fig 4.6 and Fig 4.7 shows the variation in maximum dry density (MDD) and corresponding optimum moisture content (OMC) for different percentages of fiber. It can be observed from both samples that the dry density is constantly decreasing by the addition of fiber .MDD decreases from 1.35 to 1.28 g/cm^3 for koshe sample and from 1.47 to 1.39 g/cm^{3}for dippo sample. Again OMC increases from 30.16 to 36.65% for koshe sample and from 20.21 to 27.05% for dippo sample. This is because of the addition of fiber having low density in place of soil having comparatively high density. It may be attributed to the replacement of soil with fiber of low specific gravity and high water absorption capacity. More percentage of fiber reduced dry density. When fiber is added to the soil in the presence of water, the fiber particles expand due to the absorption of water and fill the voids of soil thus contributing to the dry density. When higher contents of fiber is added, the amount of water absorbed by the fiber in the mixing stage may get expelled under the compactive effort thus contributing to the increase in OMC at higher fiber content.

Table 4.10 MDD and OMC value of reinforced koshe sample

Koshe		
Fiber content	OMC(%)	MDD(g/cm3)
0%	30.16	1.35
0.25%	33.44	1.33
0.50%	34.24	1.30
0.75%	35.33	1.29
1%	36.65	1.28

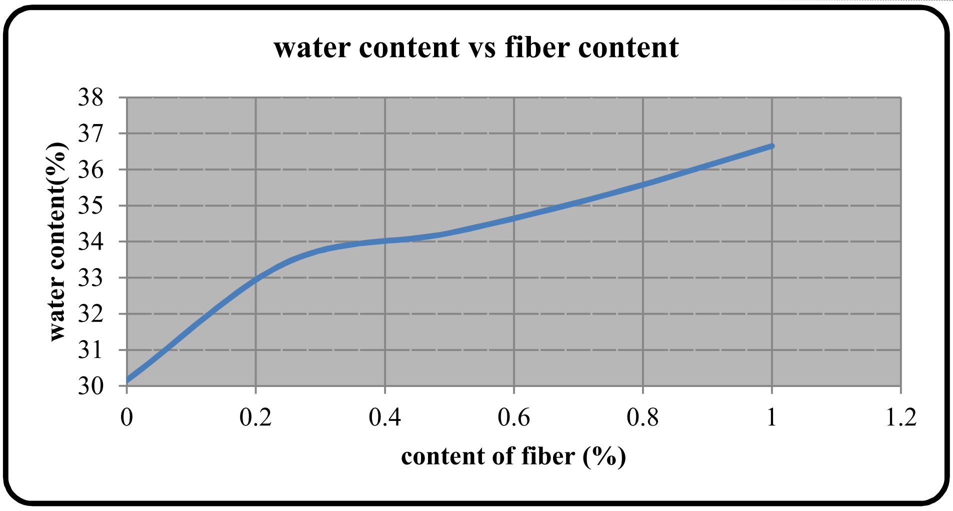

Fig 4.6 Water content vs fiber content of koshe sample

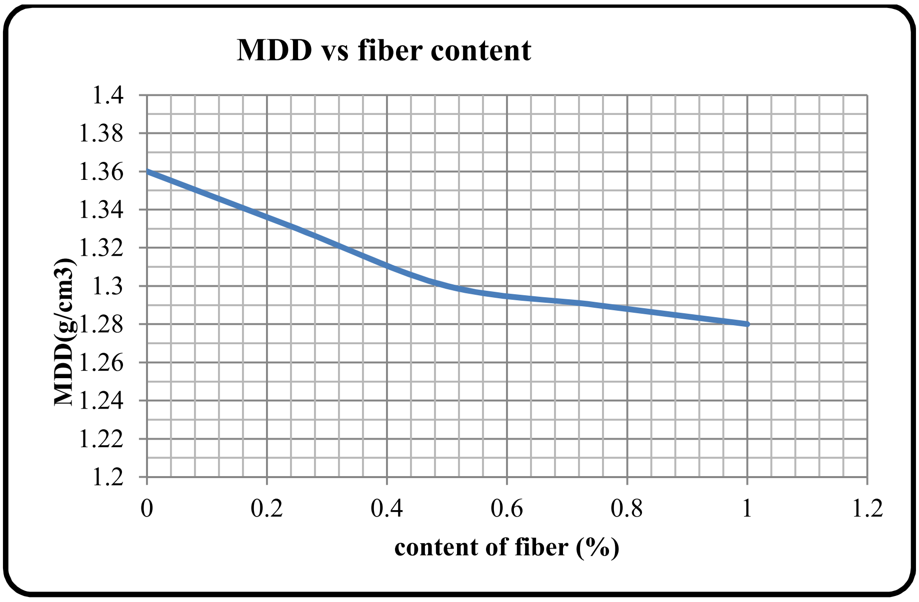

Fig 4.7 MDD vs fiber content of koshe sample

Table 4.11 MDD and OMC value of reinforced dippo sample

Dippo		
Fiber content	OMC(%)	MDD(g/cm3)
0%	20.21	1.47
0.25%	22.02	1.46
0.50%	22.29	1.45
0.75%	24.28	1.40
1%	27.05	1.39

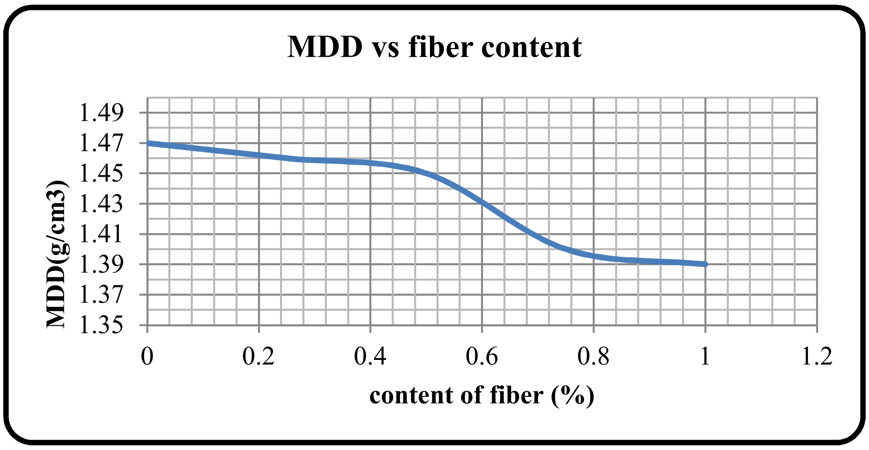

Fig 4.8 Water content vs fiber content of dippo sample

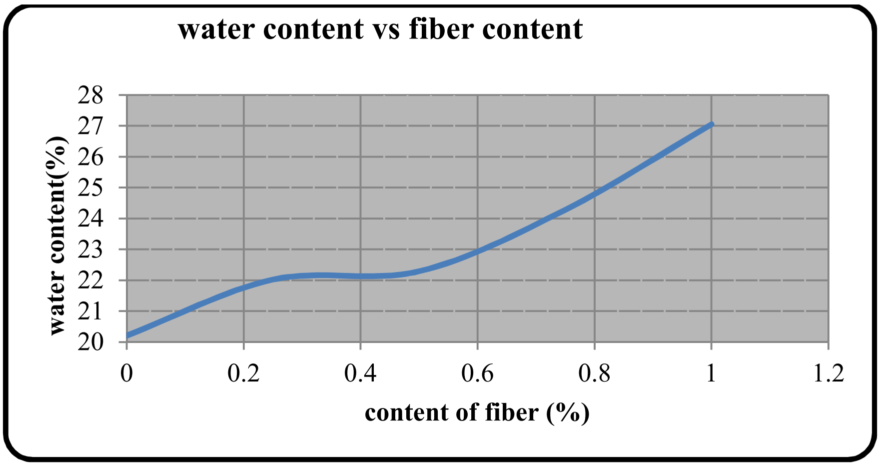

Fig 4.9 MDD vs fiber content of dippo sample

4.4 Effect of Reinforcement on CBR

The California bearing ratio test (CBR) were carried out on soil mixed with different proportion and length fiber by compacting the mixture to maximum dry density and optimum moisture content corresponding to Standard Proctor test. The specimens were soaked in water for 96 hours and tested to evaluate the strength in the worst subgrade conditions. Variations in CBR value for the addition of fiber are shown in Table 4.13and 4.14.

It can be observed that with the increase in fiber content, CBR value is increasing and reaches a maximum value of 5.47 at 0.75% and 6.22 at 0.75% fiber addition for 75 mm length and then decreases for koshe and dippo samples respectively. Hence 0.75% fiber content can be taken as the optimum ensete ventricosum fiber content for both samples. Even though the maximum dry density decreases with addition of fiber, CBR is found to be increasing. This is due to reason that randomly oriented discrete inclusions incorporated into soil mass improves its load deformation behavior by interacting with the soil particles mechanically through surface friction and also by interlocking. Also it is observed that length of fiber increases, CBR value also increases. This is attributed to the fact that for shorter fibers, the area in contact with soil is comparatively less and hence there is a less improvement in strength and stiffness of soil.

According to ERA subgrade classification, both samples improved from S1 class to S3. This shows that the thickness of pavement is reduced and also cost of project is reduced.

Table 4.12 CBR value of koshe sample

Koshe			
Fiber content	Length of fiber		
	25mm	50mm	75mm
0%	1.60		
0.25%	2.40	2.55	3.15
0.50%	2.85	2.92	4.05
0.75%	3.52	4.12	5.47
1%	3.30	3.60	4.42

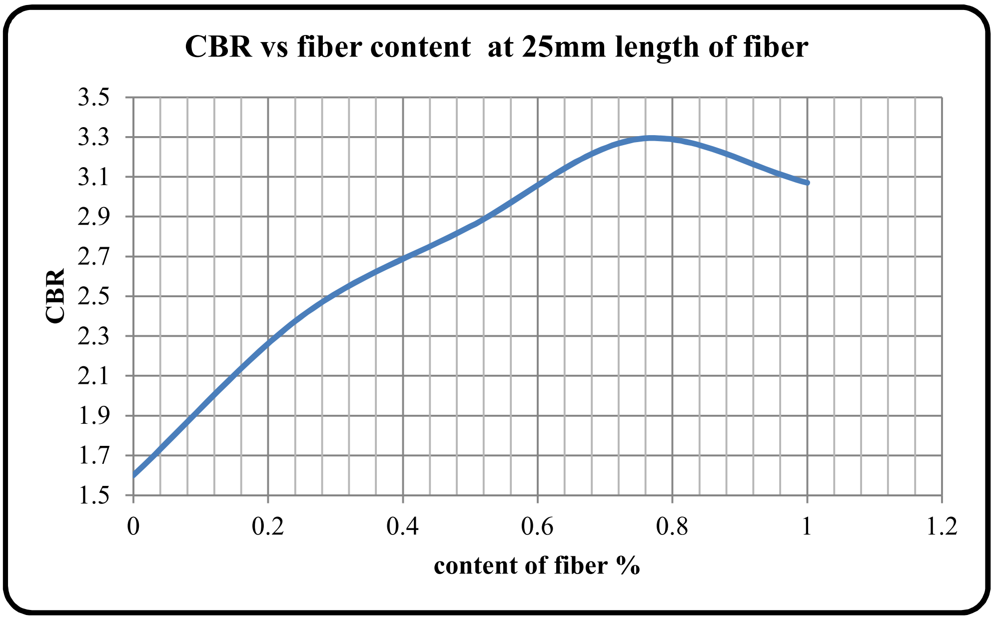

Fig 4.10CBR vs fiber content at 25mm length of fiber,koshe sample

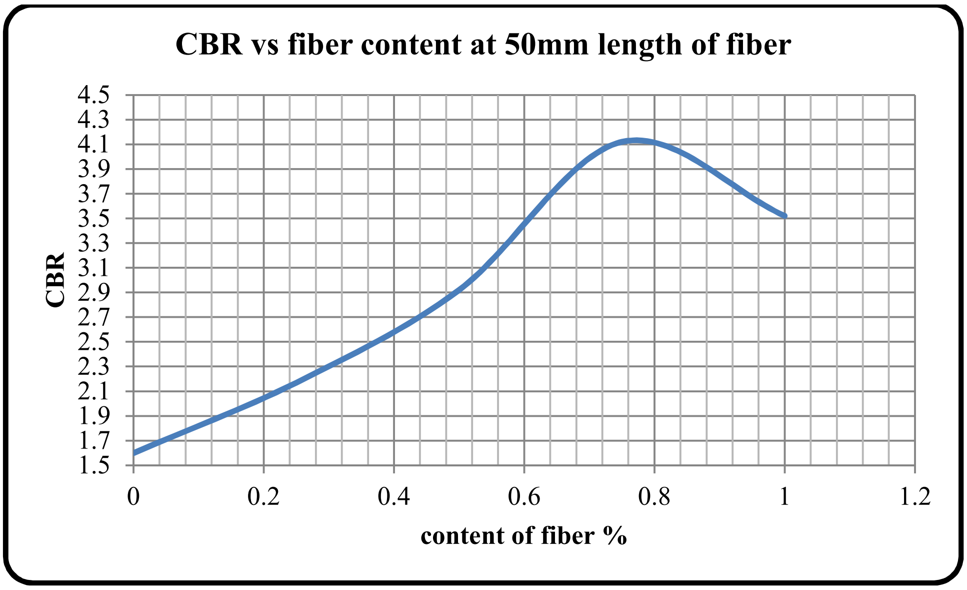

Fig 4.11 CBR vs fiber content at 50mm length of fiber,koshe sample

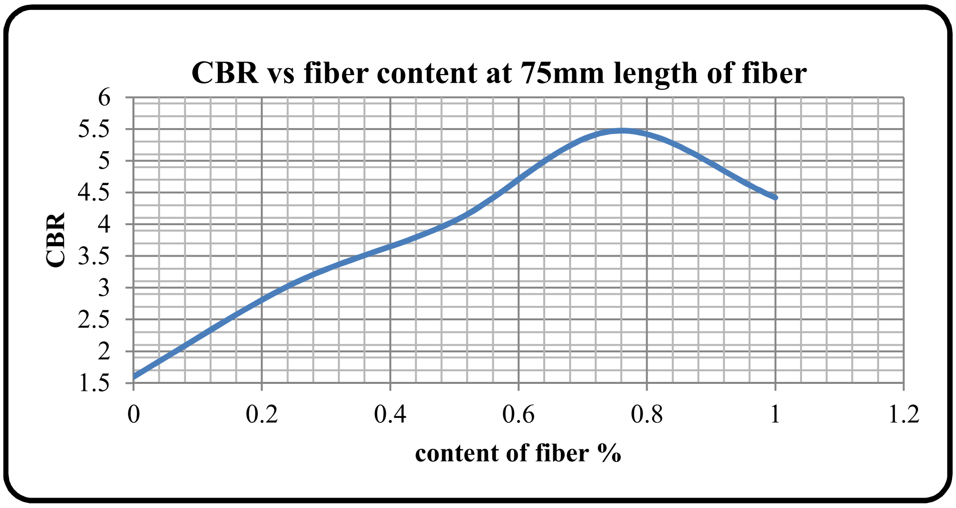

Fig 4.12 CBR vs fiber content at 75mm length of fiber,koshe sample

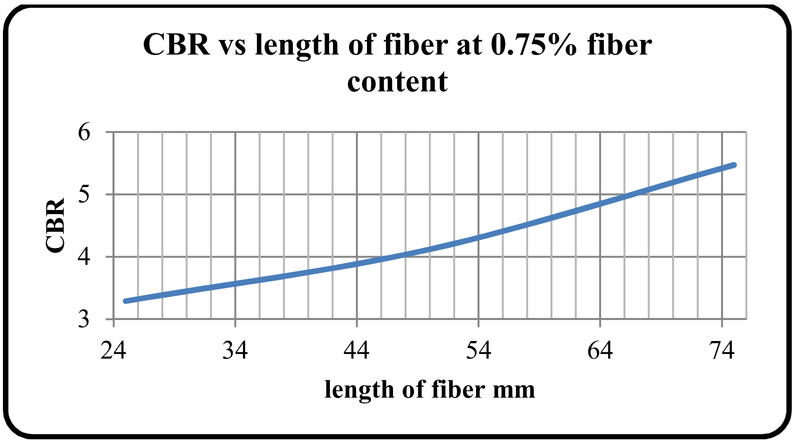

Fig 4.13 CBR vs length of fiber of koshe sample

Table 4.13 CBR value of dippo sample

Dippo			
Fiber content	Length of fiber		
	25mm	50mm	75mm
0%	2.08		
0.25%	2.93	3.00	3.45
0.50%	3.82	3.97	4.72
0.75%	4.27	5.10	6.22
1%	3.90	4.20	5.96

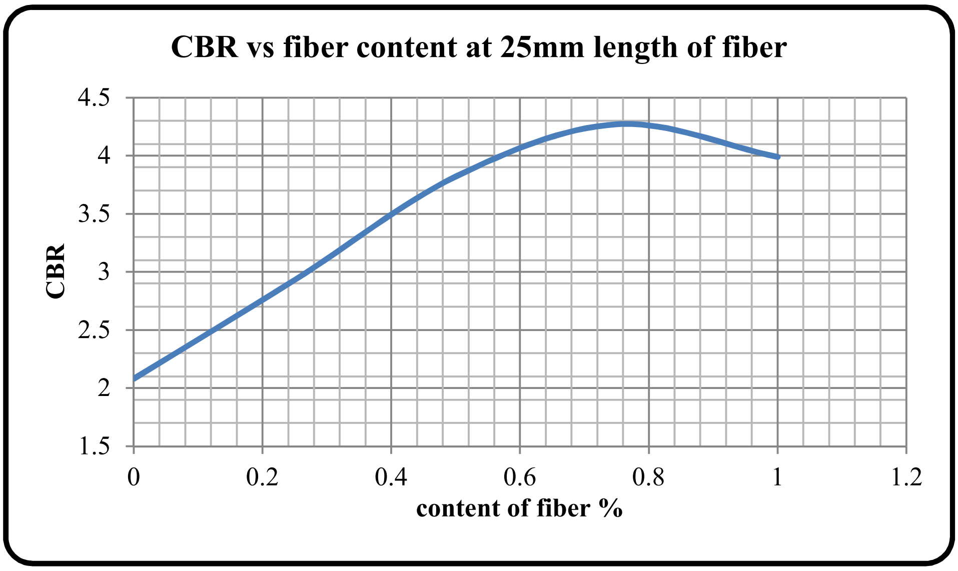

Fig4.14CBR vs fiber content at 25mm length of fiber, dippo sample

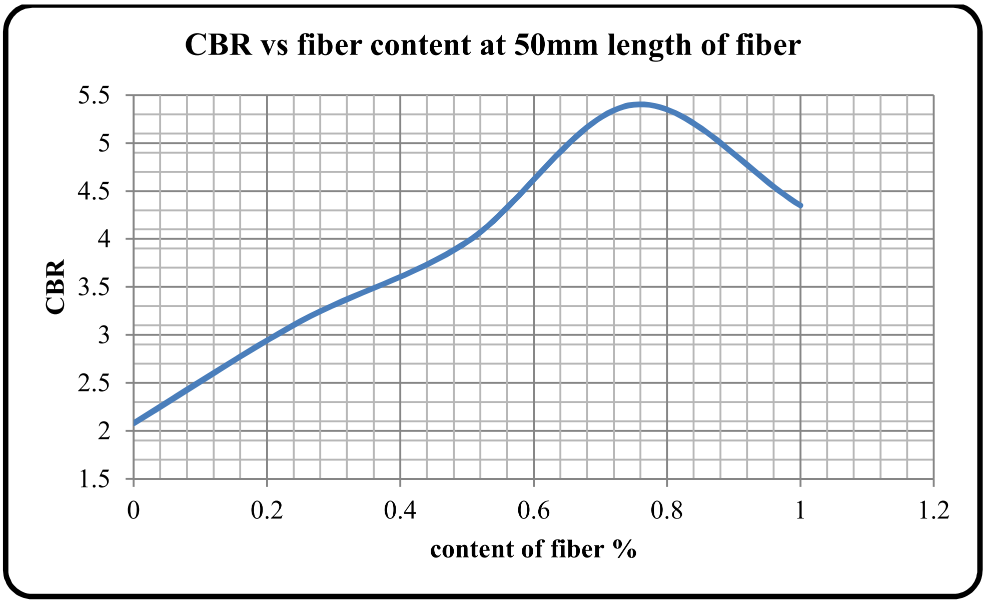

Fig 4.15 CBR vs fiber content at 50mm length of fiber,dippo sample

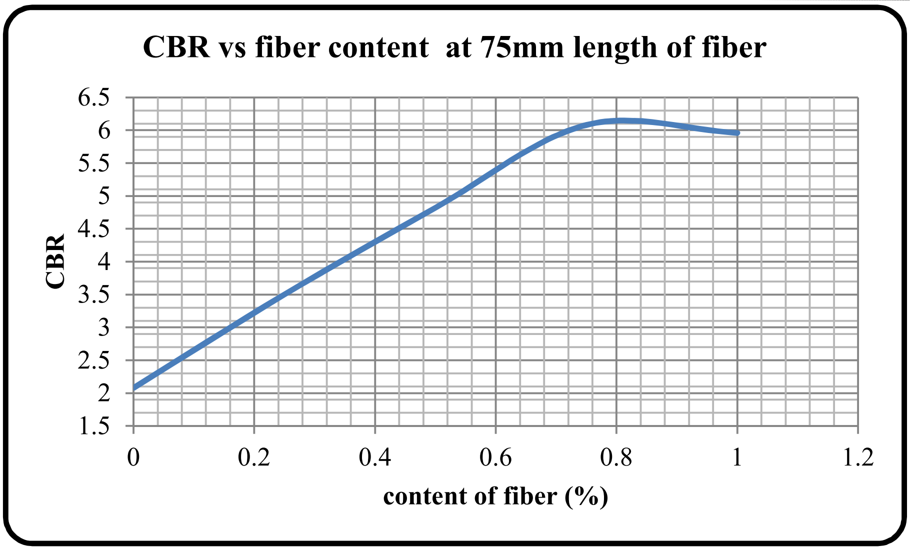

Fig 4.16CBR vs fiber content at 75mm length of fiber,dippo sample

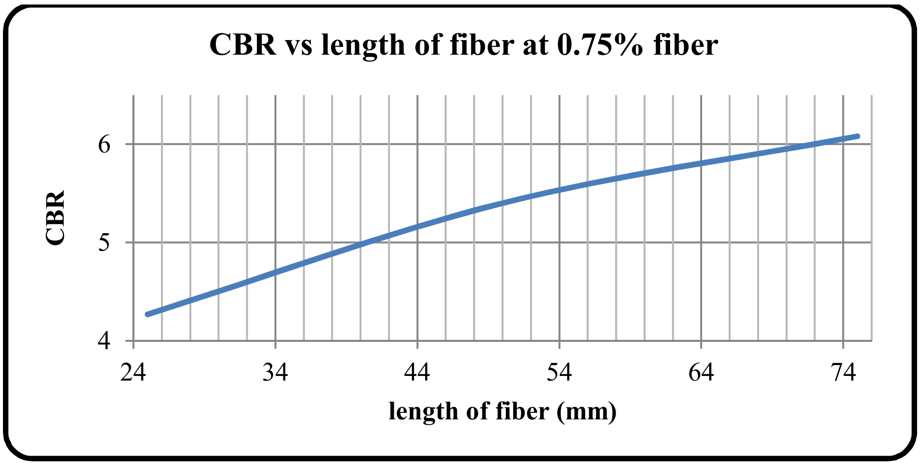

Fig 4.17 CBR vs length of fiber of dippo sample

4.5 Effect of reinforcement on UCS

The unconfined compressive strength of both soil samples with different lengths of fibers having constant of content of 0.75% fiber were calculated from the loads at failure and shown in table 4.15 and table 4.16 respectively. This constant content of 0.75% fiber is taken from CBR test result, which is relevant test for subgrade soil. The variation of UCS value of reinforced soil sample against fiber length is plotted and shown in Fig 4.18 and Fig 4.19 respectively. The Unconfined Compressive Strength value of fiber reinforced soil is highest at 75mm length fiber with constant content. UCS value increased by 91.7% at 25mm ,121.97%at 50mm, 229.9% at 75mm from plain soil for dippo sample and 57.1% at 25mm,80.5% at 50mm,176.8% at 75mm for koshe sample . It can be observed that the UCS value of fiber reinforced soil increases with increase in fiber length. The increase in strength may be due to the shear transfer mechanism induced by the fiber inclusions.

Table 4.14 UCS value of dippo sample

Dippo		
Length of fiber	Content of fiber	qu(kn/m^2)
0	0	81
25mm	0.75%	155.30
50mm	0.75%	179.80
75mm	0.75%	267.25

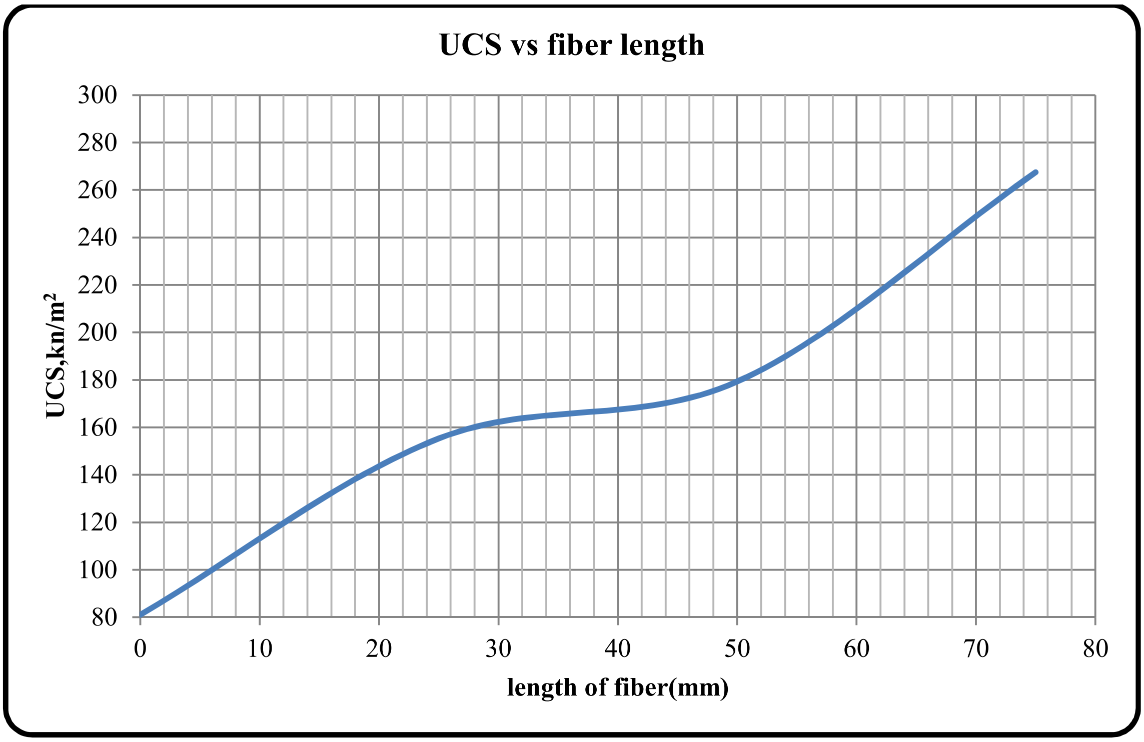

Fig 4.18 UCS vs fiber length of dippo sample

Table 4.15 UCS value of koshe sample

Koshe		
Length of fiber	Content of fiber	qu(kn/m^2)
0	0	63
25mm	0.75%	99
50mm	0.75%	113.72
75mm	0.75%	174.44

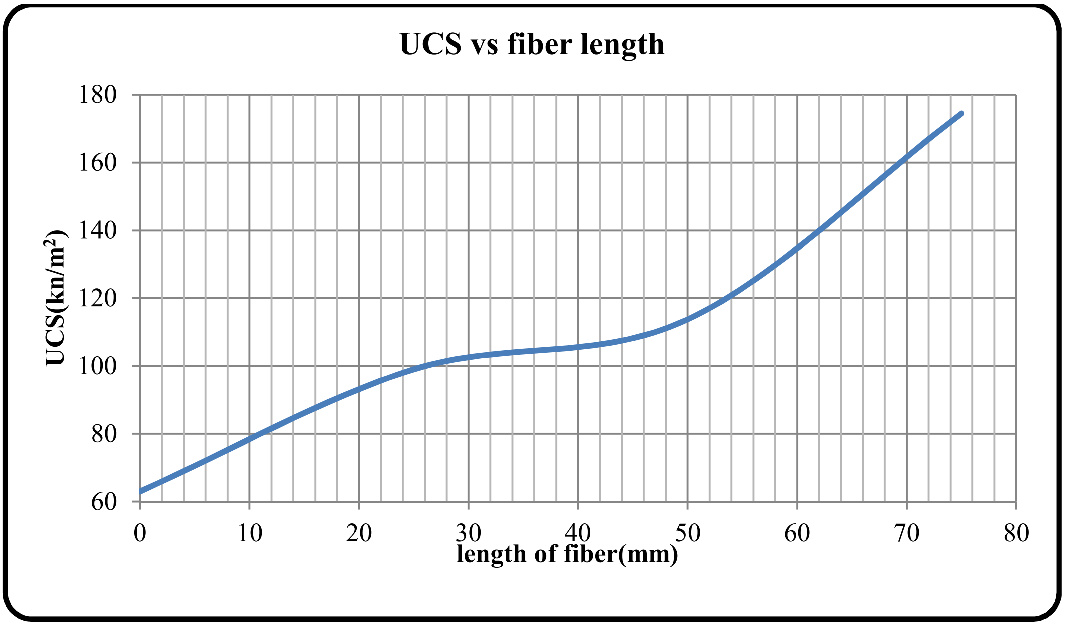

Fig 4.19 UCS vs fiber length of koshe sample

From fig. above length of fiber increases, UCS increases. According to bowels, the result on above figure shows that both samples are improved from consistency of medium to very stiff soil.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

Laboratory test result indicated that the natural subgrade soil of the subject area was classified as a material of deficient engineering property to be used as a sub-grade material. From sieve analysis tests, percentage of passing through sieve No. 200 (0.075mm sieve size) of koshe and dippo is 93.16% and 95.07 % respectively. While from the Atterberg's limit test results, the soil sample contains a liquid limit of 82.9and 80.5%, a plastic limit of 36.1% and 35.11%, and plasticity index of 46.8% and 45.39%,koshe and dippo samples respectively. Also from CBR test, natural sample has CBR value of 1.60% for koshe and 2.08% for dippo sample. Again UCS of natural sample has 63Kn/ m^2 for koshe and 81kn/m^2 dippo samples. It requires first modification and stabilization to improve its workability and engineering property.

From CBR vs fiber content, when fiber content increases also CBR value is increasing and reaches a maximum value of 5.47 at 0.75% fiber content and 6.22 at 0.75% fiber content for 75 mm length and then decreases for koshe and dippo samples respectively.
CBR value increased from 1.60% to 5.47% by 241% and from 2.08 to 6.22 by 199% for koshe and dippo samples respectively.

When 0.75% fiber content added, the CBR value reaches maximum value and then decreases. So this 0.75% fiber content can be taken as the optimum ensete ventricosum fiber content for both samples which given best results.

A series of compaction test were performed to evaluate the effect of ensete ventricosum fiber inclusion on optimum moisture content (OMC) and maximum dry density (MDD) of soil. Increasing in fiber percentage increased OMC of both samples and decreased maximum dry density. MDD decreases from 1.35 g/cm^3 of natural sample to 1.28 g/cm^3 of 1% fiber content for koshe sample and from 1.47 g/cm^3 of natural sample to 1.39 g/cm^3 of 1% fiber content for dippo sample. Again OMC increases from 30.16 to 36.65% for koshe sample and from 20.21 to 27.05% for dippo sample. The Unconfined Compressive Strength value of fiber reinforced soil is highest at 75mm length fiber with constant content. UCS value increased by 91.7% at 25mm ,121.97%at 50mm, 229.9% at 75mm from plain soil for dippo sample and 57.1% at 25mm,80.5% at 50mm,176.8% at 75mm for koshe sample .

Generally, it can be concluded that the fiber is very effective in improving the engineering property of the weak subgrade soil by increase of the percentages of fiber.

5.2 Recommendation

Based on the result obtained, the following recommendations are outlined.

- ✓ The researcher recommends for the construction purpose that fiber should be treated to reduce microbial attack and biodegradability.
- ✓ The treating material should be selected based on their treatment ability and workability.
- ✓ For further study, the researcher recommends long term durability test of ensete ventricosum fiber reinforcement.
- ✓ In this study, length of fiber greater than 75mm is not checked so it should be checked for further study.

References

[1]. Bordoloi,S., Garg,A., Sekharan,S. A Review of Physio-Biochemical Properties of Natural Fibers and Their Application in Soil Reinforcement.Journal of Adv. Civ. Eng. Mater. 2017; 6. 323–359.

[2]. Celik, E.,Nalbantoglu, Z. Effects of ground granulated blastfurnace slag (GGBS) on the swelling propertiesof lime-stabilized sulfate-bearing soils. Eng. Journal Geol. 2013;163.20–25.

[3]. Iorliam,A.Y., Agbede,I.O., Joel,M. Effect of bamboo leaf ash on cement stabilization of Makurdishal for use as flexible pavement construction material. Am. J. Sci. Ind. Res. 2012;3.166–174.

[4].Sakaray, H., Togati,N.V., Reddy, I.V.R. Investigation on Properties of Bamboo as Reinforcing Material in Concrete. Int. Journal of Eng. Res. Appl. 2012; 2.77–83.

[5]. Fagone,M., Loccarini,F., Ranocchiai,G. Strength evaluation of jute fabric for the reinforcement of rammed earth structures. Compos. Part B.2017; 113:1–13.

[6].Singh,H.P., Bagra,M. Improvement in CBR value of soil Reinforced with jute fiber. International Journal of Innovative Research in Science, Engineering and Technology.2013; 2(8): 3447-3452.

[7].Jamshidi, R., Towhata,I., Ghiassian, H., Tabarsa, R. Experimental evaluation of dynamic deformation characteristics of sheet pile retaining walls with fiber reinforced backfill. Soil DynEarthqEng 2010;30:438–46.

[8].Tsehaye, Y., Kebebew, F. Diversity and cultural use of Enset (Ensetventricosum in Bonga in situ Conservation Site, Ethiopia. Ethnobotany Research and Applications.2006; 4:147–57.

[9]. Yirmaga, M.T. Improving the Indigenous Processing of Kocho, an Ethiopian TraditionalFermented Food. Journal of Nurition and Food Science. 2013;3: 1–6.

[10]. Western Australian Supplement to the Austroads Guide to Pavement Technology Part 2: Pavement Structural Design; A guide to the structural design of bitumen surfaced roads in tropical and sub-tropical countries;2013.

[11]. Bowles, J. E. Foundation analysis and design. International edition. New York: the Mcgraw- Hill companies, Inc;1996.

[12].Ethiopian Roads Authority. Pavement Design Manual. Addis Ababa;2013.

[13]. American Concrete Pavement Association.Asphalt Paving Association; State of Ohio; State of Iowa; Rollings and Rollings;1996.

[14]. Bowles, J. E. Foundation analysis and design. International edition. New York:the Mcgraw- Hill companies, Inc;1992.

[15].Sayyed, M., Mohammad, S., Ali, Z. Simple review of soil reinforcement by using natural and synthetic fibers. Journal Construction and Building Materials.2012;30:100-116.

[16]. Brandt, S.A., Spring, A., Hiebsch, C., McCabe, J.T., Tabogie, E., Diro, M., Wolde-

Michael, G., Yntiso, G., Shigeta, M.,Tesfaye, S., The tree against hunger: enset-based agricultural systems in Ethiopia. American Association for the Advancement of Science, Washington, DC.1997.

[17]. Muzemil, S., Yemataw, Z., and Derso, E. Challenges, research status and strategy for enset(ensete ventricosum) research and development in Ethiopia. International workshop on enset.2016; 24.

[18].Birmeta, G., Nybom, H. and Bekele, E., Distinction between wild and cultivated enset (Enseteventricosum) genepools in Ethiopia using RAPD markers. Hereditas.2004;140(2):139-148.

[19]. Reddy, K.O., Ashok, B., Reddy, K.R.N., Feng,Y.E., Zhang, J. and Rajulu,A.V.Extraction and characterization of novel lignocellulosic fibers from Thespesia lampas plant. International Journal of Polymer Analysis and Characterization. 2014;19(1):.48-61.

[20].Komuraiah, A., Kumar, N.S. and Prasad, B.D. Chemical composition of natural fibers and its influence on their mechanical properties. Mechanics of composite materials.2014;50(3):359-376.

[21].Baltazar, Y.,Jimenez, A.,Sain, M. Natural fibres for automotive applications. Handbook of Natural Fibres: Processing and Applications. 2012;219.

[22].Mizera,C.,Herak, D.,Hrabe, P.,Kabutey,A.Effect of temperature and moisture content on tensile behaviour of false banana fibre (*Enseteventricosum*). International journal of agro busness. 2017;31:377-382

[23]. Prajisha,J.P.,Ajitha,A.R. Strength and Durability Study on Banana Fiber Reinforced Lime Stabilized Kuttanad Soil. International Advanced Research Journal in Science, Engineering and Technology National Conference on Emerging Trends in Engineering and Technology (NCETET').2016;3(3).158-163

[24]. Hejazi, S.M., Sheikhzadeh, M., Abtahi, S.M., Zadhoush, A. Simple Review of Soil Reinforcement by using Natural and Synthetic Fibers. Constr. Build. Mater.2012; 30:100–116.

[25]. Bordoloi, S., Hussain, R., Garg, A., Sreedeep, S., Zhou, W.H. Infiltration characteristics of natural fiber reinforced soil. Transp. Geotech. 2017; 12:37–44.

[26]. Pujari, S., Ramakrishna, A., Padal, K.T.B. Comparison of ANN and Regression Analysis for Predicting the Water Absorption Behaviour of Jute and Banana Fiber Reinforced Epoxy composites. Mater. Today: Proc. 2017; 4: 1626–1633.

[27]. Gaw, B., Zamora, S., Albano, L.D., Tao, M. Soil Reinforcement with Natural Fibers for Low-Income Housing Communities. Bachelor's Thesis, Worcester Polytechnic Institute, Worcester, MA, USA; 2011.

[28]. Ibrahim, M.M., Dufresne, A., El-Zawawy, W.K., Agblevor, F.A. Banana fibers and microfibrils as lignocellulosic reinforcements in polymer composites.

Carbohydr.Polym.2010;81: 811–819.

[29]. Gray, D.H.,Ohashi, H. Mechanics of fibre reinforcing in sand.Journal of Geotechnical Engineering ,ASCE.1983;112(8):335-353.

[30]. Gray, D.H., Al-Refeai, T. Behaviour of fabric- versus fibre-reinforcd sand. Journal of Geotechnical Engineering, ASCE.1986;112(8): 804-820.

[31]. Bouhicha,M., Aouissi, F., and Kenai,S. Performance of Composite soil reinforced with barley straw.Cement and Concrete Composites.2005; 27: 617-621.

[32]. Marandi, S.M., Bagheripour, M.H., and Zare, H. Strength and Ductility of randomly Distributed Palm Fibres Reinforced Silty-Sand Soils.American Journal of Applied Sciences.2008;5(3):209-220.

[33]. Abhijith, R. p. Effects of natural coir fibers on CBR strength of soil subgrade. International journal of scientific and Research publications.2015;5(4)

[34].Terese,S., Annie, J. Study on the effects of marine clay stabilized with Banana Fiber. International Journal of Scientific Engineering and Research.2016; 4(3):96-98.

[35]. American Society for Testing and Materials Designation: D 1883 – 99, Laboratory CBR Testing. Annual Book of ASTM Standards.04-08, West Conshohocken, Pennsylvania, 2000.

[36]. Mittal, S., Shukla, J.P. Soil Testing For Engineers, 6th ed, Khanna Publishers,New Delhi-110002;2012.

[37]. AASHTO: Standard Specification for Transportation Materials and Methods of Sampling and Testing, part II tests. American Association of State Highway and Transportation Officials, Washington, DC;2001

[38].Arora, K.R. Soil Mechanics and Foundation Engineering.Niagara,Delhi:Re-print Standard Publishers Distributer; 2004.

[39]. Park, S.S. Unconfined compressive strength and ductility of fiber-reinforced cemented sand. Construction and Building Materials.2011; 25(2):1134- 1138.

[40]. Das, B.M. Soil Mechanics Laboratory Manual. 6th ed. New work: Oxford University Press;2002;115.

Appendix

Appendix 1: Laboratory results

B. Dry density vs OMC

Table B. 1 Compaction test for 0% fiber of koshe sample

number of trial	1	2	3
weight of mold	4047.8	4047.8	4047.8
weight of mold+soil	5641.2	5716.6	5675.9
volume of mold	944	944	944
weight of soil	1593.4	1668.8	1628.1
bulk density	1.69	1.77	1.72
weight of can	51.2	37.72	40.1
weight of can+ soil	207.87	156	174.60
weight of can+ dry soil	172.83	128.59	141.85
weight of soil	121.63	90.87	101.75
weight of water	35.04	27.41	32.75
water content	28.81	30.16	32.19
dry density	1.31	1.36	1.30

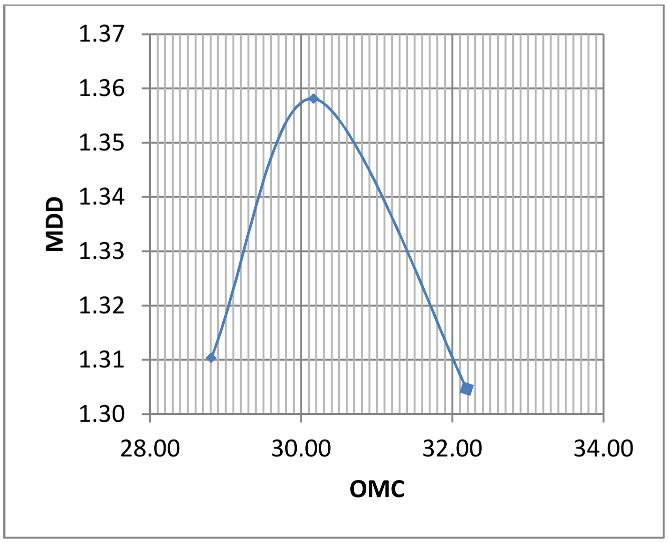

Fig B. 1 OMC vs MDD of 0% fiber of koshe sample

Table B. 2 Compaction test of 0.25% fiber of koshe sample

number of trial	1	2	3	4
weight of mold	4048.5	4048.5	4048.5	4048.5
weight of mold+soil	5655.2	5725.8	5702.5	5652.6
volume of mold	944	944	944	944
weight of soil	1606.7	1677.3	1654	1604.1
bulk density	1.70	1.78	1.75	1.70
weight of can	40.55	31.98	35.32	31.91
weight of can+ soil	211.43	196.29	201.56	234.51
weight of can+ dry soil	170.8	155.11	157.23	234.51
weight of soil	130.25	123.13	121.91	202.6
weight of water	40.63	41.18	44.33	75.91
water content	31.19	33.44	36.36	37.47
dry density	1.30	1.33	1.28	1.24

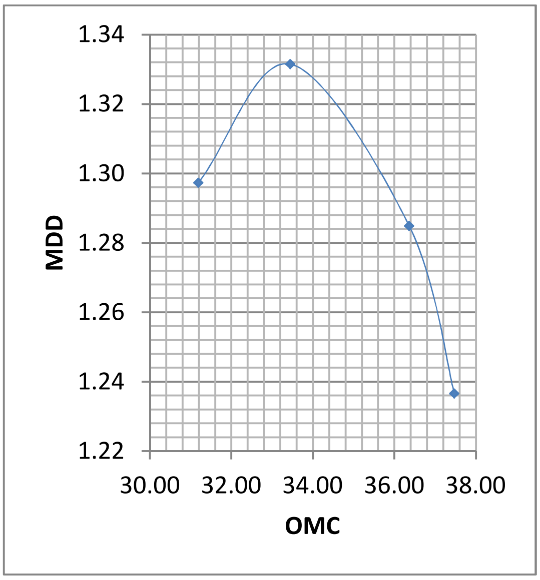

Fig B. 2 OMC vs MDD of 0.25% fiber of koshe sample

Table B. 3 Compaction test of 0.50% fiber of koshe sample

number of trial		1	2	3
weight of mold	4047.5	4047.5	4047.5	4047.5
weight of mold+soil	5649.05	5690.8	5675.5	5635.9
volume of mold	944	944	944	944
weight of soil	1601.55	1643.3	1628	1588.4
bulk density	1.70	1.74	1.72	1.68
weight of can	17.35	32.99	36.46	17.58
weight of can+ soil	159.68	231.8	243.24	185.68
weight of can+ dry soil	125.21	181.09	187.86	137.02
weight of soil	107.86	148.1	151.4	119.44
weight of water	34.47	50.71	55.38	48.66
water content	31.96	34.24	36.58	40.74
dry density	1.29	1.30	1.26	1.20

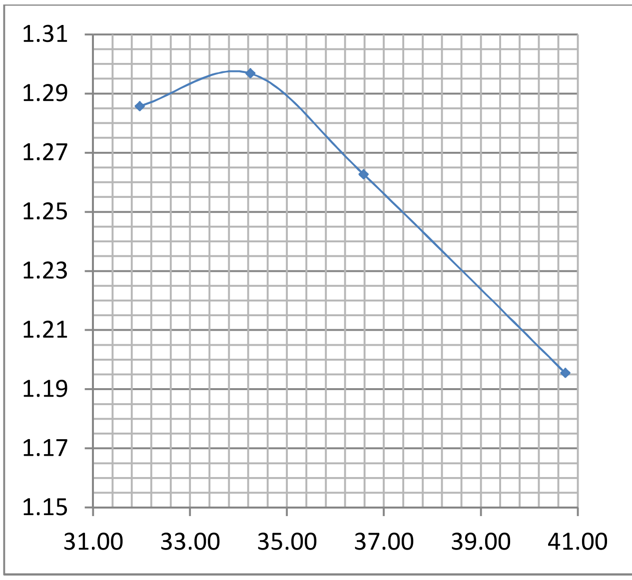

Fig B. 3 OMC vs MDD of 0.50% fiber of koshe sample

Table B. 4compaction test of 0.75% fiber of koshe sample

number of trial	1	2	3	4
weight of mold	4047.2	4047.2	4047.2	4047.2
Weight of mold+soil	5646.36	5685.42	5701.52	5671.42
volume of mold	944	944	944	944
weight of soil	1599.16	1638.22	1654.32	1624.22
bulk density	1.69	1.74	1.75	1.72
weight of can	16.98	37	17.47	17.89
weight of can+ soil	136.32	305.62	205.8	191.23
weight of can+ dry soil	106.12	236.56	156.63	141.77
weight of soil	89.14	199.56	139.16	123.88
weight of water	30.2	69.06	49.17	49.46
water content	33.88	34.61	35.33	39.93
dry density	1.27	1.29	1.29	1.23

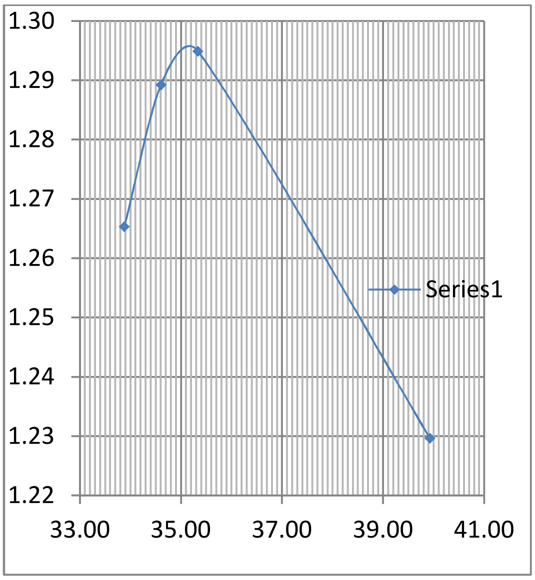

Fig B. 4 OMC vs MDD of 0.75% fiber of koshe sample

Table B. 5 Compaction test of 1% fiber of koshe sample

number of trial	1	2	3	4
weight of mold	4060.5	4060.5	4060.5	4060.5
weightof mold+soil	5621.23	5644.12	5712.96	5675.13
volume of mold	944	944	944	944
weight of soil	1560.73	1583.62	1652.46	1614.63
bulk density	1.65	1.68	1.75	1.71
weight of can	16.5	16.7	37.49	18.24
Weight of can+ soil	178.23	182.23	306.69	239.56
weight of can+ dry soil	138.34	140.78	234.2	177.24
weight of dry soil	121.84	124.08	197.81	159
weight of water	39.89	41.45	72.49	62.32
water content	32.74	33.41	36.65	39.19
dry density	1.25	1.26	1.28	1.23

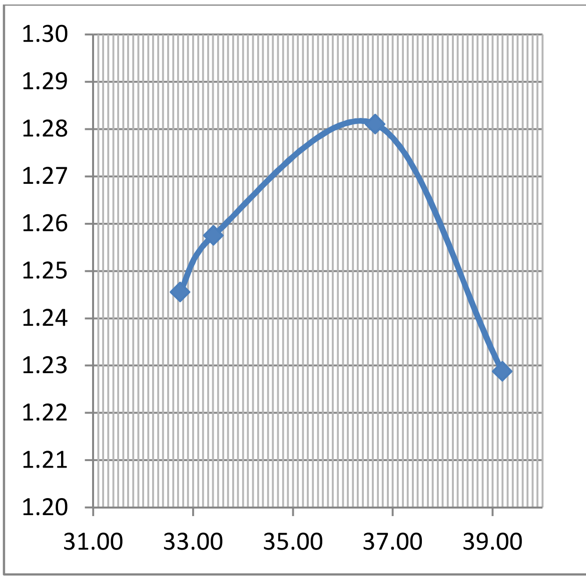

Fig B. 5 OMC vs MDD of 1% fiber of koshe sample

Table B. 6 Compaction test of 0% fiber of dippo sample

number of trial	1	2	3	4
weight of mold	4047.8	4047.8	4047.8	4047.8
weight of mold+soil	5605	5716.6	5675.9	5631.45
volumeof mold	944	944	944	944
weight of soil	1557.2	1668.8	1628.1	1583.65
bulk density	1.65	1.77	1.72	1.68
weight of can	78.5	77.9	66.7	80.2
weight of can+ soil	491.70	510.3	550.51	514.60
weight of can+ dry soil	435.50	437.60	456.80	427.60
weight of soil	357.00	359.70	390.1	347.4
weightof water	56.2	72.70	93.71	87
water content	15.74	20.21	24.02	25.04
dry density	1.43	1.47	1.39	1.34

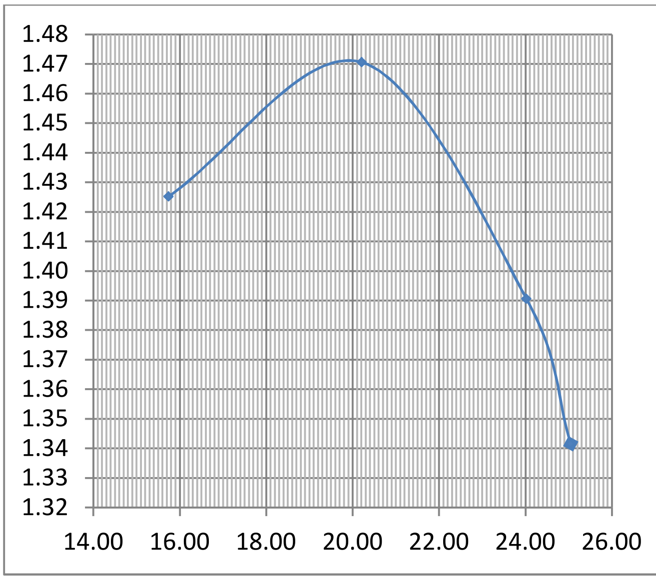

Fig B. 6 OMC vs MDD 0% fiber of dippo sample

Table B. 7 compaction test of 0.25% fiber of dippo sample

number of trial	1	2	3	4
weight of mold	4047.2	4047.2	4047.2	4047.2
weight of mold+soil	5614.3	5685.42	5730.2	5671.42
volum of mold	944	944	944	944
weight of soil	1567.1	1638.22	1683	1624.22
bulk density	1.66	1.74	1.78	1.72
weight of can	67.6	71.2	85.6	82.5
weight of can+ soil	450.2	491.5	465.32	485.5
weight of can+ dry soil	391.6	420.3	396.8	411.4
weight of soil	324	349.1	311.2	328.9
weight ofwater	58.6	71.2	68.52	74.1
water content	18.09	20.40	22.02	22.53
dry density	1.41	1.44	1.46	1.40

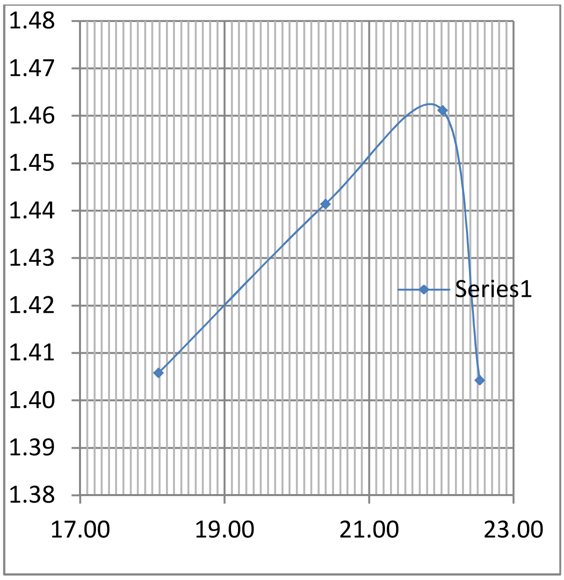

Fig B. 7 OMC vs MDD of 0.25% fiber of dippo sample

Table B. 8 compaction test of 0.50% fiber of dippo sample

number of trial			1	2
weight of mold	4048.5	4048.5	3	4
weight of mold+soil	5655.2	5725.8	4048.5	4048.5
volume ofmold	944	944	5702.5	5652.6
weight of soil	1606.7	1677.3	944	944
bulk density	1.70	1.78	1654	1604.1
weight of can	75.6	81.2	1.75	1.70
weight of can+ soil	401.3	452.1	66.8	86.5
weight of can+ dry soil	350.3	384.5	384.6	375.8
weight of soil	274.7	303.3	325.6	224.5
weight ofwater	51	67.6	258.8	201.3
water content	18.57	22.29	59	151.3
dry density	1.44	1.45	22.80	23.2

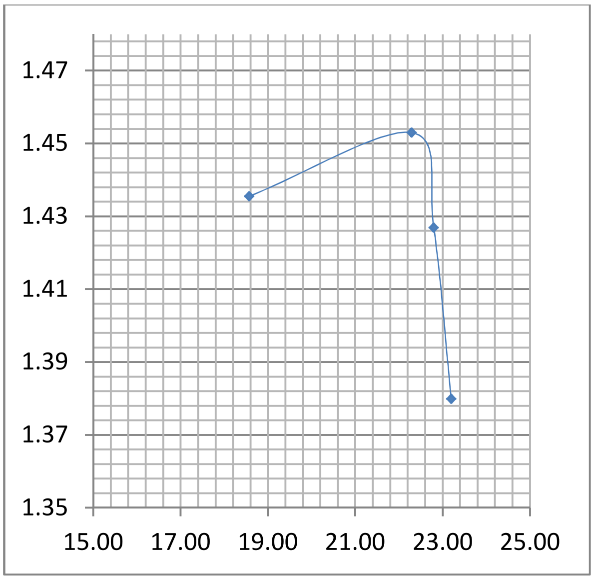

Fig B. 8 OMC VS MDD of 0.50% fiber of dippo sample

Table B. 9 Compaction test of 0.75% fiber of dippo sample

number of trial			1	2
weight of mold	4047.5	4047.5	3	4
weight of mold+soil	5635.3	5690.8	4047.5	4047.5
volume of mold	944	944	5675.5	5635.9
weight of soil	1587.8	1643.3	944	944
bulk density	1.68	1.74	1628	1588.4
weight of can	64.3	71.6	1.72	1.68
weight of can+ soil	465.6	395.6	75.6	74.3
weight of can+ dry soil	392.30	332.3	426.3	417.9
weight of soil	328	260.7	350.2	341.4
weight of water	73.30	63.3	274.6	267.1
water content	22.35	24.28	76.1	76.5
dry density	1.37	1.40	27.71	28.64

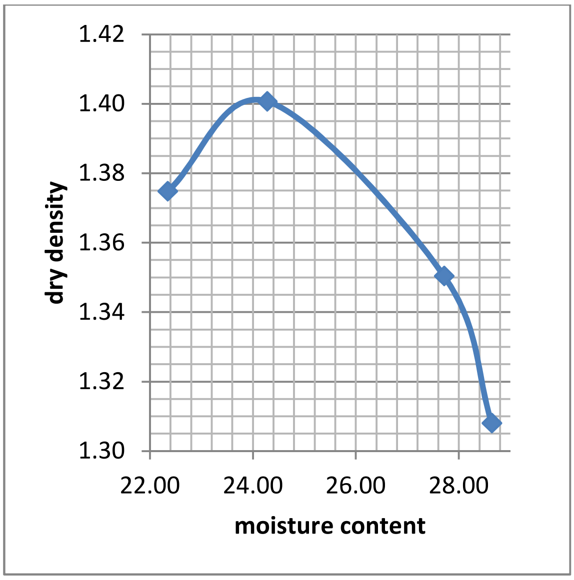

Fig B. 9 OMC VS MDD of 0.75% fiber of dippo sample

Table B. 10 Compaction test of 1% fiber of dippo sample

number of trial	1	2	3	4
weight of mold	4060.5	4060.5	4060.5	4060.5
weight of mold+soil	5610.2	5644.12	5725.4	5675.13
volume of mold	944	944	944	944
weight of soil	1549.7	1583.62	1664.9	1614.63
bulk density	1.64	1.68	1.76	1.71
weight of can	68.6	77.8	71.9	73.6
weight of can+ soil	453.6	502.8	524.6	469.3
weight of can+ dry soil	385.6	425.8	471.1	378.3
weight of dry soil	317	348	197.81	304.7
weight of water	68	77	53.5	91
water content	21.45	22.13	27.05	29.87
dry density	1.35	1.37	1.39	1.32

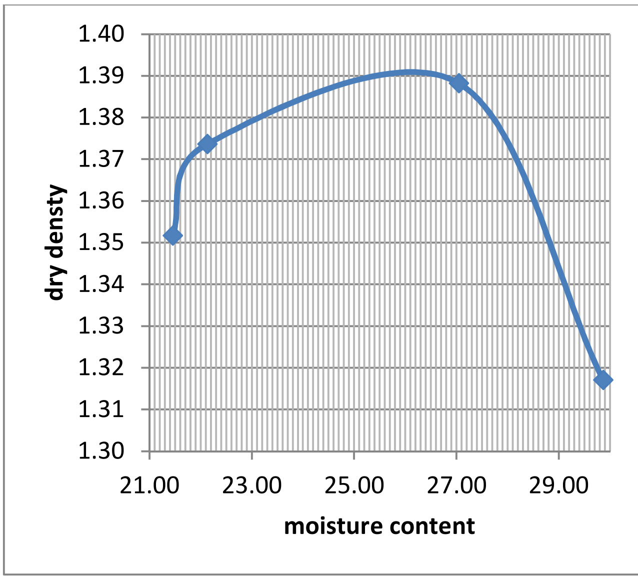

Fig B. 10 OMC vs MDD of 1% fiber of dippo sample

C. CBR

Table C. 1 CBR test of natural dippo sample

CBR for Natural Dippo		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.14	
1.27	0.21	
1.91	0.26	
2.54	0.28	2.08
3.18	0.31	
3.81	0.33	
5.08	0.36	1.80
6.07	0.38	

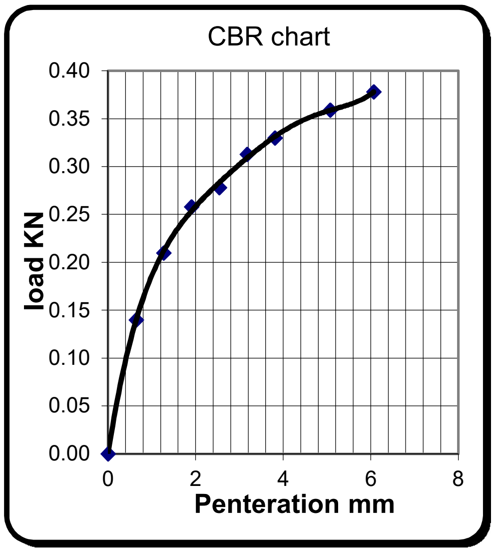

Fig C. 1 penetration vs load of natural Dippo sample

Table C. 2 CBR test at 25mm of 0.25% fiber, dippo sample

CBR at 25mm of 0.25% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm		
0.00	load reading	CBR. %
0.64	0.00	
1.27	0.19	
1.91	0.29	
2.54	0.36	2.93
3.18	0.39	
3.81	0.44	
5.08	0.46	2.51
7.62	0.50	
10.00	0.52	
12.50	0.54	

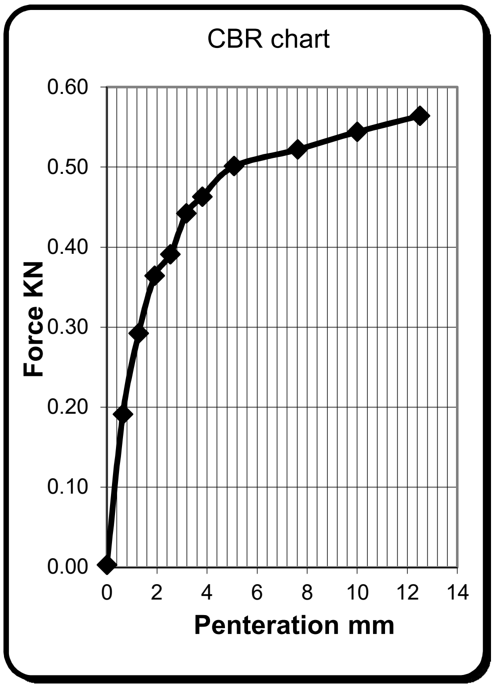

Fig C. 2 penetration vs load at 25mm of 0.25% fiber content,dippo sample

Table C. 3 CBR test at 25mmm of 0.50% fiber,dippo sample

CBR at 25mm of 0.50% fiber		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.26	
1.27	0.39	
1.91	0.47	
2.54	0.51	3.82
3.91	0.58	
5.08	0.66	3.50
6.00	0.70	
6.07	0.74	
10.00		
12.50		

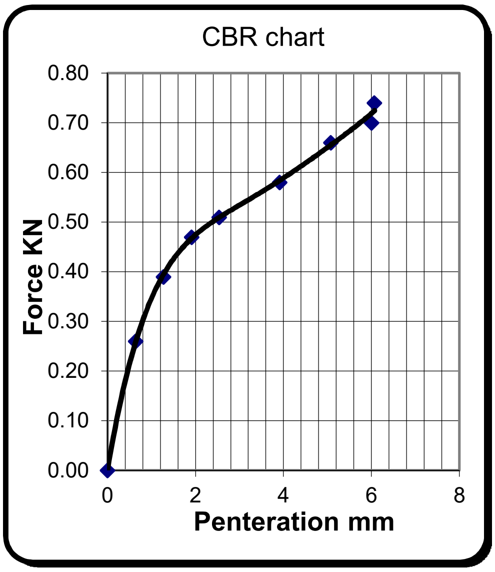

Fig C. 3 penetration vs load 25mm 0.50% fiber, dippo sample

Table C. 4 CBR test at 25mm of 0.75% fiber, dippo sample

CBR at 25mm of 0.75% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.01	
0.64	0.31	
1.27	0.46	
2.54	0.57	4.27
3.18	0.61	
3.81	0.69	
5.08	0.73	3.65
7.62	0.79	
10.00	0.84	
12.50	0.91	

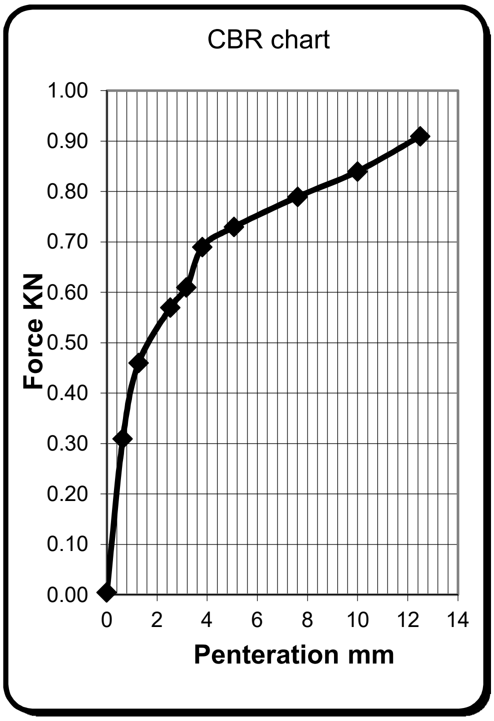

Fig C. 4penetration vs load at 25mm of 0.75% fiber, dippo sample

Table C. 5 CBR test at 25mm of 1% fiber, dippo sample

CBR at 25mm of 1% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.27	
1.27	0.40	
1.91	0.49	
2.54	0.52	3.90
3.18	0.60	
3.81	0.63	
5.08	0.69	3.45
7.62	0.74	
10.00	0.78	
12.50	0.85	

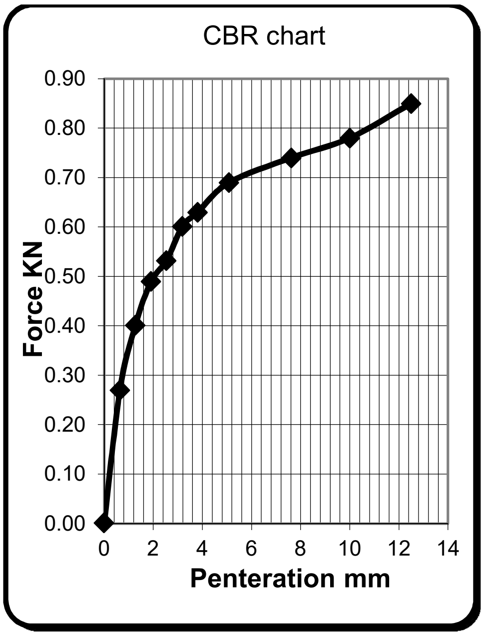

Fig C. 5 Penetration vs load at 5mm of 1%fiber,dippo sample

Table C. 6 CBR test at 50mm of 0.25% fiber, dippo sample

CBR at 50mm of 0.25% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.20	
1.27	0.30	
1.91	0.36	
2.54	0.40	3.00
3.18	0.44	
3.81	0.47	
5.08	0.52	2.60
7.62	0.59	
10.00	0.64	
12.50	0.69	

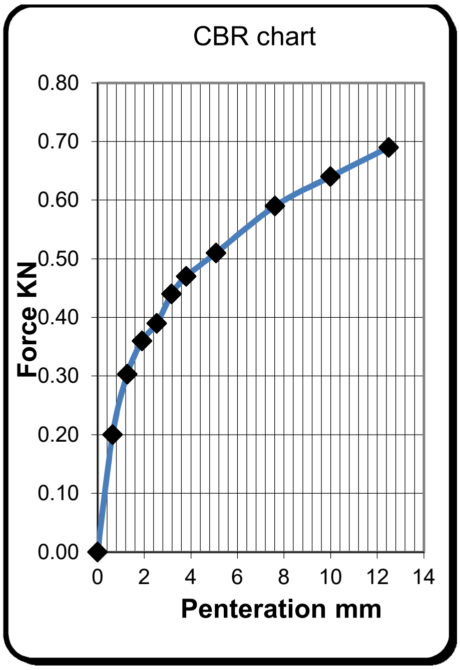

Fig C. 6 Penetration vs Load at 50mm of 0.25% fiber, dippo sample

Table C. 7 CBR test at 50mm of 0.50% fiber, dippo sample

CBR at 50mm of 0.5% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.01	
0.64	0.27	
1.27	0.40	
1.91	0.50	
2.54	0.53	3.97
3.18	0.60	
3.81	0.63	
5.08	0.69	3.45
7.62	0.73	
10.00	0.77	
12.50	0.79	

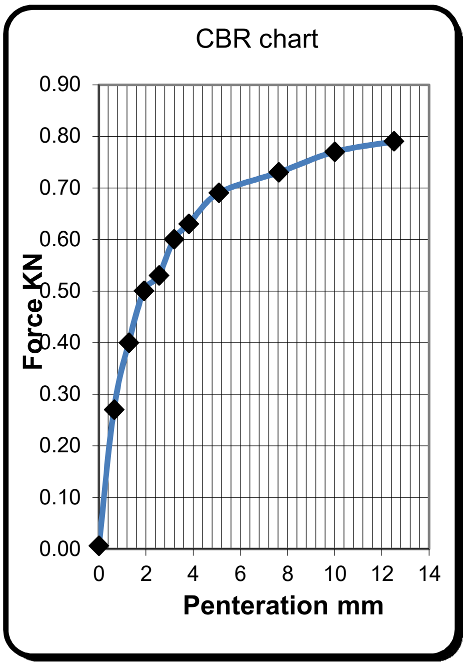

Fig C. 7 Penetration vs load at 50mm of 0.50% fiber, dippo sample

Table C. 8 CBR test at 50mm of 0.75% fiber, dippo sample

CBR at 50mm of 0.75% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.33	
1.27	0.49	
1.91	0.61	
2.54	0.68	5.10
3.18	0.75	
3.81	0.77	
5.08	0.84	4.20
7.62	0.88	
10.00	0.91	
12.50	0.94	

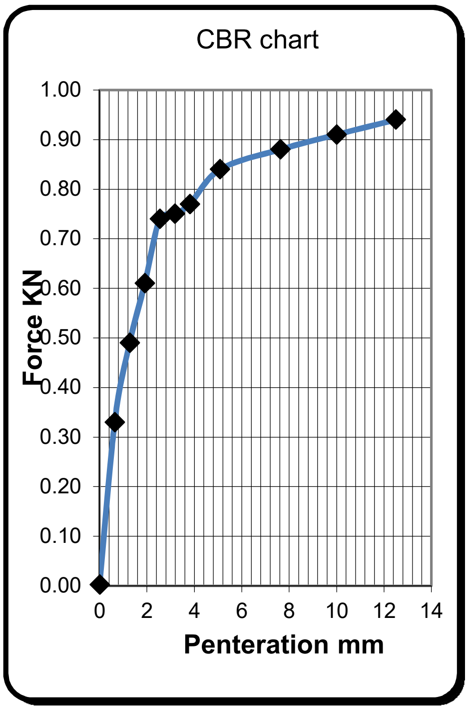

Fig C. 8penetration vs load at 50mm of 0.75% fiber, dippo sample

Table C. 9 CBR test at 50mm of 1% fiber, dippo sample

CBR at 50mm of 1% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.26	
1.27	0.39	
1.91	0.50	
2.54	0.56	4.20
3.18	0.61	
3.81	0.66	
5.08	0.71	3.55
7.62	0.74	

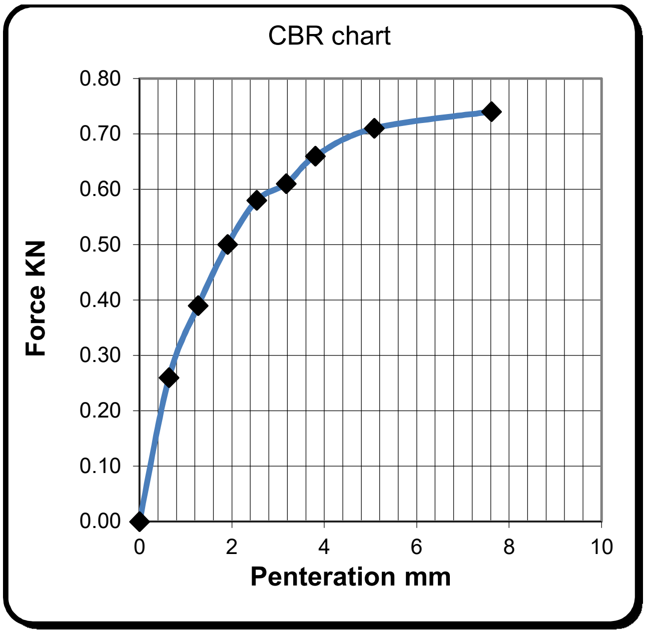

Fig C. 9 Penetration vs load at 50mm of 1% fiber,dippo sample

Table C. 10 CBR test at 75mm of 0.25% fiber, dippo sample

CBR at 75mm of 0.25% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.24	
1.27	0.35	
1.91	0.43	
2.54	0.46	3.45
3.18	0.52	
3.81	0.56	
5.08	0.60	3.02
7.62	0.64	
10.00	0.67	
12.50	0.74	

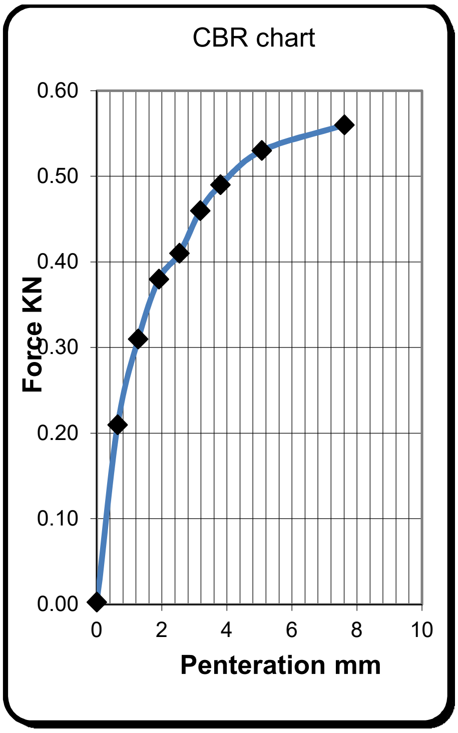

Fig C. 10 penetration vs load at 75mm of 0.25% fiber, dippo sample

Table C. 11 CBR test at 75mm of 0.50% fiber,dippo sample

CBR at 75mm of 0.50% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.32	
1.27	0.49	
1.91	0.57	
2.50	0.63	4.72
3.18	0.70	
5.08	0.77	
7.62	0.83	4.17
10.00	0.88	
12.50	0.93	

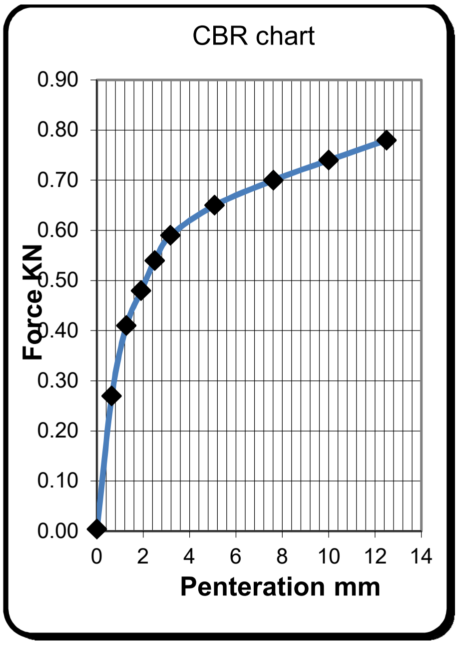

Fig C. 11 penetration vs load at 75mm of 0.50% fiber, dippo sample

Table C. 12 CBR test at 75mm of 0.75% fiber, koshe sample

CBR at 75mm of 0.75% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.41	
1.27	0.61	
1.91	0.74	
2.54	0.83	6.22
3.18	0.91	
3.81	0.96	
5.08	1.05	5.23
7.62	1.10	
10.00	1.17	
12.50	1.24	

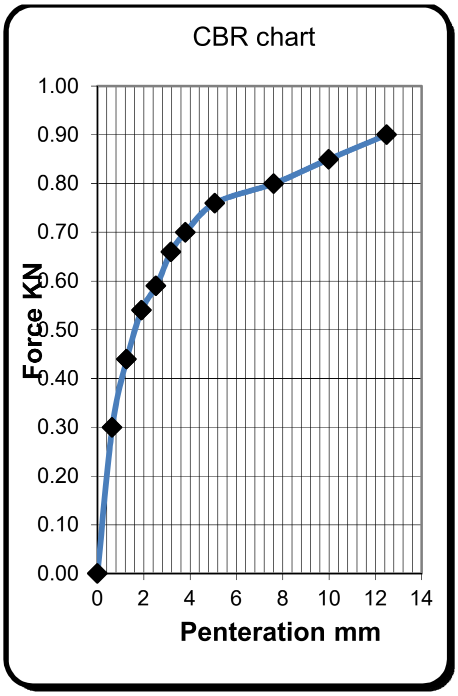

Fig C. 12 penetration vs load at 75mm of 0.75% fiber, dippo sample

Table C. 13 CBR test at 75mm of 1% fiber, dippo sample

CBR at 75mm of 1% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.40	
1.27	0.60	
1.91	0.74	
2.54	0.80	5.96
3.18	0.89	
3.81	0.94	
5.08	0.99	4.96
7.62	1.02	
10.00	1.06	
12.50	1.08	

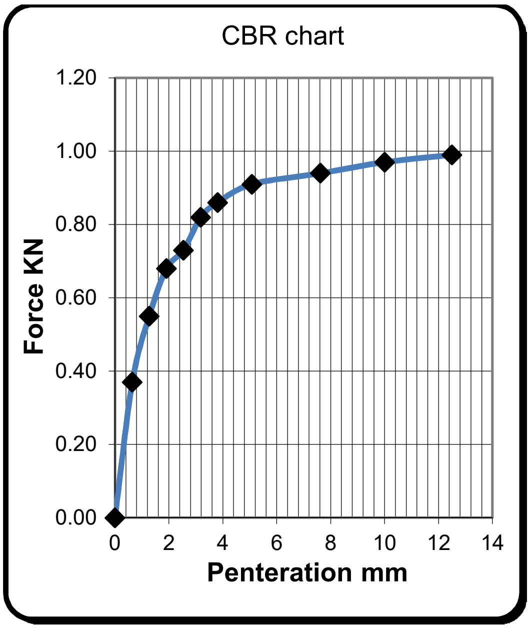

Fig C. 13 penetration vs load at 75mm of 1% fiber, dippo sample

Table C. 14 CBR test natural koshe sample

CBR for Natural		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.12	
1.27	0.15	
1.91	0.17	
2.54	0.21	1.60
3.18	0.25	
3.81	0.28	
5.08	0.30	1.50
6.07	0.33	
10.00		
12.50		

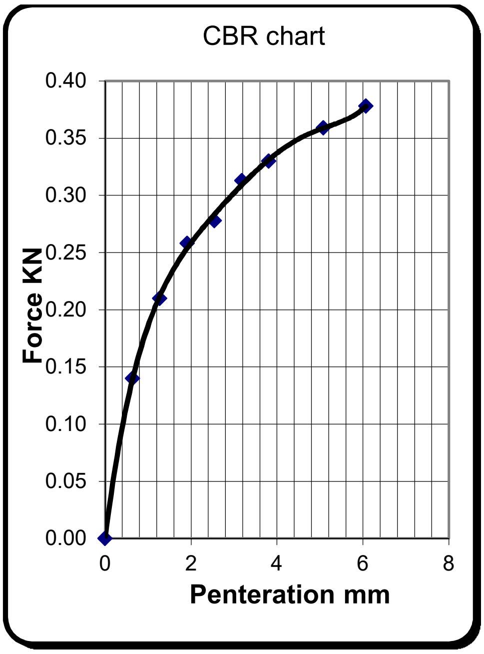

Fig C. 14 Penetration vs load of natural koshe

Table C. 15 CBR test at 25mm of 0.25% fiber, koshe sample

CBR at 25mm of 0.25% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.19	
1.27	0.22	
1.91	0.28	
2.54	0.32	2.40
3.18	0.36	
3.81	0.39	
5.08	0.43	2.15
7.62	0.47	
10.00	0.54	
12.50	0.56	

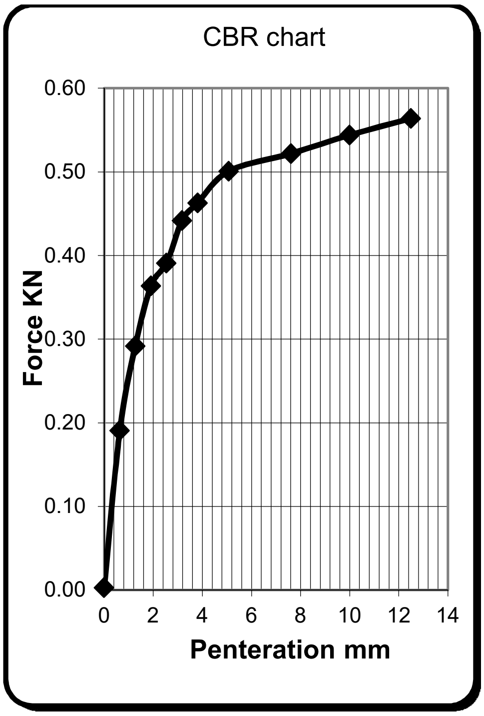

Fig C. 15 Penetration vs load at 25mm of 0.25%, koshe sample

Table C. 16 CBR test at 25mm of 0.50% fiber, koshe sample

CBR at 25mm of 0.50% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.21	
1.27	0.26	
1.91	0.31	
2.54	0.38	2.85
3.91	0.44	
5.08	0.49	2.45
6.00	0.53	
6.07	0.61	
10.00		
12.50		

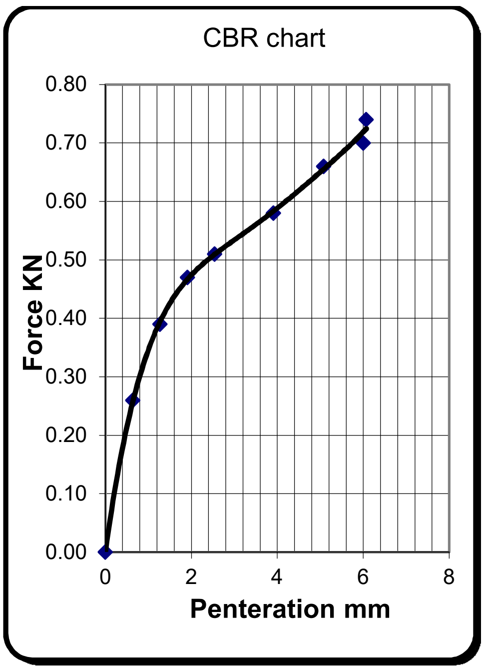

Fig C. 16 penetration vs load at 25mm of 0.50% Fiber, koshe sample

Table C. 17 CBR test at 25mm of 0.75% fiber, koshe sample

CBR at 25mm of 0.75% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.01	
0.64	0.25	
1.27	0.34	
2.54	0.47	3.52
3.18	0.55	
3.81	0.59	
5.08	0.64	3.2
7.62	0.72	
10.00	0.81	
12.50	0.89	

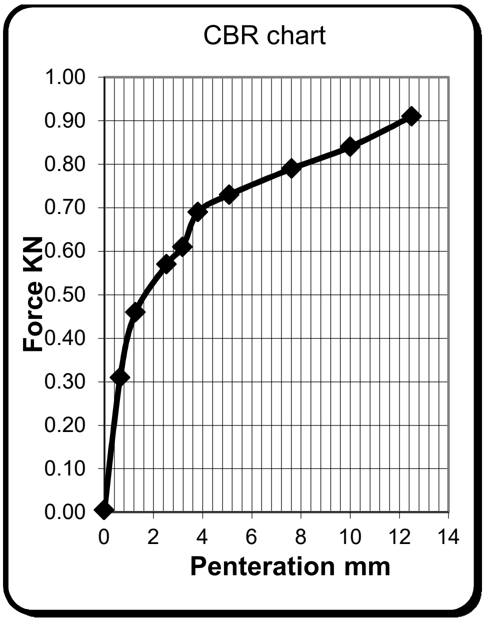

Fig C. 17 penetration vs load at 25mm of 0.75%, koshe sample

Table C. 18 CBR test at 25mm of 1% fiber, koshe sample

CBR at 25mm of 1% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.22	
1.27	0.28	
1.91	0.31	
2.54	0.44	3.30
3.18	0.46	
3.81	0.53	
5.08	0.59	2.96
7.62	0.66	
10.00	0.78	
12.50	0.85	

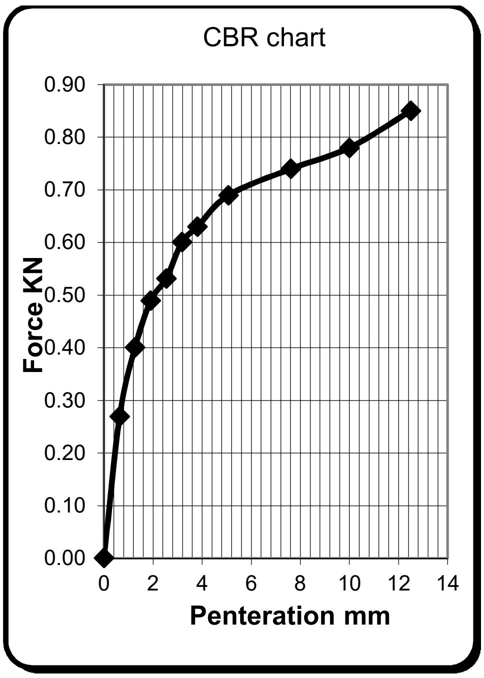

Fig C. 18 penetration vs load at 25mm of1% fiber,koshe sample

Table C. 19 CBR test at 50mm of 0.25% fiber, koshe sample

CBR at 50mm of 0.25% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.16	
1.27	0.20	
1.91	0.23	
2.54	0.34	2.55
3.18	0.36	
3.81	0.38	
5.08	0.41	2.05
7.62	0.46	
10.00		
12.50		

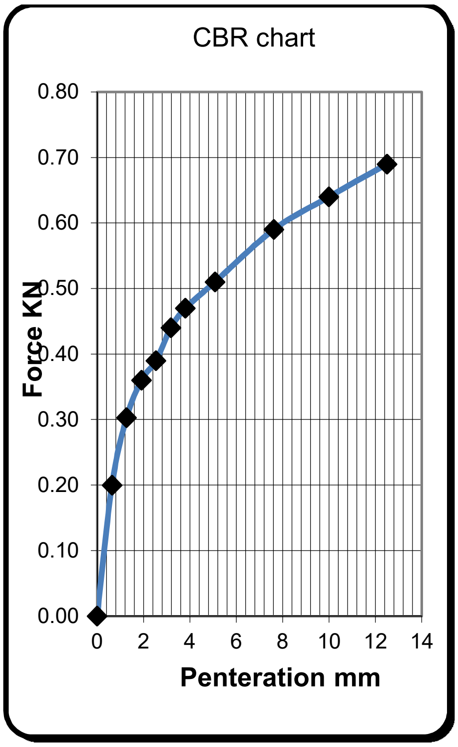

Fig C. 19 penetration vs load at 50mm of 0.25% fiber,koshe sample

Table C. 20 CBR test at 50mm of 0.50%fiber, koshe sample

CBR at 50mm of 0.50% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.01	
0.64	0.22	
1.27	0.27	
1.91	0.31	
2.54	0.39	2.92
3.18	0.45	
3.81	0.50	
5.08	0.54	2.70
7.62	0.59	
10.00	0.67	
12.50	0.75	

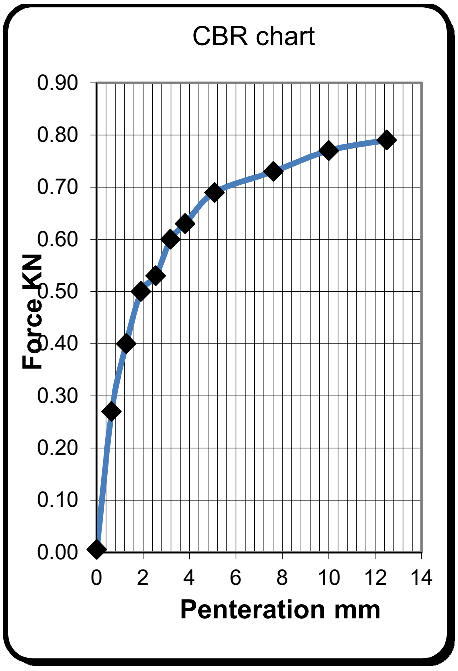

Fig C. 20 Penetration vs load at 50mm of 0.50% fiber,koshe sample

Table C. 21 CBR test at 50mm of 0.75% fiber, koshe sample

CBR at 50mm of 0.75% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.31	
1.27	0.37	
1.91	0.41	
2.54	0.55	4.12
3.18	0.62	
3.81	0.69	
5.08	0.74	3.70
7.62	0.84	
10.00	0.89	
12.50	0.94	

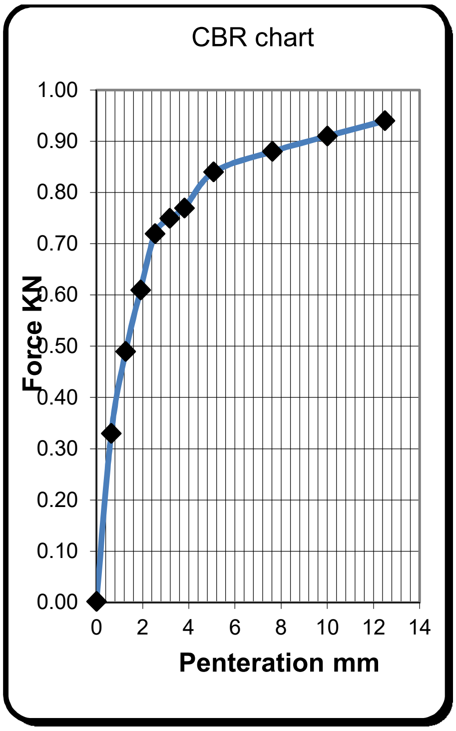

Fig C. 21 penetration vs load at 50mm of 0.75% fiber, koshe sample

Table C. 22 CBR test at 50mm of 1% fiber, koshe sample

CBR at 50mm of 1% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.24	
1.27	0.30	
1.91	0.46	
2.54	0.47	3.60
3.18	0.59	
3.81	0.63	
5.08	0.69	3.45
7.62	0.77	

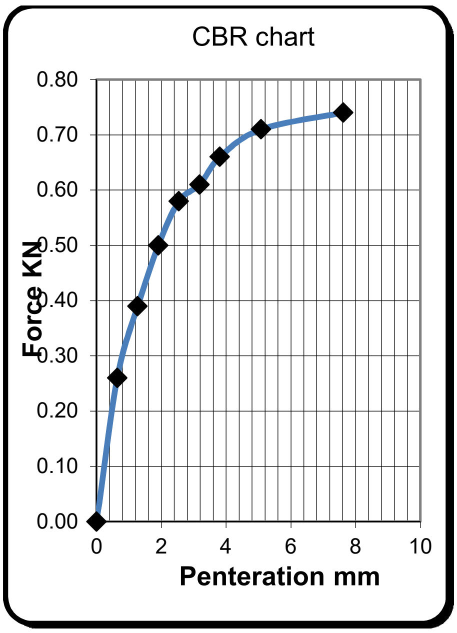

Fig C. 22 penetration vs load at 50mm of 1% fiber , koshe sample

Table C. 23 CBR test at 75mm of 0.25% fiber, koshe sample

CBR at 75mm of 0.25% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.21	
1.27	0.31	
1.91	0.38	
2.54	0.42	3.15
3.18	0.46	
3.81	0.49	
5.08	0.53	2.65
7.62	0.56	
10.00	0.59	
12.50	0.65	

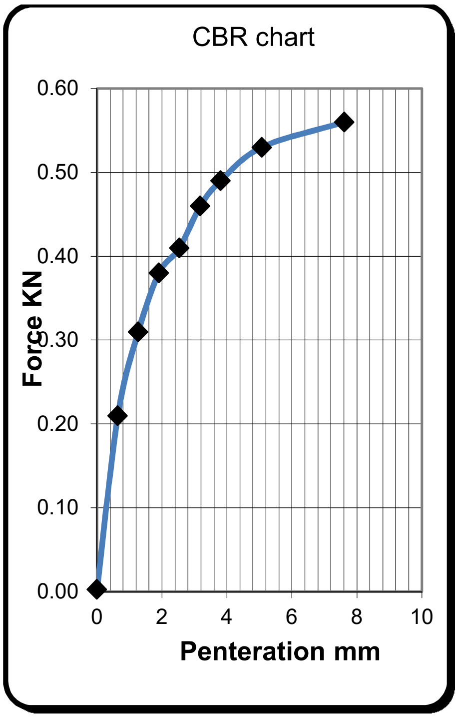

Fig C. 23 Penetration vs load at 75mm of 0.25% fiber,koshe sample

Table C. 24 CBR test at 75mm of 0.50% fiber, koshe sample

CBR at 75mm of 0.50% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.27	
1.27	0.41	
1.91	0.48	
2.50	0.54	4.05
3.18	0.59	
5.08	0.65	
7.62	0.70	3.50
10.00	0.74	
12.50	0.78	

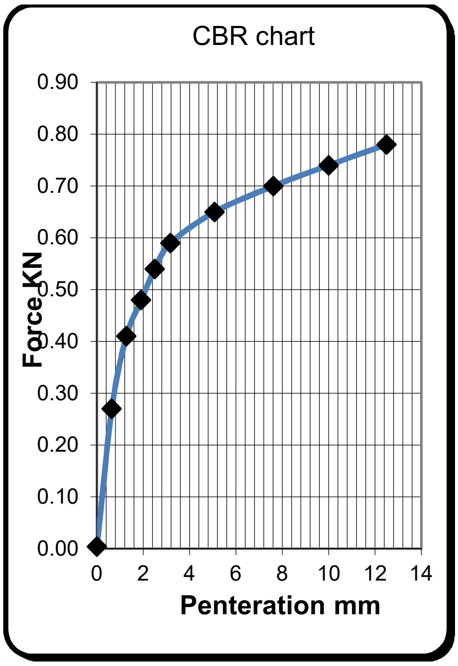

Fig C. 24 penetration vs load at 75mm of 0.50% fiber, koshe sample

Table C. 25 CBR test at 75mm of 0.75% fiber, koshe sample

CBR at 75mm of 0.75% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.37	
1.27	0.55	
1.91	0.68	
2.54	0.73	5.47
3.18	0.82	
3.81	0.86	
5.08	0.91	4.55
7.62	0.94	
10.00	0.97	
12.50	0.99	

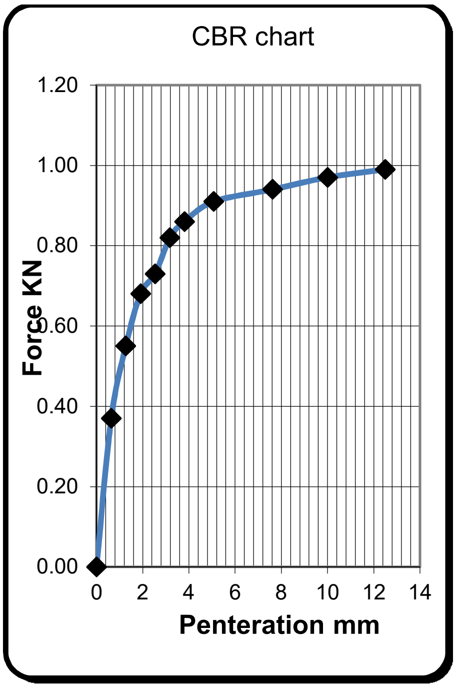

Fig C. 25 penetration vs load at 75mm of 0.75% Fiber, koshe sample

Table C. 26 CBR test at 75mm of 1% fiber, koshe sample

CBR at 75mm of 1% fiber		
penetration after 96 hrs soaking period		
plunger penetration, mm	load reading	CBR. %
0.00	0.00	
0.64	0.30	
1.27	0.44	
1.91	0.54	
2.54	0.59	4.42
3.18	0.66	
3.81	0.70	
5.08	0.76	3.80
7.62	0.80	
10.00	0.85	
12.50	0.90	

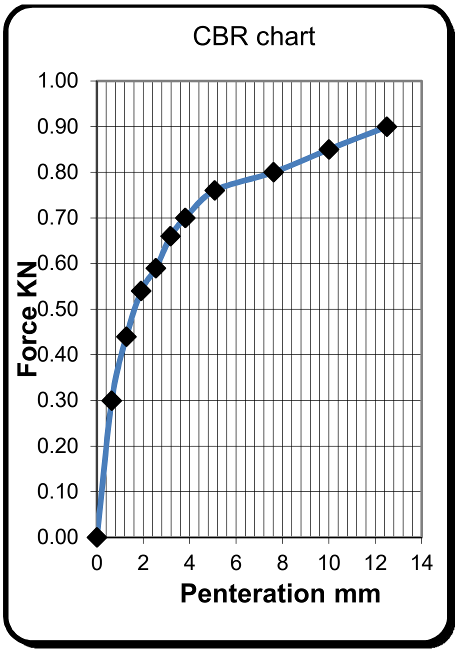

Fig C. 26 penetration vs load at 75mm of 1% fiber, koshe sample

D. Unconfined compressive strength(UCS)

Table D. 1 UCS of natural dippo sample

Test Type:	Unconfined Compression Test (ASTM D-2166)
Type of Sample:	Disturbed Soil Sample
Sample Location:	Dippo
Trial	0% Fiber
Unconfined compressive strength (qu) (KN/m^2)	81
Cohesion (c) (KN/m^2)	40.5

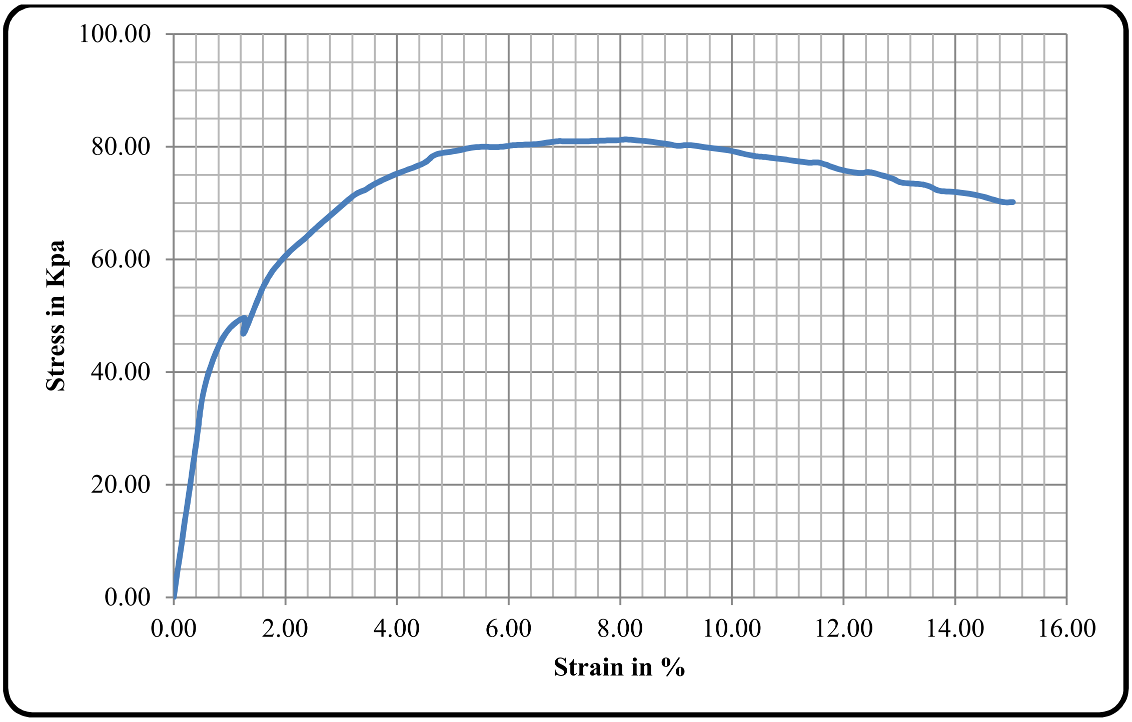

Fig D. 1stress vs strain of dippo natural sample

Table D. 2 UCS test result of natural dippo sample

Load (N)	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa)
0.00	0.00	75.00	0.00	0.00
28.56	0.28	75.00	0.37	25.10
42.55	0.42	75.00	0.55	37.33
52.84	0.67	75.00	0.89	46.20
56.93	0.95	75.00	1.26	49.59
53.93	0.95	75.00	1.26	46.97
64.31	1.23	75.00	1.64	55.80
69.94	1.49	75.00	1.99	60.47
74.22	1.78	75.00	2.37	63.92
76.37	1.92	75.00	2.56	65.64
80.04	2.17	75.00	2.90	68.57
83.73	2.44	75.00	3.25	71.47
84.90	2.57	75.00	3.43	72.33
86.46	2.72	75.00	3.62	73.51
88.59	2.97	75.00	3.96	75.06
90.53	3.25	75.00	4.33	76.41
91.70	3.39	75.00	4.51	77.25
93.45	3.52	75.00	4.69	78.57
94.61	3.79	75.00	5.06	79.24
95.78	4.07	75.00	5.42	79.91
96.17	4.34	75.00	5.79	79.93
96.56	4.48	75.00	5.97	80.10
96.95	4.60	75.00	6.13	80.29
97.53	4.87	75.00	6.49	80.45
98.50	5.14	75.00	6.86	80.94
98.70	5.26	75.00	7.02	80.96
99.08	5.54	75.00	7.39	80.95
99.66	5.82	75.00	7.76	81.10
99.86	5.95	75.00	7.93	81.11
100.25	6.09	75.00	8.11	81.26
100.25	6.37	75.00	8.49	80.93
100.05	6.65	75.00	8.86	80.44
99.86	6.78	75.00	9.04	80.13

100.25	6.92	75.00	9.23	80.28
100.05	7.19	75.00	9.59	79.81
99.86	7.46	75.00	9.94	79.34
99.28	7.71	75.00	10.27	78.58
99.08	7.84	75.00	10.46	78.27
99.08	7.98	75.00	10.64	78.11
98.89	8.27	75.00	11.02	77.62
98.70	8.53	75.00	11.38	77.16
98.89	8.68	75.00	11.57	77.14
97.72	8.96	75.00	11.95	75.91
97.34	9.23	75.00	12.30	75.30
97.72	9.36	75.00	12.47	75.46
96.75	9.65	75.00	12.86	74.37
95.97	9.78	75.00	13.03	73.63
95.97	10.03	75.00	13.37	73.35
95.65	10.15	75.00	13.54	72.96
94.81	10.29	75.00	13.72	72.16
94.81	10.56	75.00	14.08	71.86
94.42	10.83	75.00	14.44	71.26
93.45	11.13	75.00	14.83	70.21
93.56	11.28	75.00	15.03	70.13

Table D. 3 UCS test of 25mm-0.75% fiber dippo sample

Test Type:	Unconfined Compression Test (ASTM D-2166)			
Type of Sample:	Disturbed Soil Sample			
Sample Location:	Dippo			
Trail	T-01	T-02	T-03	Ave.
Unconfined compressive strength (qu) (KN/m^2)	113	158	195	155.30
Cohesion (c) (KN/m^2)	57	79	98	77.65

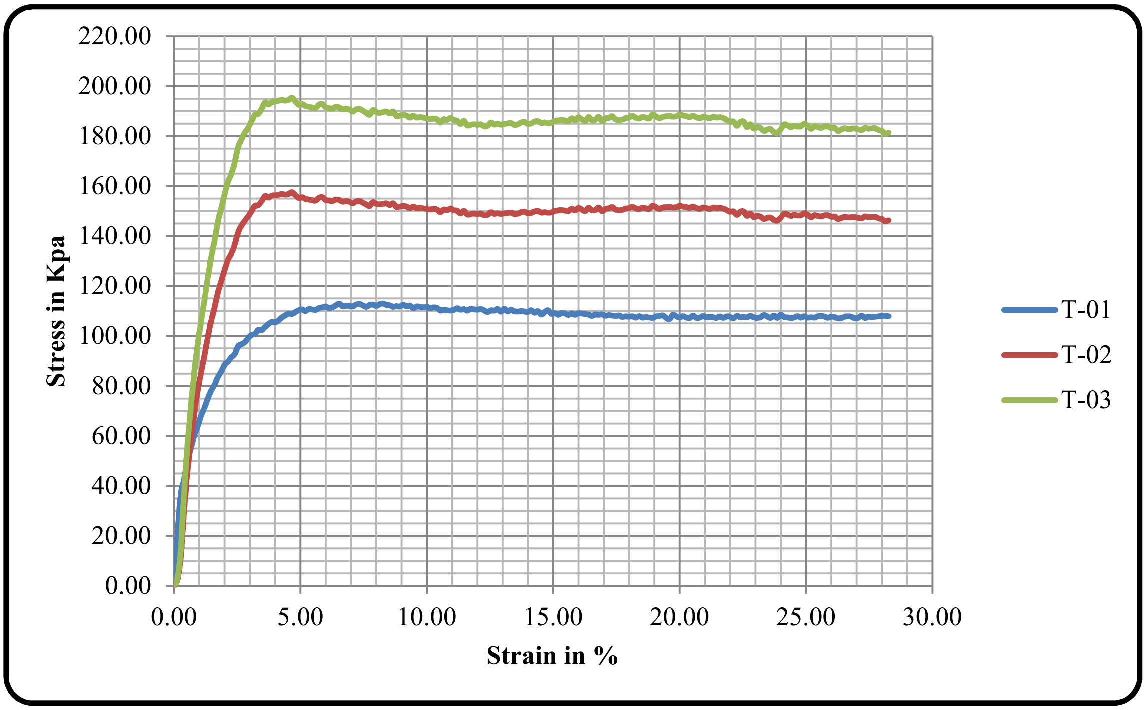

Fig D. 2strain vs stress of 25mm-0.75% fiber dippo sample

Table D. 4 UCS test at 25mm long of 0.75% fiber dippo sample

Load (N) Trial 1	Load (N) Trial 2	Load (N) Trial 3	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa) Trial 1	Stress (Kpa) Trial 2	Stress (Kpa) Trial 3
0.00	0.00	0.00	0.00	75.00	0.00	0.00	0	0
22.74	2.71	3.36	0.10	75.00	0.13	20.03	2.38491	2.957288
41.68	12.99	16.11	0.20	75.00	0.27	36.68	11.43176	14.17538
48.72	34.65	42.96	0.30	75.00	0.40	42.81	30.44305	37.74938
57.93	51.97	64.44	0.40	75.00	0.53	50.83	45.60388	56.54881
62.80	66.05	81.90	0.50	75.00	0.67	55.03	57.87682	71.76726
68.75	78.50	97.34	0.60	75.00	0.80	60.17	68.69544	85.18234
73.08	89.32	110.76	0.70	75.00	0.93	63.87	78.06545	96.80116
77.96	97.45	120.83	0.80	75.00	1.07	68.04	85.04824	105.4598
81.75	105.57	130.91	0.90	75.00	1.20	71.25	92.01542	114.0991
86.08	114.23	141.65	1.00	75.00	1.33	74.92	99.42916	123.2922
89.87	121.81	151.04	1.10	75.00	1.47	78.12	105.8837	131.2958
92.57	128.30	159.09	1.20	75.00	1.60	80.36	111.3743	138.1041
96.36	135.34	167.82	1.30	75.00	1.73	83.53	117.3263	145.4847
99.07	140.75	174.53	1.40	75.00	1.87	85.77	121.8507	151.0949
102.32	146.17	181.25	1.50	75.00	2.00	88.46	126.371	156.7001
103.94	151.04	187.29	1.60	75.00	2.13	89.74	130.4037	161.7006
106.11	154.29	191.32	1.70	75.00	2.27	91.49	133.0282	164.9549
107.73	158.62	196.69	1.80	75.00	2.40	92.76	136.5749	169.3529
111.52	164.57	204.07	1.90	75.00	2.53	95.89	141.5044	175.4655
112.60	167.82	208.10	2.00	75.00	2.67	96.69	144.1015	178.6858
113.69	170.53	211.46	2.10	75.00	2.80	97.49	146.2279	181.3226
115.85	172.69	214.14	2.20	75.00	2.93	99.20	147.8769	183.3674
117.47	175.40	217.50	2.30	75.00	3.07	100.45	149.9912	185.9891
118.02	178.11	220.86	2.40	75.00	3.20	100.78	152.0992	188.603
120.18	178.65	221.53	2.50	75.00	3.33	102.49	152.3502	188.9142
120.18	180.81	224.20	2.60	75.00	3.47	102.35	153.9795	190.9346
121.81	183.52	227.56	2.70	75.00	3.60	103.59	156.0715	193.5287
123.43	182.98	226.90	2.80	75.00	3.73	104.82	155.397	192.6923
124.51	184.06	228.23	2.90	75.00	3.87	105.59	156.0977	193.5612
124.51	184.60	228.90	3.00	75.00	4.00	105.45	156.3386	193.8598

125.59	185.15	229.59	3.10	75.00	4.13	106.21	156.5866	194.1673
127.22	185.69	230.26	3.20	75.00	4.27	107.44	156.8248	194.4628
128.30	185.69	230.26	3.30	75.00	4.40	108.21	156.6064	194.192
129.38	186.23	230.93	3.40	75.00	4.53	108.96	156.8428	194.4851
129.38	187.31	232.26	3.50	75.00	4.67	108.81	157.532	195.3397
130.47	186.23	230.93	3.60	75.00	4.80	109.57	156.4047	193.9418
131.55	185.15	229.59	3.70	75.00	4.93	110.33	155.2799	192.547
132.09	185.69	230.26	3.80	75.00	5.07	110.62	155.5143	192.8378
131.55	185.15	229.59	3.90	75.00	5.20	110.02	154.8443	192.0069
132.63	185.15	229.59	4.00	75.00	5.33	110.76	154.6265	191.7369
132.63	185.15	229.59	4.10	75.00	5.47	110.61	154.4087	191.4668
132.63	185.15	229.59	4.20	75.00	5.60	110.45	154.1909	191.1968
133.72	186.77	231.59	4.30	75.00	5.73	111.20	155.3204	192.5973
134.26	187.31	232.26	4.40	75.00	5.87	111.49	155.5491	192.8809
134.80	186.23	230.93	4.50	75.00	6.00	111.78	154.4332	191.4972
134.26	186.23	230.93	4.60	75.00	6.13	111.18	154.2141	191.2255
134.80	186.23	230.93	4.70	75.00	6.27	111.47	153.9951	190.9539
135.88	187.31	232.26	4.80	75.00	6.40	112.20	154.6678	191.7881
136.96	187.31	232.26	4.90	75.00	6.53	112.93	154.4475	191.5149
135.88	186.77	231.59	5.00	75.00	6.67	111.88	153.7825	190.6904
136.42	187.31	232.26	5.10	75.00	6.80	112.16	154.0068	190.9685
136.42	187.31	232.26	5.20	75.00	6.93	112.00	153.7865	190.6953
136.42	186.77	231.59	5.30	75.00	7.07	111.84	153.1235	189.8731
137.50	187.85	232.93	5.40	75.00	7.20	112.57	153.788	190.6971
138.05	188.39	233.60	5.50	75.00	7.33	112.86	154.0084	190.9705
137.50	187.85	232.93	5.60	75.00	7.47	112.24	153.346	190.1491
136.96	187.31	232.26	5.70	75.00	7.60	111.64	152.6849	189.3293
138.05	186.77	231.59	5.80	75.00	7.73	112.37	152.025	188.511
138.59	188.93	234.27	5.90	75.00	7.87	112.64	153.561	190.4156
138.05	188.39	233.60	6.00	75.00	8.00	112.04	152.9005	189.5966
139.13	188.39	233.60	6.10	75.00	8.13	112.76	152.6789	189.3218
139.67	188.93	234.27	6.20	75.00	8.27	113.03	152.8943	189.5889
139.13	189.48	234.96	6.30	75.00	8.40	112.43	153.1165	189.8645
139.13	188.93	234.27	6.40	75.00	8.53	112.27	152.4498	189.0378
138.59	190.02	235.62	6.50	75.00	8.67	111.67	153.1058	189.8512
139.13	188.39	233.60	6.60	75.00	8.80	111.94	151.5709	187.9479
139.13	188.93	234.27	6.70	75.00	8.93	111.77	151.7831	188.2111

140.21	189.48	234.96	6.80	75.00	9.07	112.48	152.0021	188.4826
139.67	189.48	234.96	6.90	75.00	9.20	111.88	151.7792	188.2063
140.21	188.93	234.27	7.00	75.00	9.33	112.15	151.1164	187.3844
139.13	190.02	235.62	7.10	75.00	9.47	111.12	151.7648	188.1883
140.21	189.48	234.96	7.20	75.00	9.60	111.82	151.1106	187.3772
140.21	190.02	235.62	7.30	75.00	9.73	111.65	151.3177	187.634
140.21	190.02	235.62	7.40	75.00	9.87	111.49	151.0942	187.3569
140.75	190.02	235.62	7.50	75.00	10.00	111.75	150.8707	187.0797
140.21	190.02	235.62	7.60	75.00	10.13	111.16	150.6472	186.8025
140.75	190.56	236.29	7.70	75.00	10.27	111.42	150.8512	187.0555
140.75	190.56	236.29	7.80	75.00	10.40	111.26	150.627	186.7775
139.67	189.48	234.96	7.90	75.00	10.53	110.24	149.5505	185.4426
140.21	191.10	236.96	8.00	75.00	10.67	110.50	150.6043	186.7493
140.21	191.10	236.96	8.10	75.00	10.80	110.33	150.3795	186.4706
140.21	192.18	238.30	8.20	75.00	10.93	110.17	151.0033	187.2441
140.75	191.64	237.63	8.30	75.00	11.07	110.43	150.3536	186.4385
141.84	191.64	237.63	8.40	75.00	11.20	111.12	150.1282	186.159
141.29	190.56	236.29	8.50	75.00	11.33	110.52	149.058	184.8319
141.84	192.18	238.30	8.60	75.00	11.47	110.78	150.0991	186.1229
141.29	190.56	236.29	8.70	75.00	11.60	110.19	148.6097	184.276
142.38	191.10	236.96	8.80	75.00	11.73	110.87	148.806	184.5195
142.38	191.64	237.63	8.90	75.00	11.87	110.70	149.0011	184.7614
142.38	191.64	237.63	9.00	75.00	12.00	110.53	148.7757	184.4819
142.92	192.18	238.30	9.10	75.00	12.13	110.78	148.9689	184.7214
142.38	191.64	237.63	9.20	75.00	12.27	110.20	148.3249	183.9228
141.84	192.18	238.30	9.30	75.00	12.40	109.61	148.5168	184.1608
142.92	193.81	240.32	9.40	75.00	12.53	110.28	149.5484	185.4401
142.92	193.27	239.65	9.50	75.00	12.67	110.11	148.9044	184.6415
144.00	193.81	240.32	9.60	75.00	12.80	110.78	149.0925	184.8747
142.92	193.81	240.32	9.70	75.00	12.93	109.78	148.8645	184.592
144.54	194.35	240.99	9.80	75.00	13.07	110.85	149.0507	184.8229
143.46	194.89	241.66	9.90	75.00	13.20	109.85	149.2356	185.0521
144.54	195.43	242.33	10.00	75.00	13.33	110.51	149.4192	185.2798
144.00	194.89	241.66	10.10	75.00	13.47	109.93	148.7771	184.4836
144.00	195.43	242.33	10.20	75.00	13.60	109.76	148.9595	184.7097
144.54	196.51	243.67	10.30	75.00	13.73	110.00	149.5515	185.4439
144.54	197.06	244.35	10.40	75.00	13.87	109.83	149.7383	185.6755

144.54	196.51	243.67	10.50	75.00	14.00	109.66	149.0892	184.8706
145.63	197.06	244.35	10.60	75.00	14.13	110.32	149.2747	185.1006
144.54	198.14	245.69	10.70	75.00	14.27	109.32	149.8598	185.8261
145.63	198.68	246.36	10.80	75.00	14.40	109.97	150.0345	186.0428
144.00	198.14	245.69	10.90	75.00	14.53	108.57	149.3936	185.2481
145.63	198.68	246.36	11.00	75.00	14.67	109.63	149.5671	185.4632
146.71	198.68	246.36	11.10	75.00	14.80	110.27	149.3334	185.1734
145.08	199.22	247.03	11.20	75.00	14.93	108.88	149.5049	185.3861
145.63	200.30	248.37	11.30	75.00	15.07	109.12	150.0798	186.099
145.08	200.84	249.04	11.40	75.00	15.20	108.53	150.2482	186.3077
146.17	201.39	249.72	11.50	75.00	15.33	109.18	150.4227	186.5242
146.17	201.39	249.72	11.60	75.00	15.47	109.01	150.1859	186.2305
145.63	201.39	249.72	11.70	75.00	15.60	108.43	149.949	185.9367
146.71	203.01	251.73	11.80	75.00	15.73	109.06	150.9164	187.1363
146.17	202.47	251.06	11.90	75.00	15.87	108.49	150.2768	186.3432
147.25	204.09	253.07	12.00	75.00	16.00	109.12	151.2391	187.5365
147.25	203.55	252.40	12.10	75.00	16.13	108.95	150.5995	186.7434
147.25	203.01	251.73	12.20	75.00	16.27	108.77	149.9612	185.9519
147.25	205.18	254.42	12.30	75.00	16.40	108.60	151.3228	187.6403
146.71	204.09	253.07	12.40	75.00	16.53	108.03	150.2789	186.3458
147.79	204.63	253.74	12.50	75.00	16.67	108.65	150.4358	186.5404
147.79	206.26	255.76	12.60	75.00	16.80	108.48	151.3915	187.7255
148.33	204.63	253.74	12.70	75.00	16.93	108.70	149.9544	185.9435
147.79	206.26	255.76	12.80	75.00	17.07	108.13	150.9063	187.1238
148.33	206.80	256.43	12.90	75.00	17.20	108.35	151.0581	187.312
148.33	207.88	257.77	13.00	75.00	17.33	108.17	151.6025	187.9871
148.33	206.80	256.43	13.10	75.00	17.47	108.00	150.5716	186.7088
148.87	206.80	256.43	13.20	75.00	17.60	108.22	150.3284	186.4072
148.33	207.34	257.10	13.30	75.00	17.73	107.65	150.477	186.5915
148.87	208.42	258.44	13.40	75.00	17.87	107.87	151.0157	187.2594
148.87	208.96	259.11	13.50	75.00	18.00	107.69	151.1611	187.4398
149.41	210.05	260.46	13.60	75.00	18.13	107.91	151.7026	188.1112
148.87	209.51	259.79	13.70	75.00	18.27	107.34	151.0661	187.322
149.96	209.51	259.79	13.80	75.00	18.40	107.95	150.8197	187.0164
149.41	210.59	261.13	13.90	75.00	18.53	107.38	151.3494	187.6733
149.96	210.59	261.13	14.00	75.00	18.67	107.60	151.1017	187.3662
149.96	210.59	261.13	14.10	75.00	18.80	107.42	150.854	187.059

149.96	212.75	263.81	14.20	75.00	18.93	107.25	152.1511	188.6673
151.04	212.21	263.14	14.30	75.00	19.07	107.84	151.5153	187.8789
151.58	211.67	262.47	14.40	75.00	19.20	108.05	150.8807	187.0921
152.12	212.75	263.81	14.50	75.00	19.33	108.25	151.4003	187.7364
151.04	213.30	264.49	14.60	75.00	19.47	107.31	151.5408	187.9106
150.50	213.84	265.16	14.70	75.00	19.60	106.75	151.673	188.0745
153.20	213.84	265.16	14.80	75.00	19.73	108.48	151.4214	187.7626
152.66	214.38	265.83	14.90	75.00	19.87	107.92	151.5516	187.924
152.12	215.46	267.17	15.00	75.00	20.00	107.36	152.0617	188.5565
153.20	215.46	267.17	15.10	75.00	20.13	107.94	151.8082	188.2422
152.66	215.46	267.17	15.20	75.00	20.27	107.38	151.5548	187.928
152.66	215.46	267.17	15.30	75.00	20.40	107.20	151.3014	187.6137
154.29	216.54	268.51	15.40	75.00	20.53	108.16	151.8051	188.2383
153.20	216.00	267.84	15.50	75.00	20.67	107.22	151.1724	187.4538
153.75	216.00	267.84	15.60	75.00	20.80	107.42	150.9184	187.1388
154.83	217.09	269.19	15.70	75.00	20.93	108.00	151.4246	187.7665
154.29	217.09	269.19	15.80	75.00	21.07	107.44	151.1692	187.4498
154.83	217.09	269.19	15.90	75.00	21.20	107.63	150.9139	187.1332
154.83	218.17	270.53	16.00	75.00	21.33	107.45	151.408	187.746
154.83	218.17	270.53	16.10	75.00	21.47	107.27	151.1514	187.4278
155.91	218.71	271.20	16.20	75.00	21.60	107.83	151.2683	187.5727
155.37	218.71	271.20	16.30	75.00	21.73	107.28	151.011	187.2537
156.45	218.17	270.53	16.40	75.00	21.87	107.84	150.3815	186.4731
156.45	217.63	269.86	16.50	75.00	22.00	107.65	149.7533	185.6941
155.91	218.17	270.53	16.60	75.00	22.13	107.10	149.8683	185.8367
157.54	216.54	268.51	16.70	75.00	22.27	108.03	148.4939	184.1324
156.99	218.71	271.20	16.80	75.00	22.40	107.47	149.7247	185.6587
157.54	219.25	271.87	16.90	75.00	22.53	107.66	149.8365	185.7973
157.54	217.09	269.19	17.00	75.00	22.67	107.48	148.105	183.6502
158.62	218.71	271.20	17.10	75.00	22.80	108.03	148.9529	184.7017
158.08	217.09	269.19	17.20	75.00	22.93	107.47	147.5943	183.0169
158.08	218.17	270.53	17.30	75.00	23.07	107.29	148.0719	183.6092
158.62	218.17	270.53	17.40	75.00	23.20	107.47	147.8153	183.291
160.24	217.09	269.19	17.50	75.00	23.33	108.38	146.8282	182.067
159.70	218.17	270.53	17.60	75.00	23.47	107.82	147.3021	182.6546
159.16	218.71	271.20	17.70	75.00	23.60	107.27	147.4094	182.7876
160.78	217.63	269.86	17.80	75.00	23.73	108.18	146.4255	181.5676

159.70	217.63	269.86	17.90	75.00	23.87	107.26	146.1695	181.2502
161.87	219.79	272.54	18.00	75.00	24.00	108.53	147.3617	182.7285
160.78	222.50	275.90	18.10	75.00	24.13	107.61	148.917	184.657
160.78	222.50	275.90	18.20	75.00	24.27	107.42	148.6552	184.3325
160.78	221.96	275.23	18.30	75.00	24.40	107.23	148.0334	183.5614
161.32	223.04	276.57	18.40	75.00	24.53	107.40	148.4913	184.1292
162.41	223.04	276.57	18.50	75.00	24.67	107.94	148.229	183.8039
161.87	223.58	277.24	18.60	75.00	24.80	107.39	148.3249	183.9228
162.95	225.21	279.26	18.70	75.00	24.93	107.91	149.1413	184.9352
162.41	224.66	278.58	18.80	75.00	25.07	107.36	148.5128	184.1559
162.95	223.58	277.24	18.90	75.00	25.20	107.53	147.5359	182.9445
162.95	225.21	279.26	19.00	75.00	25.33	107.34	148.3466	183.9498
164.03	225.21	279.26	19.10	75.00	25.47	107.85	148.0817	183.6213
164.57	225.21	279.26	19.20	75.00	25.60	108.02	147.8168	183.2928
164.57	226.29	280.60	19.30	75.00	25.73	107.82	148.2595	183.8417
164.03	226.83	281.27	19.40	75.00	25.87	107.28	148.3465	183.9496
165.11	226.29	280.60	19.50	75.00	26.00	107.79	147.7271	183.1816
165.11	226.83	281.27	19.60	75.00	26.13	107.59	147.8128	183.2879
164.57	225.75	279.93	19.70	75.00	26.27	107.05	146.8435	182.086
165.11	226.83	281.27	19.80	75.00	26.40	107.20	147.2792	182.6262
166.20	227.91	282.61	19.90	75.00	26.53	107.72	147.7124	183.1633
166.74	227.91	282.61	20.00	75.00	26.67	107.87	147.4443	182.8309
166.74	228.45	283.28	20.10	75.00	26.80	107.67	147.5249	182.9309
166.20	229.00	283.96	20.20	75.00	26.93	107.13	147.6107	183.0373
166.74	229.00	283.96	20.30	75.00	27.07	107.28	147.3414	182.7033
168.36	229.00	283.96	20.40	75.00	27.20	108.13	147.072	182.3693
167.28	230.62	285.97	20.50	75.00	27.33	107.24	147.8412	183.323
168.36	230.62	285.97	20.60	75.00	27.47	107.73	147.5699	182.9867
168.36	231.16	286.64	20.70	75.00	27.60	107.53	147.6435	183.078
168.90	231.70	287.31	20.80	75.00	27.73	107.68	147.7159	183.1677

Table D. 5 UCS result at 50mm length of 0.75% fiber,dippo sample

Test Type:	Unconfined Compression Test (ASTM D-2166)			
Type of Sample:	Disturbed Soil Sample			
Sample Location:	Dippo			
Trial	T-01	T-02	T-03	Ave.
Unconfined compressive strength (qu) (KN/m^2)	185	189	165	179.30
Cohesion (c) (KN/m^2)	92	94	82	89.65

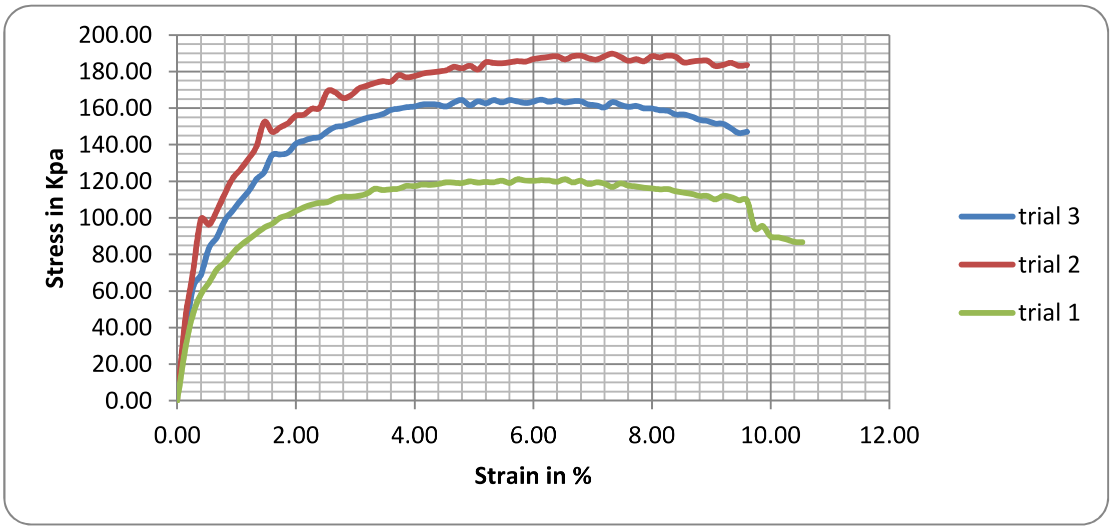

Fig D. 3strain vs stress at 50mm of 0.75% fiber dippo sample

Table D. 6 UCS result at 50mm length of 0.75% fiber,dippo sample

Load (N) Trial 1	Load (N) Trial 2	Load (N) Trial 3	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa) Trial 1	Stress (Kpa) Trial 2	Stress (Kpa) Trial 3
0.00	0.00	0.97	0.00	75.00	0.00	0.00	0.00	0.86
47.98	49.93	40.14	0.10	75.00	0.13	42.27	43.99	35.36
82.25	80.32	70.49	0.20	75.00	0.27	72.37	70.67	62.02
100.85	113.03	78.41	0.30	75.00	0.40	88.61	99.32	68.90
111.63	109.67	94.99	0.40	75.00	0.53	97.95	96.23	83.35
124.36	118.48	101.84	0.50	75.00	0.67	108.98	103.83	89.24
131.21	129.26	112.60	0.60	75.00	0.80	114.83	113.12	98.54
140.26	139.05	118.85	0.70	75.00	0.93	122.58	121.52	103.87
147.86	144.92	125.34	0.80	75.00	1.07	129.05	126.48	109.39
153.74	151.77	131.27	0.90	75.00	1.20	134.00	132.28	114.42
159.61	159.60	139.05	1.00	75.00	1.33	138.93	138.92	121.03
165.49	175.35	143.94	1.10	75.00	1.47	143.85	152.42	125.12
169.40	169.33	154.74	1.20	75.00	1.60	147.05	146.99	134.33
175.29	172.38	155.28	1.30	75.00	1.73	151.96	149.44	134.61
178.22	175.26	156.71	1.40	75.00	1.87	154.29	151.73	135.67
182.14	180.27	162.49	1.50	75.00	2.00	157.47	155.85	140.48
186.05	181.18	164.61	1.60	75.00	2.13	160.63	156.43	142.12
188.98	185.14	166.46	1.70	75.00	2.27	162.94	159.63	143.52
190.95	186.06	167.50	1.80	75.00	2.40	164.41	160.20	144.22
191.93	196.87	171.35	1.90	75.00	2.53	165.03	169.28	147.33
195.84	196.24	174.34	2.00	75.00	2.67	168.16	168.50	149.70
197.81	192.93	175.26	2.10	75.00	2.80	169.62	165.44	150.28
197.96	195.18	177.23	2.20	75.00	2.93	169.52	167.14	151.76
199.09	199.80	179.21	2.30	75.00	3.07	170.25	170.86	153.25
201.71	201.70	181.18	2.40	75.00	3.20	172.25	172.24	154.72
206.62	203.83	182.44	2.50	75.00	3.33	176.20	173.82	155.58
205.64	205.14	184.07	2.60	75.00	3.47	175.12	174.70	156.76
206.41	205.11	186.96	2.70	75.00	3.60	175.54	174.43	159.00
207.25	209.64	188.02	2.80	75.00	3.73	176.01	178.04	159.68
210.52	208.41	189.23	2.90	75.00	3.87	178.54	176.75	160.48
210.12	209.61	190.01	3.00	75.00	4.00	177.95	177.52	160.92
212.49	211.45	191.54	3.10	75.00	4.13	179.71	178.83	161.99

211.98	212.50	192.03	3.20	75.00	4.27	179.03	179.47	162.18
213.47	213.47	191.89	3.30	75.00	4.40	180.04	180.04	161.84
215.42	214.49	191.04	3.40	75.00	4.53	181.43	180.64	160.89
215.42	217.06	193.95	3.50	75.00	4.67	181.17	182.55	163.12
215.36	216.45	195.78	3.60	75.00	4.80	180.87	181.78	164.43
217.39	218.42	192.59	3.70	75.00	4.93	182.32	183.18	161.52
216.40	216.21	195.54	3.80	75.00	5.07	181.23	181.07	163.76
217.38	221.31	194.50	3.90	75.00	5.20	181.80	185.09	162.66
217.38	221.12	196.84	4.00	75.00	5.33	181.54	184.67	164.39
219.36	221.31	195.57	4.10	75.00	5.47	182.94	184.56	163.10
217.41	222.22	197.33	4.20	75.00	5.60	181.06	185.06	164.33
221.31	223.29	196.84	4.30	75.00	5.73	184.04	185.69	163.69
220.33	223.29	195.98	4.40	75.00	5.87	182.97	185.43	162.75
221.21	225.26	197.22	4.50	75.00	6.00	183.44	186.80	163.55
221.30	226.41	198.82	4.60	75.00	6.13	183.26	187.49	164.64
221.41	227.31	197.66	4.70	75.00	6.27	183.09	187.96	163.45
220.33	228.15	198.82	4.80	75.00	6.40	181.93	188.39	164.17
223.26	226.34	197.75	4.90	75.00	6.53	184.09	186.63	163.06
224.14	228.78	198.82	5.00	75.00	6.67	184.55	188.37	163.70
222.41	229.50	199.15	5.10	75.00	6.80	182.87	188.70	163.74
219.35	228.11	197.24	5.20	75.00	6.93	180.09	187.28	161.94
221.30	227.54	196.99	5.30	75.00	7.07	181.43	186.55	161.50
221.95	230.13	195.87	5.40	75.00	7.20	181.70	188.40	160.35
217.38	232.10	199.73	5.50	75.00	7.33	177.71	189.74	163.28
222.44	230.32	198.28	5.60	75.00	7.47	181.58	188.02	161.86
219.36	228.00	197.14	5.70	75.00	7.60	178.81	185.85	160.70
218.80	229.41	198.01	5.80	75.00	7.73	178.10	186.73	161.17
217.72	228.33	196.68	5.90	75.00	7.87	176.96	185.59	159.86
216.85	232.11	196.84	6.00	75.00	8.00	176.00	188.38	159.76
216.12	231.61	195.94	6.10	75.00	8.13	175.15	187.71	158.80
217.38	233.23	195.87	6.20	75.00	8.27	175.92	188.74	158.51
215.42	232.76	193.69	6.30	75.00	8.40	174.08	188.09	156.52
214.45	229.22	193.95	6.40	75.00	8.53	173.04	184.96	156.50
213.47	230.13	192.89	6.50	75.00	8.67	172.00	185.42	155.42
211.52	231.04	190.91	6.60	75.00	8.80	170.18	185.89	153.60
211.12	231.41	190.36	6.70	75.00	8.93	169.61	185.91	152.93
208.56	228.15	188.94	6.80	75.00	9.07	167.31	183.02	151.57

212.49	229.22	188.95	6.90	75.00	9.20	170.21	183.61	151.35
211.52	231.01	186.08	7.00	75.00	9.33	169.19	184.77	148.84
208.57	229.23	183.23	7.10	75.00	9.47	166.58	183.08	146.34
208.91	230.13	184.38	7.20	75.00	9.60	166.61	183.53	147.04

Table D. 7 UCS test at 75mm length of 0.75% fiber,dippo sample

Test Type:	Unconfined Compression Test (ASTM D-2166)		
Type of Sample:	Disturbed Soil Sample		
Sample Location:	Dippo		
Trial	T-01	T-02	Ave.
Unconfined compressive strength (qu) (KN/m^2)	240	294	267.25
Cohesion (c) (KN/m^2)	120	147	133.62

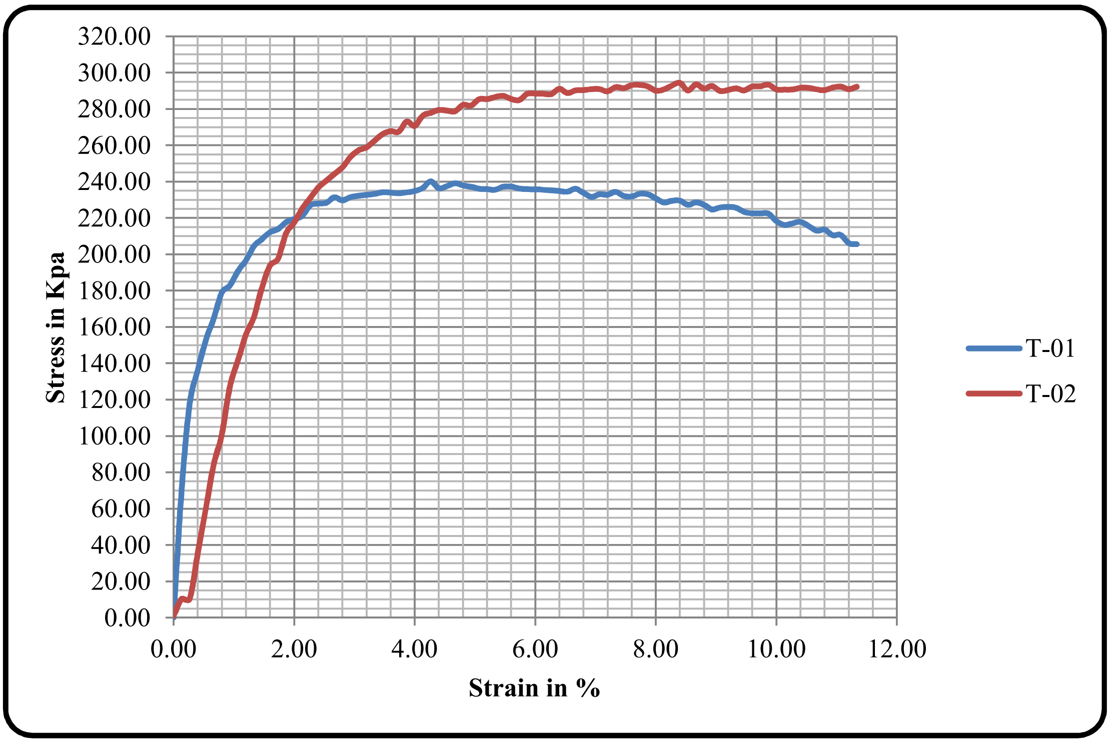

Fig D. 4strain vs stress of at 75mm length of 0.75% fiber, dippo sample

Table D. 8 UCS result of at 75mm length of 0.75% fiber, dippo sample

Load (N) Trial 1	Load (N) Trial 2	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa) Trial 1	Stress (Kpa) Trial 2
0.00	1.11	0.00	75.00	0.00	0.00	0.98
79.90	11.75	0.10	75.00	0.13	70.39	10.35
133.95	11.75	0.20	75.00	0.27	117.85	10.34
155.00	39.95	0.30	75.00	0.40	136.19	35.10
173.90	68.15	0.40	75.00	0.53	152.59	59.80
188.00	96.35	0.50	75.00	0.67	164.75	84.43
204.45	115.15	0.60	75.00	0.80	178.92	100.77
209.15	145.50	0.70	75.00	0.93	182.79	127.16
218.55	162.15	0.80	75.00	1.07	190.75	141.52
225.60	178.60	0.90	75.00	1.20	196.63	155.67
235.00	190.35	1.00	75.00	1.33	204.55	165.69
239.70	209.15	1.10	75.00	1.47	208.36	181.80
244.40	223.25	1.20	75.00	1.60	212.16	193.80
246.75	227.95	1.30	75.00	1.73	213.91	197.61
251.45	244.40	1.40	75.00	1.87	217.69	211.58
253.80	251.45	1.50	75.00	2.00	219.42	217.39
256.15	260.85	1.60	75.00	2.13	221.15	225.21
263.20	267.90	1.70	75.00	2.27	226.93	230.98
264.80	274.95	1.80	75.00	2.40	228.00	236.74
265.55	279.65	1.90	75.00	2.53	228.33	240.46
269.44	284.35	2.00	75.00	2.67	231.36	244.16
267.90	289.05	2.10	75.00	2.80	229.72	247.86
270.25	296.10	2.20	75.00	2.93	231.42	253.55
271.47	300.80	2.30	75.00	3.07	232.14	257.23
272.60	303.15	2.40	75.00	3.20	232.79	258.88
273.50	307.85	2.50	75.00	3.33	233.24	262.53
274.95	312.55	2.60	75.00	3.47	234.15	266.17
275.11	314.90	2.70	75.00	3.60	233.96	267.80
275.00	314.90	2.80	75.00	3.73	233.55	267.43
276.00	321.95	2.90	75.00	3.87	234.07	273.04
277.30	319.60	3.00	75.00	4.00	234.85	270.67
279.65	326.65	3.10	75.00	4.13	236.51	276.26

284.35	329.00	3.20	75.00	4.27	240.15	277.86
280.22	331.35	3.30	75.00	4.40	236.33	279.45
282.00	331.35	3.40	75.00	4.53	237.50	279.06
284.30	331.35	3.50	75.00	4.67	239.10	278.67
283.24	336.05	3.60	75.00	4.80	237.88	282.23
282.84	336.06	3.70	75.00	4.93	237.21	281.84
281.89	340.75	3.80	75.00	5.07	236.08	285.38
282.00	341.25	3.90	75.00	5.20	235.84	285.39
282.00	343.10	4.00	75.00	5.33	235.51	286.54
284.35	344.40	4.10	75.00	5.47	237.14	287.22
284.94	342.89	4.20	75.00	5.60	237.29	285.56
284.01	342.54	4.30	75.00	5.73	236.19	284.86
284.00	347.22	4.40	75.00	5.87	235.84	288.34
284.35	347.88	4.50	75.00	6.00	235.80	288.48
284.35	348.25	4.60	75.00	6.13	235.47	288.38
284.35	348.47	4.70	75.00	6.27	235.13	288.15
284.35	352.50	4.80	75.00	6.40	234.80	291.07
284.35	350.15	4.90	75.00	6.53	234.46	288.72
286.70	352.50	5.00	75.00	6.67	236.06	290.24
284.35	353.11	5.10	75.00	6.80	233.79	290.33
282.00	354.31	5.20	75.00	6.93	231.53	290.90
284.35	354.85	5.30	75.00	7.07	233.12	290.92
284.35	353.88	5.40	75.00	7.20	232.79	289.71
286.70	357.20	5.50	75.00	7.33	234.38	292.01
284.35	356.94	5.60	75.00	7.47	232.12	291.38
284.35	359.55	5.70	75.00	7.60	231.79	293.09
286.70	360.24	5.80	75.00	7.73	233.36	293.22
286.70	359.69	5.90	75.00	7.87	233.03	292.35
284.35	357.34	6.00	75.00	8.00	230.78	290.02
282.00	358.71	6.10	75.00	8.13	228.54	290.71
283.54	361.90	6.20	75.00	8.27	229.46	292.87
284.00	364.25	6.30	75.00	8.40	229.50	294.35
281.58	359.55	6.40	75.00	8.53	227.21	290.13
283.69	364.25	6.50	75.00	8.67	228.58	293.49
282.42	361.90	6.60	75.00	8.80	227.22	291.17
279.65	364.25	6.70	75.00	8.93	224.67	292.63
281.49	361.35	6.80	75.00	9.07	225.81	289.88

282.24	362.55	6.90	75.00	9.20	226.08	290.41
282.00	364.25	7.00	75.00	9.33	225.56	291.35
279.65	363.36	7.10	75.00	9.47	223.35	290.21
279.00	366.60	7.20	75.00	9.60	222.50	292.36
279.42	367.22	7.30	75.00	9.73	222.51	292.43
279.65	368.95	7.40	75.00	9.87	222.36	293.37
274.95	366.14	7.50	75.00	10.00	218.30	290.71
272.60	366.60	7.60	75.00	10.13	216.12	290.64
274.11	367.22	7.70	75.00	10.27	216.99	290.70
275.61	368.95	7.80	75.00	10.40	217.85	291.63
273.10	369.38	7.90	75.00	10.53	215.55	291.54
270.25	368.95	8.00	75.00	10.67	212.98	290.77
271.45	368.95	8.10	75.00	10.80	213.61	290.33
267.90	371.30	8.20	75.00	10.93	210.50	291.74
268.55	372.61	8.30	75.00	11.07	210.69	292.34
263.20	371.30	8.40	75.00	11.20	206.19	290.87
262.80	373.65	8.50	75.00	11.33	205.56	292.27

Table D. 9 UCS test natural koshe sample

Test Type:	Unconfined Compression Test (ASTM D-2166)
Type of Sample:	Disturbed Soil Sample
Sample Location:	Koshe
Unconfined compressive strength (qu) (KN/m^2)	63
Cohesion (c) (KN/m^2)	31.5

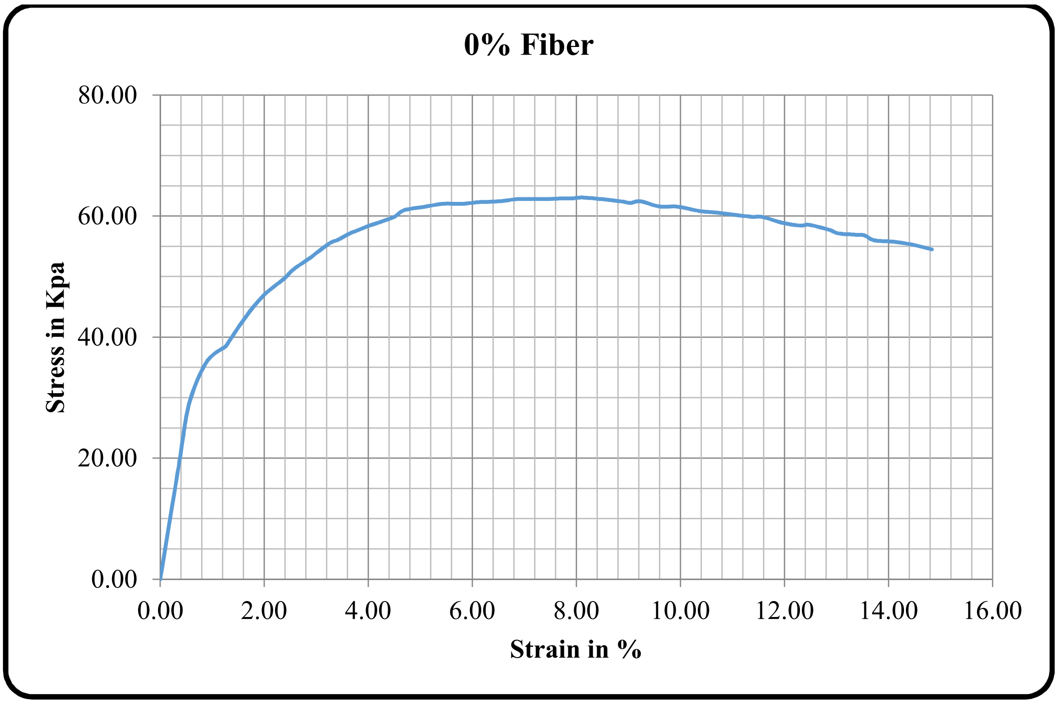

Fig D. 5strain vs stress of natural koshe sample

Table D. 10 UCS result natural koshe sample

Load (N)	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa)
0.00	0.00	75.00	0.00	0.00
22.16	0.28	75.00	0.37	19.48
33.01	0.42	75.00	0.55	28.96
41.00	0.67	75.00	0.89	35.85
44.17	0.95	75.00	1.26	38.47
44.17	0.95	75.00	1.26	38.47
49.90	1.23	75.00	1.64	43.30
54.27	1.49	75.00	1.99	46.92
57.59	1.78	75.00	2.37	49.60
59.54	1.92	75.00	2.56	51.18
62.11	2.17	75.00	2.90	53.21
64.97	2.44	75.00	3.25	55.46
65.88	2.57	75.00	3.43	56.13
67.08	2.72	75.00	3.62	57.03
68.74	2.97	75.00	3.96	58.24
70.25	3.25	75.00	4.33	59.29
71.15	3.39	75.00	4.51	59.94
72.51	3.52	75.00	4.69	60.97
73.41	3.79	75.00	5.06	61.49
74.32	4.07	75.00	5.42	62.01
74.62	4.34	75.00	5.79	62.02
74.92	4.48	75.00	5.97	62.15
75.22	4.60	75.00	6.13	62.29
75.67	4.87	75.00	6.49	62.42
76.43	5.14	75.00	6.86	62.80
76.58	5.26	75.00	7.02	62.82
76.88	5.54	75.00	7.39	62.81
77.33	5.82	75.00	7.76	62.92
77.48	5.95	75.00	7.93	62.93
77.78	6.09	75.00	8.11	63.05
77.78	6.37	75.00	8.49	62.79
77.63	6.65	75.00	8.86	62.41

77.47	6.78	75.00	9.04	62.17
77.97	6.92	75.00	9.23	62.44
77.22	7.19	75.00	9.59	61.59
77.48	7.46	75.00	9.94	61.56
77.03	7.71	75.00	10.27	60.97
76.88	7.84	75.00	10.46	60.73
76.88	7.98	75.00	10.64	60.61
76.73	8.27	75.00	11.02	60.23
76.58	8.53	75.00	11.38	59.87
76.73	8.68	75.00	11.57	59.86
75.83	8.96	75.00	11.95	58.90
75.52	9.23	75.00	12.30	58.43
75.83	9.36	75.00	12.47	58.55
75.07	9.65	75.00	12.86	57.71
74.47	9.78	75.00	13.03	57.13
74.47	10.03	75.00	13.37	56.91
74.47	10.15	75.00	13.54	56.80
73.56	10.29	75.00	13.72	55.99
73.56	10.56	75.00	14.08	55.76
73.26	10.83	75.00	14.44	55.29
72.51	11.13	75.00	14.83	54.48
72.51	11.28	75.00	15.03	54.35

Table D. 11 UCS test at 25mm length of 0.75% fiber, koshe sample

Test Type:	Unconfined Compression Test (ASTM D-2166)			
Type of Sample:	Disturbed Soil Sample			
Sample Location:	koshe			
Trail	T-01	T-02	T-03	Ave.
Unconfined compressive strength (qu) (KN/m^2)	102	104	91	99.00
Cohesion (c) (KN/m^2)	51	52	46	49.50

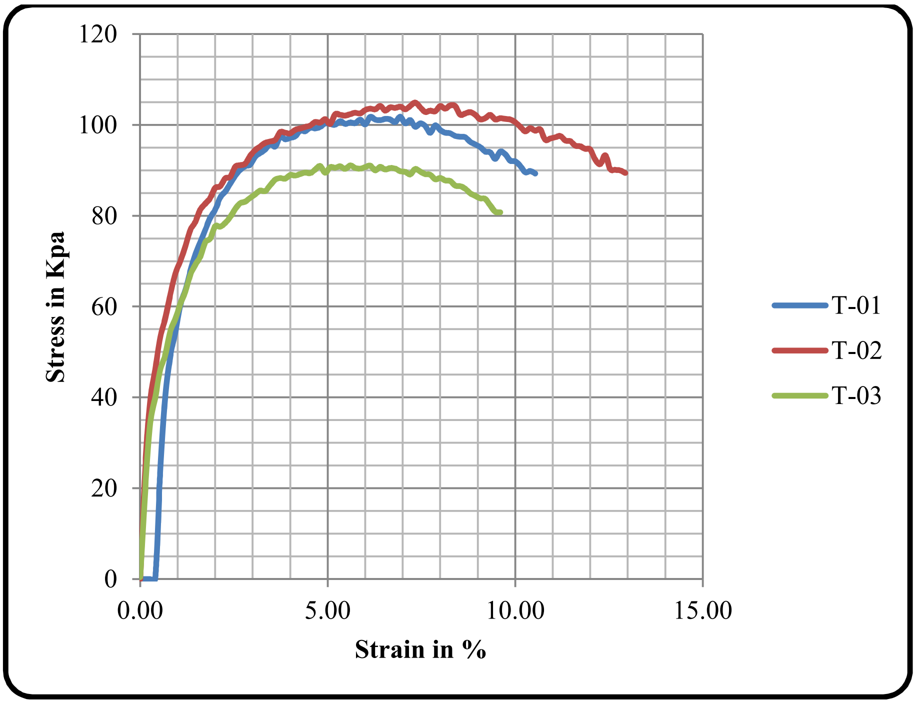

Fig D. 6strain vs stress at 25mm length of 0.75% fiber, koshe sample

Table D. 12 UCS result at 25mm length of 0.75% fiber, koshe sample

Load (N) Trial 1	Load (N) Trial 2	Load (N) Trial 3	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa) Trial 1	Stress (Kpa) Trial 2	Stress (Kpa) Trial 3
0.00	0.00	0.54	0.00	75.00	0.00	0.00	0.00	0.00
26.53	27.61	22.20	0.10	75.00	0.13	0.00	0.00	0.12
45.47	44.39	38.98	0.20	75.00	0.27	0.00	0.00	0.48
55.76	52.51	45.47	0.30	75.00	0.40	23.37	24.32	19.56
61.72	60.63	52.51	0.40	75.00	0.53	40.01	39.06	34.29
68.75	65.51	56.30	0.50	75.00	0.67	48.99	46.14	39.96
72.54	71.46	62.26	0.60	75.00	0.80	54.15	53.20	46.08
77.42	76.87	65.51	0.70	75.00	0.93	60.25	57.40	49.34
81.75	80.12	69.29	0.80	75.00	1.07	63.48	62.54	54.48
84.99	83.91	72.54	0.90	75.00	1.20	67.66	67.18	57.25
88.24	88.24	76.87	1.00	75.00	1.33	71.35	69.93	60.48
91.49	90.41	79.58	1.10	75.00	1.47	74.08	73.14	63.23
93.66	93.65	81.75	1.20	75.00	1.60	76.81	76.81	66.91
96.91	95.28	85.54	1.30	75.00	1.73	79.53	78.59	69.18
98.53	96.90	86.62	1.40	75.00	1.87	81.30	81.30	70.96
100.70	99.61	89.87	1.50	75.00	2.00	84.01	82.60	74.15
102.86	100.15	89.87	1.60	75.00	2.13	85.30	83.89	74.99
104.48	102.32	90.95	1.70	75.00	2.27	87.06	86.12	77.69
105.57	102.86	92.57	1.80	75.00	2.40	88.80	86.47	77.59
106.11	105.56	94.74	1.90	75.00	2.53	90.08	88.22	78.41
108.27	106.11	96.36	2.00	75.00	2.67	90.90	88.57	79.71
109.36	106.65	96.90	2.10	75.00	2.80	91.24	90.77	81.46
110.44	108.81	97.99	2.20	75.00	2.93	92.97	91.11	82.74
112.06	110.44	99.07	2.30	75.00	3.07	93.77	91.45	83.09
111.52	111.52	100.15	2.40	75.00	3.20	94.57	93.18	83.91
114.23	112.60	100.15	2.50	75.00	3.33	95.83	94.44	84.72
113.69	113.14	101.78	2.60	75.00	3.47	95.23	95.23	85.52
114.23	113.68	103.40	2.70	75.00	3.60	97.41	96.02	85.41
114.77	115.85	103.94	2.80	75.00	3.73	96.82	96.35	86.68
116.39	115.85	103.94	2.90	75.00	3.87	97.14	96.68	87.93
116.39	115.85	105.02	3.00	75.00	4.00	97.47	98.39	88.27
117.48	116.93	105.02	3.10	75.00	4.13	98.71	98.25	88.15

117.48	117.47	105.57	3.20	75.00	4.27	98.57	98.11	88.94
118.02	118.02	106.11	3.30	75.00	4.40	99.35	98.89	88.82
119.10	118.56	106.11	3.40	75.00	4.53	99.22	99.21	89.16
119.10	119.64	107.19	3.50	75.00	4.67	99.53	99.54	89.49
119.10	119.64	108.27	3.60	75.00	4.80	100.30	99.85	89.37
120.18	120.72	106.65	3.70	75.00	4.93	100.16	100.62	90.15
119.64	119.64	108.27	3.80	75.00	5.07	100.02	100.48	90.93
120.18	122.35	108.27	3.90	75.00	5.20	100.79	101.25	89.44
120.18	122.35	108.81	4.00	75.00	5.33	100.20	100.20	90.68
121.27	122.35	108.27	4.10	75.00	5.47	100.51	102.32	90.55
120.18	122.89	109.35	4.20	75.00	5.60	100.37	102.18	90.87
122.35	123.43	108.81	4.30	75.00	5.73	101.13	102.04	90.29
121.81	123.43	108.81	4.40	75.00	5.87	100.08	102.34	91.07
121.81	124.51	109.35	4.50	75.00	6.00	101.75	102.65	90.49
122.35	125.05	109.90	4.60	75.00	6.13	101.15	102.50	90.36
122.35	125.05	108.81	4.70	75.00	6.27	101.01	103.25	90.68
121.81	126.14	109.90	4.80	75.00	6.40	101.31	103.55	91.01
123.43	125.05	109.35	4.90	75.00	6.53	101.17	103.41	89.98
121.81	126.14	109.90	5.00	75.00	6.67	100.58	104.16	90.75
122.89	126.14	109.90	5.10	75.00	6.80	101.77	103.11	90.17
121.27	126.68	109.35	5.20	75.00	6.93	100.29	103.86	90.49
122.35	126.14	109.35	5.30	75.00	7.07	101.04	103.71	90.36
121.81	127.22	108.81	5.40	75.00	7.20	99.56	104.01	89.78
120.18	128.30	110.44	5.50	75.00	7.33	100.31	103.42	89.65
122.35	127.22	109.90	5.60	75.00	7.47	99.72	104.15	89.08
121.27	126.14	109.35	5.70	75.00	7.60	98.25	104.89	90.28
120.73	126.68	109.35	5.80	75.00	7.73	99.88	103.85	89.71
120.73	126.68	108.27	5.90	75.00	7.87	98.85	102.82	89.14
120.18	128.30	108.81	6.00	75.00	8.00	98.27	103.11	89.01
120.18	127.76	108.27	6.10	75.00	8.13	98.13	102.97	88.00
120.18	128.84	108.27	6.20	75.00	8.27	97.54	104.13	88.31
119.10	128.84	107.19	6.30	75.00	8.40	97.40	103.54	87.75
118.56	126.68	107.19	6.40	75.00	8.53	97.26	104.27	87.62
118.02	127.22	106.65	6.50	75.00	8.67	96.24	104.11	86.62
116.94	127.76	105.57	6.60	75.00	8.80	95.67	102.22	86.49
116.94	127.22	105.02	6.70	75.00	8.93	95.09	102.51	85.93
115.31	126.14	104.48	6.80	75.00	9.07	94.08	102.79	84.94

117.48	126.68	104.48	6.90	75.00	9.20	93.95	102.21	84.37
116.94	127.76	102.86	7.00	75.00	9.33	92.50	101.19	83.81
115.31	126.68	101.23	7.10	75.00	9.47	94.10	101.48	83.69
115.31	127.22	101.23	7.20	75.00	9.60	93.53	102.19	82.27

Table D. 13 UCS test at 50mm length of 0.75% fiber, koshe sample

Test Type:	Unconfined Compression Test (ASTM D-2166)		
Type of Sample:	Disturbed Soil Sample		
Sample Location:	Koshe		
Trail	T-01	T-02	Ave.
Unconfined compressive strength (qu) (KN/m^2)	102	125	113.72
Cohesion (c) (KN/m2)	51	63	56.86

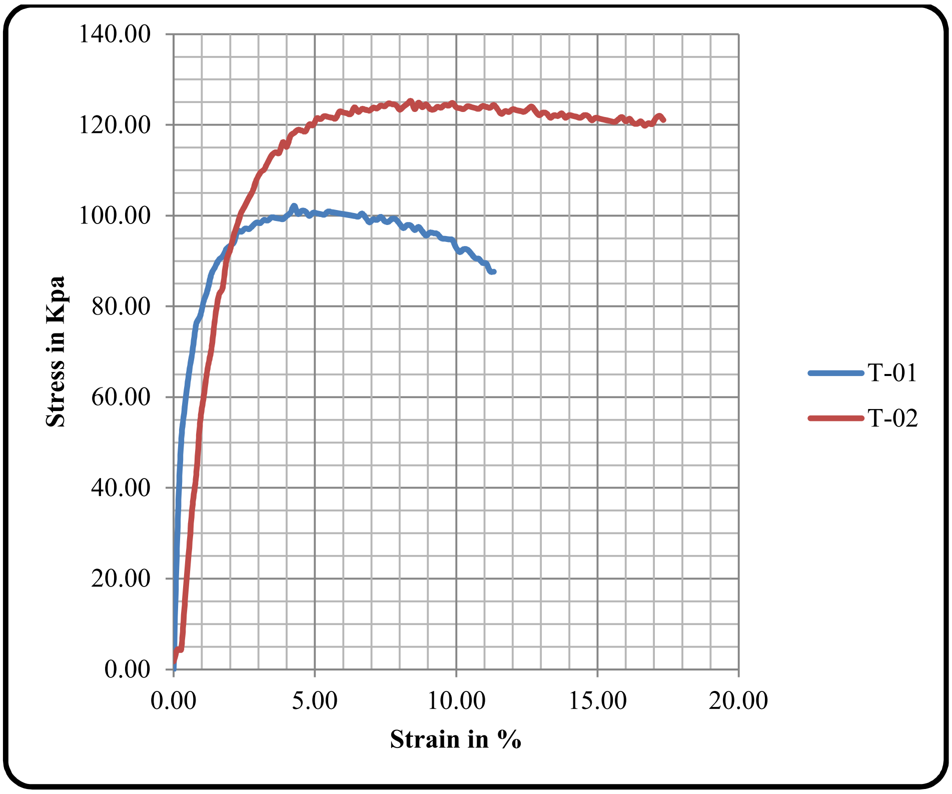

Fig D. 7 strain vs stress at 50mm length of 0.75% fiber, koshe sample

Table D. 14 UCS result at 50mm length of 0.75% fiber,koshe sample

Load (N) Trial 1	Load (N) Trial 2	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa) Trial 1	Stress (Kpa) Trial 2
0.00	2.00	0.00	75.00	0.27	50.15	4.40
34.00	5.00	0.10	75.00	0.40	57.99	14.94
57.00	5.00	0.20	75.00	0.53	64.93	25.45
66.00	17.00	0.30	75.00	0.67	70.10	35.93
74.00	29.00	0.40	75.00	0.80	76.14	42.88
80.00	41.00	0.50	75.00	0.93	77.78	54.19
87.00	49.00	0.60	75.00	1.07	81.17	60.22
89.00	62.00	0.70	75.00	1.20	83.67	66.24
93.00	69.00	0.80	75.00	1.33	87.04	70.50
96.00	76.00	0.90	75.00	1.47	88.66	77.36
100.00	81.00	1.00	75.00	1.60	90.28	82.47
102.00	89.00	1.10	75.00	1.73	91.02	84.09
104.00	95.00	1.20	75.00	1.87	92.63	90.04
105.00	97.00	1.30	75.00	2.00	93.37	92.51
107.00	104.00	1.40	75.00	2.13	94.11	95.83
108.00	107.00	1.50	75.00	2.27	96.57	98.29
109.00	111.00	1.60	75.00	2.40	96.43	100.74
112.00	114.00	1.70	75.00	2.53	97.16	102.32
112.00	117.00	1.80	75.00	2.67	97.03	103.90
113.00	119.00	1.90	75.00	2.80	97.75	105.47
113.00	121.00	2.00	75.00	2.93	98.48	107.90
114.00	123.00	2.10	75.00	3.07	98.34	109.46
115.00	126.00	2.20	75.00	3.20	99.06	110.16
115.00	128.00	2.30	75.00	3.33	98.92	111.71
116.00	129.00	2.40	75.00	3.47	99.64	113.26
116.00	131.00	2.50	75.00	3.60	99.50	113.96
117.00	133.00	2.60	75.00	3.73	99.36	113.80
117.00	134.00	2.70	75.00	3.87	99.23	116.19
117.00	134.00	2.80	75.00	4.00	99.93	115.18
117.00	137.00	2.90	75.00	4.13	100.64	117.56
118.00	136.00	3.00	75.00	4.27	102.19	118.24
119.00	139.00	3.10	75.00	4.40	100.36	118.92

121.00	140.00	3.20	75.00	4.53	101.06	118.75
119.00	141.00	3.30	75.00	4.67	100.92	118.58
120.00	141.00	3.40	75.00	4.80	99.94	120.10
120.00	141.00	3.50	75.00	4.93	100.64	119.93
119.00	143.00	3.60	75.00	5.07	100.50	121.44
120.00	143.00	3.70	75.00	5.20	100.36	121.27
120.00	145.00	3.80	75.00	5.33	100.22	121.93
120.00	145.00	3.90	75.00	5.47	100.91	121.76
120.00	146.00	4.00	75.00	5.60	100.77	121.59
121.00	146.00	4.10	75.00	5.73	100.63	121.42
121.00	146.00	4.20	75.00	5.87	100.48	122.90
121.00	146.00	4.30	75.00	6.00	100.34	122.73
121.00	148.00	4.40	75.00	6.13	100.20	122.56
121.00	148.00	4.50	75.00	6.27	100.06	122.38
121.00	148.00	4.60	75.00	6.40	99.91	123.86
121.00	148.00	4.70	75.00	6.53	99.77	122.86
121.00	150.00	4.80	75.00	6.67	100.45	123.51
121.00	149.00	4.90	75.00	6.80	99.49	123.33
122.00	150.00	5.00	75.00	6.93	98.52	123.15
121.00	150.00	5.10	75.00	7.07	99.20	123.80
120.00	150.00	5.20	75.00	7.20	99.06	123.62
121.00	151.00	5.30	75.00	7.33	99.73	124.26
121.00	151.00	5.40	75.00	7.47	98.77	124.08
122.00	152.00	5.50	75.00	7.60	98.63	124.72
121.00	152.00	5.60	75.00	7.73	99.30	124.54
121.00	153.00	5.70	75.00	7.87	99.16	124.36
122.00	153.00	5.80	75.00	8.00	98.21	123.37
122.00	153.00	5.90	75.00	8.13	97.25	124.00
121.00	152.00	6.00	75.00	8.27	97.92	124.63
120.00	153.00	6.10	75.00	8.40	97.78	125.25
121.00	154.00	6.20	75.00	8.53	96.83	123.46
121.00	155.00	6.30	75.00	8.67	97.49	124.89
120.00	153.00	6.40	75.00	8.80	96.55	123.90
121.00	155.00	6.50	75.00	8.93	95.60	124.52
120.00	154.00	6.60	75.00	9.07	96.26	123.54
119.00	155.00	6.70	75.00	9.20	96.12	123.36
120.00	154.00	6.80	75.00	9.33	95.98	123.98

120.00	154.00	6.90	75.00	9.47	95.04	123.80
120.00	155.00	7.00	75.00	9.60	94.90	124.41
119.00	155.00	7.10	75.00	9.73	94.76	124.23
119.00	156.00	7.20	75.00	9.87	94.62	124.84
119.00	156.00	7.30	75.00	10.00	92.89	123.86
119.00	157.00	7.40	75.00	10.13	91.96	123.68
117.00	156.00	7.50	75.00	10.27	92.62	123.49
116.00	156.00	7.60	75.00	10.40	92.48	124.10
117.00	156.00	7.70	75.00	10.53	91.56	123.92
117.00	157.00	7.80	75.00	10.67	90.63	123.73
116.00	157.00	7.90	75.00	10.80	90.50	123.55
115.00	157.00	8.00	75.00	10.93	89.57	124.15
115.00	157.00	8.10	75.00	11.07	89.44	123.96
114.00	158.00	8.20	75.00	11.20	87.74	123.78
114.00	158.00	8.30	75.00	11.33	87.61	124.37
112.00	158.00	8.40	75.00	11.47	0.00	123.40
112.00	159.00	8.50	75.00	11.60	0.00	122.44

Table D. 15 UCS test at 75mm length of 0.75%fiber, koshe sample

Test Type:	Unconfined Compression Test (ASTM D-2166)			
Type of Sample:	Disturbed Soil Sample			
Sample Location:	Koshe			
Trail	T-01	T-02	T-03	Ave.
Unconfined compressive strength (qu) (KN/m^2)	154	178	191	174.44
Cohesion (c) (KN/m^2)	77	89	96	87.22

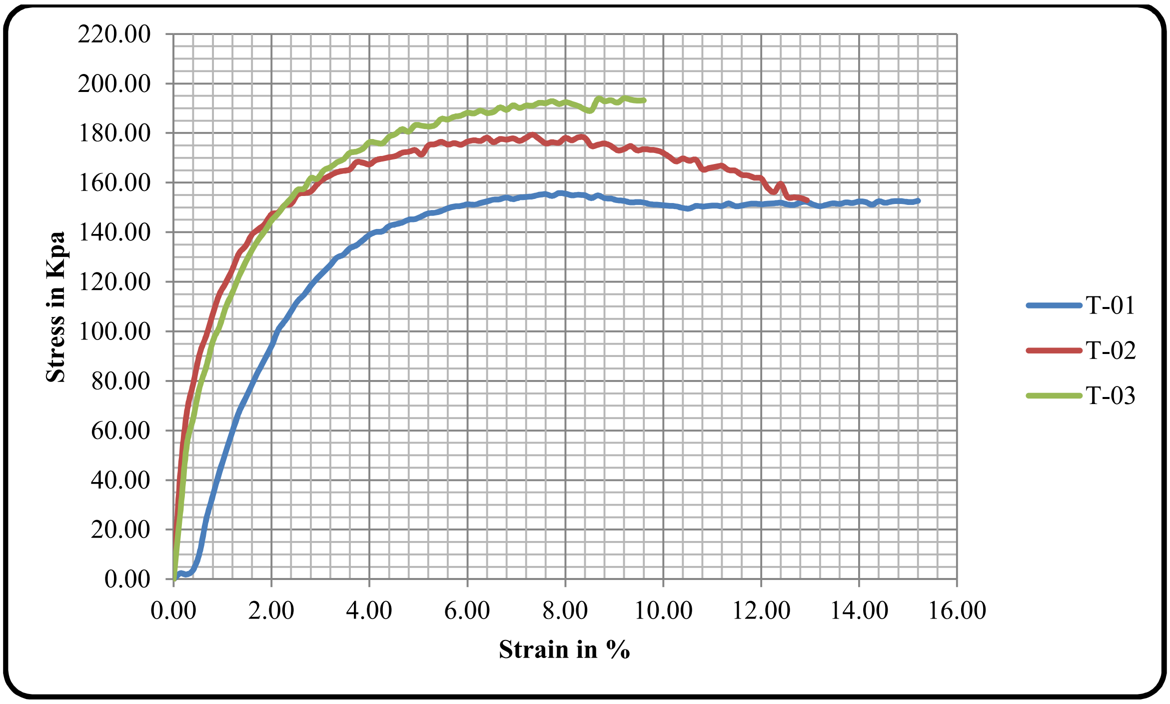

Fig D. 8 strain vs stress at 75mm length of 0.75% fiber,koshe sample

Table D. 16 UCS result at 75mm length of 0.75% fiber, koshe sample

Load (N) Trial 1	Load (N) Trial 2	Load (N) Trial 3	Sample Deformation ΔL (mm)	ho (mm)	Strain In %	Stress (Kpa) Trial 1	Stress (Kpa) Trial 2	Stress (Kpa) Trial 3
0.00	0.00	0.00	0.00	75.00	0.00	0.00	0.00	0.00
2.71	47.21	29.74	0.10	75.00	0.13	2.38	41.59	26.20
2.17	75.91	61.20	0.20	75.00	0.27	1.91	66.79	53.84
4.33	89.79	73.94	0.30	75.00	0.40	3.81	78.90	64.97
12.45	103.68	88.39	0.40	75.00	0.53	10.93	90.98	77.56
27.61	112.20	97.74	0.50	75.00	0.67	24.19	98.32	85.65
38.44	122.20	109.64	0.60	75.00	0.80	33.64	106.94	95.95
49.26	131.45	116.44	0.70	75.00	0.93	43.05	114.88	101.76
59.01	137.01	125.79	0.80	75.00	1.07	51.50	119.58	109.79
68.21	143.49	132.59	0.90	75.00	1.20	59.45	125.07	115.57
77.42	150.89	140.24	1.00	75.00	1.33	67.38	131.34	122.07
83.91	154.60	147.04	1.10	75.00	1.47	72.94	134.39	127.81
90.41	160.14	152.99	1.20	75.00	1.60	78.48	139.01	132.81
96.90	162.93	158.08	1.30	75.00	1.73	84.01	141.24	137.04
102.86	165.70	162.36	1.40	75.00	1.87	89.04	143.45	140.56
108.82	170.33	167.44	1.50	75.00	2.00	94.08	147.26	144.76
116.40	171.26	170.83	1.60	75.00	2.13	100.49	147.86	147.49
120.73	174.97	175.09	1.70	75.00	2.27	104.09	150.86	150.96
125.60	175.89	178.49	1.80	75.00	2.40	108.14	151.44	153.68
130.47	180.51	182.73	1.90	75.00	2.53	112.18	155.21	157.12
133.72	181.45	183.57	2.00	75.00	2.67	114.82	155.81	157.63
138.05	182.37	188.68	2.10	75.00	2.80	118.37	156.38	161.79
141.84	186.07	188.68	2.20	75.00	2.93	121.46	159.33	161.57
145.09	188.85	192.93	2.30	75.00	3.07	124.07	161.49	164.98
148.34	190.70	194.63	2.40	75.00	3.20	126.67	162.85	166.21
152.13	192.55	197.19	2.50	75.00	3.33	129.73	164.20	168.16
153.75	193.47	198.89	2.60	75.00	3.47	130.93	164.76	169.37
157.00	194.39	202.28	2.70	75.00	3.60	133.51	165.32	172.02
158.62	198.11	203.14	2.80	75.00	3.73	134.70	168.25	172.52
161.33	198.11	204.84	2.90	75.00	3.87	136.82	168.01	173.72
164.04	197.59	208.23	3.00	75.00	4.00	138.92	167.34	176.35
165.66	199.95	208.23	3.10	75.00	4.13	140.10	169.10	176.11

166.20	200.88	208.23	3.20	75.00	4.27	140.36	169.65	175.86
168.91	201.82	211.63	3.30	75.00	4.40	142.45	170.21	178.48
169.99	202.74	213.33	3.40	75.00	4.53	143.16	170.75	179.67
171.08	204.59	215.88	3.50	75.00	4.67	143.88	172.06	181.56
172.70	205.35	215.03	3.60	75.00	4.80	145.04	172.46	180.59
173.24	206.43	218.43	3.70	75.00	4.93	145.29	173.13	183.19
174.86	204.59	218.43	3.80	75.00	5.07	146.44	171.34	182.94
176.49	209.22	218.43	3.90	75.00	5.20	147.60	174.97	182.68
177.03	210.14	219.28	4.00	75.00	5.33	147.84	175.50	183.13
178.11	211.61	222.68	4.10	75.00	5.47	148.53	176.48	185.71
179.74	210.58	222.68	4.20	75.00	5.60	149.68	175.37	185.45
180.82	211.54	224.38	4.30	75.00	5.73	150.37	175.92	186.60
181.36	211.07	225.23	4.40	75.00	5.87	150.60	175.28	187.04
182.44	212.91	226.92	4.50	75.00	6.00	151.29	176.56	188.18
182.44	213.84	226.93	4.60	75.00	6.13	151.07	177.08	187.91
183.53	213.81	228.64	4.70	75.00	6.27	151.76	176.80	189.06
184.61	215.70	227.79	4.80	75.00	6.40	152.43	178.11	188.09
185.69	213.84	228.64	4.90	75.00	6.53	153.11	176.32	188.52
186.23	215.70	231.18	5.00	75.00	6.67	153.33	177.60	190.35
187.32	215.70	230.33	5.10	75.00	6.80	154.01	177.35	189.38
186.77	216.62	232.87	5.20	75.00	6.93	153.34	177.85	191.19
187.86	215.70	231.89	5.30	75.00	7.07	154.01	176.84	190.12
188.40	217.55	233.44	5.40	75.00	7.20	154.23	178.10	191.11
188.94	219.39	233.72	5.50	75.00	7.33	154.45	179.35	191.07
190.02	217.55	235.44	5.60	75.00	7.47	155.11	177.59	192.19
190.56	215.70	235.66	5.70	75.00	7.60	155.33	175.83	192.10
190.02	216.62	236.98	5.80	75.00	7.73	154.67	176.32	192.89
191.65	216.62	235.89	5.90	75.00	7.87	155.77	176.07	191.73
191.65	219.39	237.13	6.00	75.00	8.00	155.54	178.06	192.46
191.11	218.47	236.65	6.10	75.00	8.13	154.88	177.06	191.79
191.65	220.32	235.89	6.20	75.00	8.27	155.09	178.30	190.90
191.65	220.32	234.58	6.30	75.00	8.40	154.87	178.04	189.56
190.56	216.62	234.44	6.40	75.00	8.53	153.76	174.79	189.17
192.19	217.55	240.54	6.50	75.00	8.67	154.85	175.29	193.81
191.11	218.47	239.67	6.60	75.00	8.80	153.76	175.77	192.83
191.11	217.55	240.54	6.70	75.00	8.93	153.53	174.78	193.24
190.56	215.70	239.67	6.80	75.00	9.07	152.86	173.04	192.26

190.56	216.62	242.23	6.90	75.00	9.20	152.64	173.52	194.03
190.02	218.47	241.88	7.00	75.00	9.33	151.98	174.74	193.47
190.56	216.62	241.79	7.10	75.00	9.47	152.19	173.01	193.11
190.56	217.55	242.23	7.20	75.00	9.60	151.97	173.50	193.18

Appendix 2: Standards

Table E. 1 ERA Subgrade strength class

Class	CBR Range in %
S1	<3
S2	3,4
S3	5,6,7
S4	8_15
S5	15-30
S6	>30

Table E. 2 AASHTO soil classification

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

Table E. 3 Consistency of cohesive soil[41]

Consistency	q_u (lb/ft^2
Very soft	0–500
Soft	500–1000
Medium	1000–2000
Stiff	2000–4000
Very stiff	4000–8000

Table E. 4 Unified soil classification system(USCS)

Major divisions	Subdivisions	USCS symbol	Typical names	Laboratory classification criteria	
Coarse-grained soils (More than 50% retained on No. 200 sieve)	Gravels (More than 50% of coarse fraction retained on No. 4 sieve)	GW	Well-graded gravels or gravel-sand mixtures, little or no fines	Less than 5% fines[a]	$C_u \geq 4$ and $1 \leq C_c \leq 3$
		GP	Poorly graded gravels or gravelly sands, little or no fines	Less than 5% fines[a]	Does not meet C_u and/or C_c criteria listed above
		GM	Silty gravels, gravel-sand-silt mixtures	More than 12% fines[a]	Minus No. 40 soil plots below the A-line
		GC	Clayey gravels, gravel-sand-clay mixtures	More than 12% fines[a]	Minus No. 40 soil plot on or above the A-line
	Sands (50% or more of coarse fraction passes No. 4 sieve)	SW	Well-graded sands or gravelly sands, little or no fines	Less than 5% fines[a]	$C_u \geq 6$ and $1 \leq C_c \leq 3$
		SP	Poorly graded sands or gravelly sands, little or no fines	Less than 5% fines[a]	Does not meet C_u and/or C_c criteria listed above
		SM	Silty sands, sand-silt mixtures	More than 12% fines[a]	Minus No. 40 soil plots below the A-line
		SC	Clayey sands, sand-clay mixtures	More than 12% fines[a]	Minus No. 40 soil plots on or above the A-line

Major divisions	Subdivisions	USCS symbol	Typical names	Laboratory classification criteria	
Fine-grained soils (50% or more passes the No. 200 sieve)	Silts and clays (liquid limit less than 50)	ML	Inorganic silts, rock flour, silts of low plasticity	Inorganic soil	PI < 4 or plots below A-line
		CL	Inorganic clays of low plasticity, gravelly clays, sandy clays, etc.	Inorganic soil	PI > 7 and plots on or above A-line[b]
		OL	Organic silts and organic clays of low plasticity	Organic soil	LL (oven dried)/LL (not dried) < 0.75
	Silts and clays (liquid limit 50 or more)	MH	Inorganic silts, micaceous silts, silts of high plasticity	Inorganic soil	Plots below A-line
		CH	Inorganic highly plastic clays, fat clays, silty clays, etc.	Inorganic soil	Plots on or above A-line
		OH	Organic silts and organic clays of high plasticity	Organic soil	LL (oven dried)/LL (not dried) < 0.75
Peat	Highly organic	PT	Peat and other highly organic soils	Primarily organic matter, dark in color, and organic odor	

[a] "Fines" are those soil particles that pass the No. 200 sieve. For gravels with between 5% to 12% fines, use of dual symbols required (i.e., GW-GM, GW-GC, GP-GM, or GP-GC). For sands with between 5% to 12% fines, use of dual symbols required (i.e., SW-SM, SW-SC, SP-SM, or SP-SC).

[b] If $4 \leq PI \leq 7$ and plots above A-line, then dual symbol (i.e., CL-ML) is required.

[c] $C_u = D_{60}/D_{10}$ and $C_c = (D_{30})^2/[(D_{10})(D_{60})]$ where D_{60} = soil particle diameter corresponding to 60% finer by weight (from grain size curve).