SOIL BIOENGINEERING USING ARECA CATECHU FIBER

A dissertation phase-I submitted in

Partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY CIVIL ENGINEERING

In

(*With specialization in Geotechnical Engineering)*

Under

ASSAM SCIENCE AND TECHNOLOGY UNIVERSITY

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Submitted by:

RITURAJ DAS

Roll No: PG/C/23/16

ASTU Registration No: 326008118

Under the guidance of

Dr. SASANKA BORAH

ASSOCIATE PROFESSOR

ASSAM ENGINEERING COLLEGE

DEPARTMENT OF CIVIL ENGINEERING

DECLARATION

I hereby declare that the work presented in the dissertation phase-I " Soil Bioengineering using Areca Catechu Fiber " in partial fulfillment of the requirement for the award of the degree of "MASTER OF TECHNOLOGY" in Civil Engineering (with specialization in Geotechnical Engineering), submitted in the Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13 under Assam Science & Technology University, is a real record of the work carried out under the supervision of Dr. Sasanka Borah, Associate Professor, Department of Civil Engineering, Assam Engineering College.

I do hereby declare that this project report is solemnly done by me and is my effort and that no part of it has been plagiarized without citation.

Date : RITURAJ DAS

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

Date: Dr. SASANKA BORAH

Associate Professor

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati-13

CERTIFICATE OF SUPERVISION

This is the certified that the work presented in the project report entitled "Soil Bioengineering using Areca Catechu Fiber" is submitted by Rituraj Das, bearing Roll No: PG/C/23/16, a student of M.Tech 3rd semester, Department of Civil Engineering, Assam Engineering College, to the Assam Science and Technology University in partial fulfillment of the requirement for award of the degree of Master of Technology in Civil Engineering with Specialization in Geotechnical Engineering under my guidance and supervision.

Date:

Place:

Dr. SASANKA BORAH

Associate Professor

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati-781013

CERTIFICATE FROM HEAD OF THE DEPARTMENT

This is to certify that the project report entitled "Soil Bioengineering using Areca Catechu Fiber" has been submitted by Rituraj Das, bearing Roll No: PG/C/23/16, a student of M.Tech 3rd Semester, Geotechnical Engineering (Civil Engineering), Assam Engineering College, in partial fulfillment of the requirements for the award of the degree of Master of Technology in Geotechnical Engineering of Assam Science & Technology University.

Date :

Place :

DR. JAYANTA PATHAK

Professor and Head of Department

Department of Civil Engineering

Assam Engineering College

Guwahati – 781013

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Date :

Place :

RITURAJ DAS

M. Tech 3rd semester

Geotechnical Engineering

Department of Civil Engineering

Assam Engineering College

Guwahati - 781013

ABSTRACT

Environmental awareness and an increasing concern for sustainable development have accelerated many geotechnical engineers to replace the conventional synthetic fibers with environment friendly limited life geotextiles (LLGs)/fibers. Reinforcing of soils with different type of natural fibers with an aim to increase strength is comparatively new reinforcing technique. This research demonstrates the potential use of areca nut fibers (Areca Catechu) which is considered as agro waste product as a sustainable and eco-friendly soil bioengineering solution for various geotechnical applications, including soil erosion control and slope stabilization. The investigation is based on a series of unconfined compressive strength (UCS) tests at different fiber contents and compaction conditions. The results show significant improvements in soil's shear strength, stiffness, and resistance to deformation with the addition of areca nut fiber. The findings have significant implications for the development of innovative, nature-based solutions for soil stabilization and environmental sustainability.

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CHAPTER – 1
INTRODUCTION

1.1 General

Soil is often regarded as a combination of four basic types of constituents: gravel, sand, clay, and silt. Generally it has low tensile and shear strength and its environmental conditions strongly affects its characteristics. Reinforcement on the other hand, is the mechanism of incorporating certain materials into the soil, to increase desired properties within the soil.

Soil bioengineering is such a technique that uses living plants to create structures that help stabilize soil and control erosion and flooding. It is the use of living plant materials to provide some engineering function. Soil bioengineering is an effective tool for treatment of a variety of unstable and / or eroding sites. More recently Schiechtl (1980) has encouraged the use of soil bioengineering with a variety of European examples. It is now widely practiced throughout the world for the treatment of erosion and unstable slopes (Gray, D.H. and A.T. Leiser, 1982).

Growing Environmental awareness and gradual concern over climate change in general have increased the concern of sustainable development along with use of nature friendly materials to achieve that. In geotechnical aspect, during the last decade research has been done to apply natural materials like jute, banana, coconut fiber etc. in improving the soil characteristics viz. increase in shear strength, improving ductility, erosion, degradability etc. Agro wastes are non-hazardous wastes that are accumulated every day in a large scale throughout the world. These wastes if can be brought into use in reinforcing the strength of soil, it can be used for various purposes which can mitigate the problem of such waste disposal to a large scale. This study encompasses use of such agro waste product “Areca Catechu” fiber as a reinforcing agent to improve soil characteristics.

Areca nut (Areca Catechu L.) is an important commercial plantation crop of India. The economic produce of the crop is fruit, also called supari/Betel-Nut. India is the major producer of areca nut which accounts for 50% of production and 43% area under areca nut in the world. Other major producers are South and Southeast Asian countries such as Bangladesh, Myanmar, Indonesia, China, Sri Lanka and Thailand. In 2020, the world areca nut production was 17.96 lakh tonnes from an area of 12.26 lakh hectares with an average yield level of 1.46 tonnes/ha (Dr. Shripad Bhat, V. Arunachalam, Paramesha V). India continues to be dominating the world in the production and productivity of areca nut and simultaneously with its husk fibers as an unmanaged agro-waste comprehensively. At present, the majority of waste is disposed of by burning which resulted in a loss of the potential source of organic matter and valuable plant nutrients. This husk can be used as raw material due to its low cost, less weight, low density and biodegradability for the production of value-added products through bio-softening which aims to achieve a polishing effect and avoids the use of caustic chemicals thereby minimizing pollution.

Table 1: State-wise production of areca nut in India (Source: National Horticulture Board)

SI No.	State	Production (000' tonnes)	Share (%)
1.	Karnataka	1139.95	78.84
2.	Kerela	100.05	6.92
3.	Assam	61.18	4.23
4.	Meghalaya	24.35	1.68
5.	West Bengal	23.60	1.63
6.	Others	96.72	6.69

Betel nut fruits have three maturation levels: raw, ripe, and matured, Yusriah et al. (2014). The raw betel nut fruit is green in appearance, with a soft husk and kernel. Ripe betel nut fruits are yellow to golden, with a spongy husk that retains more juicy liquid than raw or aged fruits. Matured betel nut fruit is acquired when the ripe fruit has attained complete maturity and has detached from the fruit bunch. Mature betel nut fruit typically has brownish shades with coarse fiber.

Fig 1: Stages of areca nut (Das & Singh, 2015)

1.2 Botanical description

a) Preferred scientific name- Areca Catechu Linnaeus
b) Family- Arecaceae (Palmae), palm family

1.3 Fiber properties

From the analysis of the difference in physical appearance, betel nut fruits are divided into three types according to the maturity level. At each stage of maturity level the fiber length, diameter and density of betel nut husk fiber is found to vary. Betel nut fiber is derived from the fibrous component that surrounds the betel nut fruit. The fibrous component of the fruit contains fine and coarse fibers. The coarse fibers are irregularly lignified betel nut husk fibers, comprised of cellulose, hemicellulose, lignin, pectin, and proto-pectin in various amounts. According to Choudhury et al. (2009), coarse fibers exhibit high specific mechanical strength and toughness.

Fig 2: Areca nut husk along with its fibers

From various studies it was observed that raw betel nut husk fiber was having the highest fiber length, followed by ripe and matured betel nut husk fiber respectively. The length of betel nut husk fiber may depend on the size of nutshell. The smaller the nutshell shorter is the length of the fiber. The maximum length of areca fiber is near to about 35 mm. The moisture absorption of areca fiber increases with increase in hemicellulose content which decreases the fiber performance. The moisture content, one of the important factor in the plant fiber is naturally proportional to the ripening process of the fruit. At the ripe stage was found to be the highest of all three types of fiber, while matured betel nut husk fiber was observed with the lowest moisture content and raw betel nut husk fiber contained slightly lower moisture content than that of ripe betel nut husk fiber.

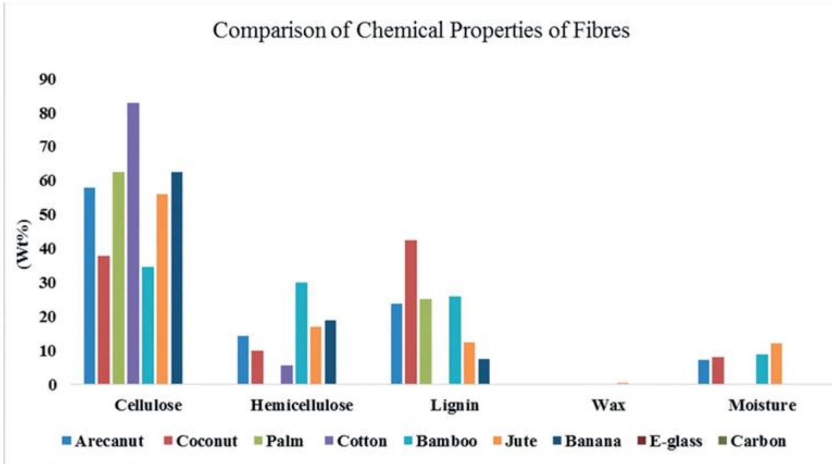

Fig 3: Comparison of chemical properties of areca nut, other natural fibers and synthetic fibers (Kamath et al.,2017)

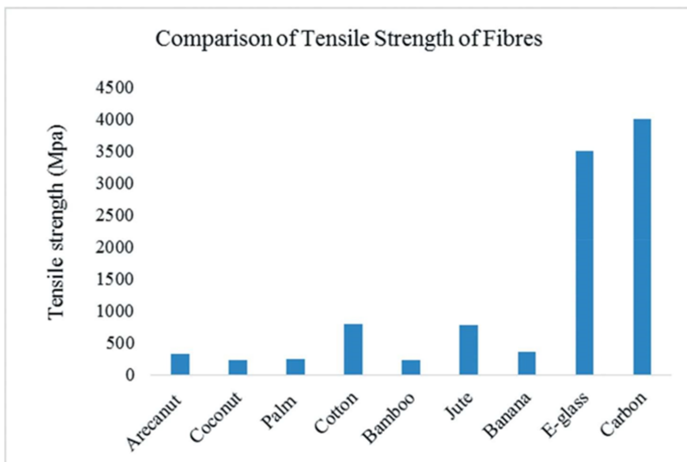

Fig 4: Comparison of tensile strength of different natural and synthetic fibers with areca nut fibers (Kamath, Sampathkumar, and Bennehalli 2017).

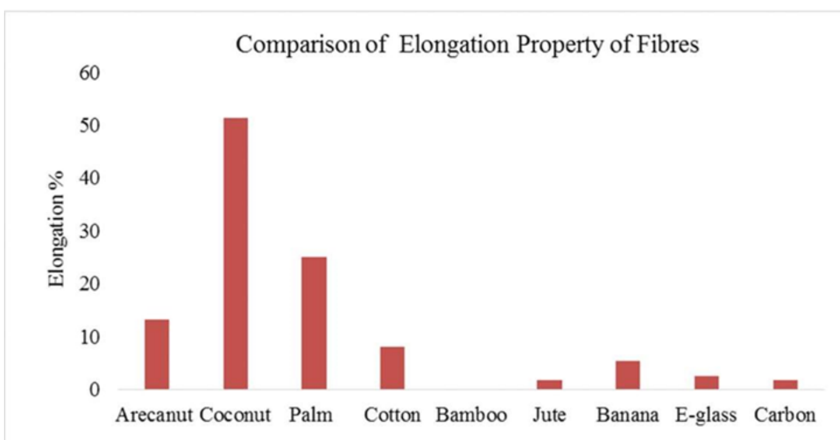

Fig 5: Comparison of elongation property of different natural and synthetic fibers with Areca nut fibers (Kamath, Sampathkumar, and Bennehalli 2017).

1.4 Extraction of Fibers

The areca nut shell is separated from the seeds and dried in the sun. Soaking of areca nut shells aims to loosen the fibers present in the shells. Three articles reported the duration of soaking, namely 24 hours (Borah & Dutta, 2018), 3 days (Mathapati et al., 2022) and 7 days (Muralidhar et al., 2019). Areca nut shell fiber is dried in the sun. Based on the literature, some people dry the fibers for two environmental days (Mahyudin et al., 2020) and some for 2-4 days (Madnasri et al., 2022). However, there are no reports on the water content limit required to proceed to the next stage. The fiber is extracted from the areca nut shell and the extraction process can be done by machine or by hand. However, mechanical stripping is quicker and easier.

1.5 Fibers in soil reinforcement

Randomly distributed fiber-reinforced soil (RDFS) is among the new ground improvement techniques in which fiber of desired dimensions and quantity are added in the soil, mixed randomly and laid in position after compaction process. A non-traditional soil stabilization technology, RDFS is recently being used to improve soil properties. RDFS differs from conventional soil-reinforcing methods in its orientation. Conventional geotechnical engineering has focused on planar reinforcement (e.g. metal strips, sheets of synthetic fabrics). Contrastingly, in RDFS, fiber is mixed randomly in soil thus making a homogeneous mass and maintains isotropy in strength. Due to this random distribution of fibers, fiber reinforcement doesn’t induce any clear cut potential plane of weakness.

1.5.1 Mechanism of randomly distributed fiber reinforced soil

Fiber reinforced soil behaves as a composite material. Here, fiber of relatively high tensile strength is randomly mixed in a matrix of soil. Shear stresses in the soil mobilize tensile resistance in the fibers, which in turn imparts greater strength to the soil. Fig. 6 below shows a schematic sketch of the soil-fiber matrix. The use of RDFS mimics the behavior of plant roots and contributes to the stability of soil mass by adding strength to the near-surface soils in which the effective stress is found to be low.

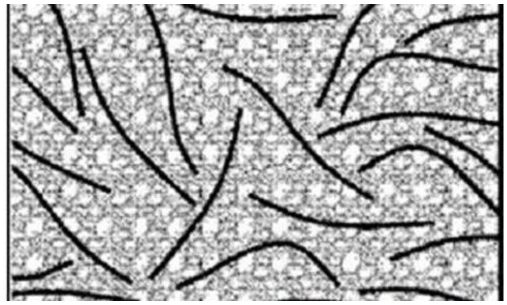

Fig. 6 Soil Fiber matrix (Sadek et Al. 2010)

Fig. 7 shows the interaction between a fiber and soil when stress is applied onto the fiber. Under imposed stress, the fiber deforms and in the process interlocks the soil. This mobilization of frictional resistance at the soil-fiber interface also leads to soil strength. These two primary factors are responsible for the enhanced performance of fiber reinforced soils. The function of the bond developed or interlock is basically to transfer the stress from the soil to the discrete inclusions by mobilizing the tensile strength of discrete inclusions.

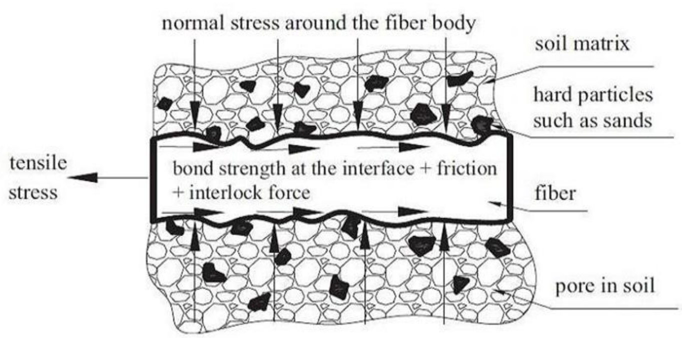

Fig. 7 Soil Fiber interaction mechanism (Tang et al.2007)

The present study focuses on the use of betel nut fibers as a reinforcing agent in soil to increase its shear strength, study its behavior at different compositions, changing moisture content of soil as well as its compaction conditions. The principal study has been of the randomly distributed fiber-reinforced soil (also known as RDFS) with inclusion of natural betel nut fibers. A series of Unconfined Compression Strength (UCS) test has been mainly conducted to determine its shear strength and discuss its stress- strain relationship.

CHAPTER - 2

LITERATURE REVIEW

2.1 Review of available literatures

Fibers can be used as a reinforcing material in soil to impart tensile strength. Previous studies reported the suitability of using synthetic fibers, such as polypropylene (PP), polyvinyl alcohol (PVA), and natural fibers such as coir, jute, banana etc in soft ground applications.

Maher & Y.C Ho (1994) This paper evaluates mechanical properties of a kaolinite/fiber soil composite by a series of laboratory unconfined-compression, splitting-tension, three-point-bending, and hydraulic-conductivity tests. The inclusion of randomly distributed fibers significantly increased the peak compressive strength, ductility, splitting tensile strength, and flexural toughness of kaolinite clay. The increase in strength and toughness was a function of fiber length and content, and the water content of the composite. Increasing fiber content increased the compressive and tensile strength, and the toughness index of kaolinite clay. The contribution of fibers to peak compressive and tensile strengths were reduced, and ductility increased, with increasing fiber length. The fiber inclusion increased the hydraulic conductivity of the composite.

Prabhakar & Sridhar (2002) This paper investigates effect of sisal fiber in soil as the reinforcement material and it was randomly included at four different percentages of fiber content, i.e. 0.25, 0.5, 0.75 and 1% by weight of raw soil. Four different lengths of fibre, i.e. 10, 15, 20 and 25 mm are also considered as one of the parameters for the study. It focused on the strength behaviour of the soil reinforced with randomly included sisal fibre. The reinforced soil samples were subjected to compaction and triaxial compression tests. The results of these tests have clearly shown a significant improvement in the failure deviator stress, shear strength parameters (C and φ) of the soil. The paper also concludes that sisal fiber can be considered as a good earth reinforcement material.

Kumar et. al (2006) In this paper, polyester fibers were mixed with soft clay soil to investigate the relative strength gain in terms of unconfined compression test. Samples were tested in unconfined compression with 0%, 0.5%, 1.0%, 1.5% and 2.0% plain and crimped polyester fibers. The results presented show that the degree of compaction affected the relative benefits of fiber reinforcement for the subject soil. Samples compacted after mixing various proportions of sand into clay (varying from 0% to 12% of clay) were also tested. It was observed that unconfined compressive strength of clay increases with the addition of fibers and it further increases when fibers are mixed in clay sand mixture.

Paul & Sarkar (2009) This paper evaluates performance of natural fiber reinforced laterite soil for road pavement construction. Two types of fiber Coconut + Areca tree fiber were considered for the study with different lengths and proportions. Firstly, the fibers were treated with NaOH solution for 4 days to increase the flexural and tensile strength of individual fibers. Secondly, the fibers were coated with low viscosity bitumen emulsion to increase the durability of fibers. The modified compaction test was performed on two different proportions of natural fiber (50% of coconut fiber + 50% of areca fiber) for 0.3% and 0.6% of total soil weight and for two fiber lengths 30 mm and 60 mm respectively. The strength improves on wet of optimum and MDD value increased by 60.8 % which is expected to perform better under heavy traffic load conditions on interstate highways. The maximum UCS value achieved at 0.3% fiber content and 30 mm fiber length of both coconut and areca tree fiber. The Permeability of the reinforced soil is also reduced. Thus, the study concluded that 0.3% fiber of 30 mm length is the optimum dose of fiber for reinforcing soil prepared with natural fiber.

R. Thenmozhi & Indhumathi (2011) This paper determines the behaviour of clay soil reinforced with glass fiber, coir fiber and metal fiber of lengths 6mm, 12mm, 20mm in a random manner. The composite soils were tested under laboratory conditions and examined for unconfined compression strength (UCS) and compaction test. The fibers are mixed randomly with soil in varying percentages (0.25%, 0.5%, 0.75% and 1%) by dry weight of soil and compacted to maximum dry density at optimum moisture content. The test results indicate a reduction in the maximum dry density and increase in optimum moisture content of soil due to the addition of fibers. It also indicates an improvement in the UCS of soil due to the addition of fibers.

Güllü and Khudir (2014) In this paper, studies had been carried out to find out the effect of freeze–thaw cycles on unconfined compressive strength (UCS) of silty soil treated with jute fiber, steel fiber and lime. The stress–strain behavior (post-peak strength, strain hardening, ductility, brittleness index, resilient modulus) of the stabilized soil has also been discussed due to the treatment effects. An extensive laboratory study has been carried out conducting UCS tests under the freeze–thaw cycles of 0, 1, 2 and 3. The study results that the UCS value of native soil has been performed best due to the combination of effective stabilizer rates all together (i.e., 4% lime + 075% jute fiber + 0.25% steel fiber). The other stabilizer combinations also show good contributions to UCS of native soil. As for the stress–strain responses, the inclusions due to the jute fiber alone in terms of post-peak strength, strain hardening, and ductility are better than the ones of steel fiber and lime at all freeze–thaw cycles.

Neelu Vibhakar & Siddharth (2014) In this paper, study is carried out to evaluate the effect of fiber inclusions on strength parameters and CBR value of clay soil. A detailed laboratory tests were conducted on virgin sample and coir-fiber reinforced clay. Test are performed by varying the fiber content in different proportions (1%, 2% and 3% by weight). It is found that upto 2% fiber content, there is a considerable amount of increase in both unconfined compressive strength of soil and CBR value and above 2% there is slight decrease in UCC value and no significant increase in CBR value. The optimum fiber content of the soil is found to be 2%.

Kumar et. al (2019) This paper includes stabilization of organic soil with rice husk ash (RHA) strengthened with randomly distributed nylon fibers. To investigate the impact of RHA and nylon fiber on strength properties of organic soil, standard proctor compaction, unconfined compressive strength (UCS), unsoaked and soaked CBR tests were conducted. The experimented results disclose that inclusion of different dosages of RHA and nylon fiber in organic soil leads to increase in the optimum moisture content and decrease in maximum dry density. The best results are found for the mix proportion of "soil + 15% RHA +1.0% nylon fiber". It is concluded that the united effect of RHA and nylon fiber can improve strength properties of poor or weak organic soil.

Patil & Pusadkar (2020) In this paper, an attempt has been made to improve black cotton soil characteristics by using the waste material such as banana fiber. The study includes experiments that were conducted to understand the density & moisture content of soil by reinforcing the soil with randomly distributed banana fibers. The laboratory tests were conducted on locally available black cotton soil. The banana fiber were added to the soil in varying percentages of 0.0 %, 0.50 %, 1 %, 1.5 % and 2 % and in varying lengths of 1 cm,2cm and 3 cm randomly. It was observed that MDD is decreasing and OMC is increasing with increase in % of fibers and length of fiber.

A. K. Lawer (2021) In this paper, the effects of coconut fiber (30 mm, 60 mm and 90 mm fiber lengths) and palm fiber on some geotechnical characteristics of a weak lateritic subgrade. The lateritic soil was blended with various percentages of the fibers varying between 0.1 and 1.0% by weight of dry soil. The mixed materials were then subjected to various laboratory tests including compaction, unconfined compression test and 4-day-soaked California bearing ratio test. From the results, it was observed that increasing the fiber content decreased the maximum dry density and increased the optimum moisture content. The inclusion of the fiber increased the soaked CBR from 7 to a maximum of 18, 22, and 25 at 30 mm, 60 mm and 90 mm fiber lengths, respectively. The unconfined compressive strength also increased from 140 to a maximum of 353 kPa, 398 kPa and 447 kPa, respectively, for 30 mm, 60 mm and 90 mm fiber lengths. Similarly, palm fiber inclusion recorded maximum soaked CBR value of 14% and UCS value of 352 kPa. These peak values were obtained at optimum fiber contents of 0.2%.

K. Agarwal et. al (2021) This paper studies the effects of randomly distributed polypropylene fiber inclusions on the mechanical behavior of expansive soil. Reinforced soil specimens were prepared at four different fiber contents (0.05%, 0.1%, 0.15% and 0.2%) and the aspect ratio of fibers (L/D) was kept as 250. A series of compaction tests, unconfined compressive strength (UCS) and split tensile strength (STS) tests were performed on the unreinforced and fiber reinforced soil specimens. The results proved that, the UCS and STS values increased to a greater extent with the inclusion of fibers to the expansive soil. It was noticed that, the effect of polypropylene fiber inclusion on the compaction parameters was not much significant (less than 5% variation) due to light weight and less water absorption capacity of PP fibers. The highest UCS values were obtained with 0.15% fiber content with 12 mm length of fibers for that UCS values increased up to 51% of that of the unreinforced soil.

2.2 Past studies on areca nut fiber in various civil engineering applications

Lekha et. al (2014) This paper presents the effect of including randomly spaced areca nut coir to the soil mix. Addition of areca nut coir to the lateritic soil resulted in medium improvement in the soil properties and the optimum content was found to be 0.6% by weight of soil. The addition of areca nut coir along with 3% of cement by weight of soil resulted in significant increase in the UCS and CBR values. The paper concludes that soil stabilized with areca nut coir is more economical since it is naturally available as an agricultural waste and also only a small amount of cement is sufficient to achieve the optimum stabilization. Hence, overall cost of the road construction can be reduced while comparing with the conventional methods.

Das and Singh (2015) This paper reports the recycling of areca nut husk ash as supplementary cementitious material in respect of cement mortars. The mixes are prepared with five percentages (0, 10, 15, 20, and 25) of areca nut husk ash as partial replacement of Portland cement. The properties investigated are; chemical composition, particle size, presence of crystalline matter, compressive strength, water absorption and sorption. Mortar cubes are tested for compressive strength up to the age of 56 days, whereas water absorption and sorption tests are carried out at the age of 28 days. Test results have shown that areca nut husk ash is an effective Pozzolona up to the optimal replacement ratio of 20% cement with better water absorption characteristics.

Das and Singh (2017) In this paper, an experimental programme was undertaken to study the effect of individual and combined inclusion of locally available brown waste materials (areca nut husk, water hyacinth stem) and commercial synthetic fiber (recron 3s) on the geotechnical characteristics of a lateritic soil. Two models of fiber reinforcement on soil were considered: firstly, the fibers were mixed randomly with the soil and secondly, the fibers were introduced sequentially in horizontal discrete layers in the direction of the major principal plane of the soil matrix. A series of laboratory tests including the compaction test, unconfined compressive strength and California bearing ratio were carried out on soil reinforced with areca nut coir, water hyacinth stem and recron fiber at varying percentages to examine the strength of reinforced soil. The results found that samples reinforced with recron and coir, individually and in combination showed increasing strength with increase fiber content in both the models, while water hyacinth stem showed an initial increase followed by a decline at higher fiber content. The optimum fiber content of 0.5% for areca nut coir, 0.5% for recron and 0.125% for water hyacinth stem by dry weight of soil were recommended for strengthening the lateritic soil.

P. Sudhakaran et. al (2018) In this paper, bottom ash (BA) is used as a stabilizing agent, and the suitability of natural areca fiber as reinforcement is demonstrated through detailed experimental investigations and reliability analysis. It includes compaction tests, unconfined compression strength (UCS) tests, California bearing ratio (CBR) tests, and split tensile strength tests. The BA content was varied from 0 to 40%, the fiber content was varied from 0 to 1.5%, and the corresponding performance assessment was carried out. A small amount of cement (3%) was also added to improve the pozzolanic reaction. The UCS and split tensile strength tests were conducted on samples at different curing periods with a maximum curing for 90 days, whereas CBR tests were conducted after 7 days of curing for both soaked and unsoaked conditions. There was considerable increase in UCS, CBR, and split tensile strength of the soil with addition of BA, and the strength values increased tremendously in the presence of areca fiber.

Ramakrishna Hegde et al. (2018) The research work was aimed at developing areca nut fiber reinforced epoxy resin polymer composite and investigating the mechanical properties of the developed composite. Areca fibers were extracted from dried areca husks by soaking in water for 5 days. Extracted fibers were washed with deionized water and dried at room temperature for 15 days. Fibers were alkaline treated by soaking them in 10% sodium hydroxide solution at 30°C for 36 hours followed by neutralizing with 2% acetic acid solution, water washing and drying. The tensile strength of the composite was found to be 9.19 MPa by the tensile test carried out on the standard tensile specimens. Thus the composite developed has the adequate strength and hardness which makes this composite potential material for low strength applications in automobile, military packaging and construction industries.

CHAPTER – 3

AIM AND OBJECTIVE

The aim and objectives of this study are given below:

a) Determination of physical properties such as liquid limit, plastic limit, specific gravity, grain size distribution, optimum moisture content (OMC) and maximum dry density (MDD) by proctor compaction test of the collected sample.

b) Determination of OMC and MDD of the soil mixed with varying percentage of areca fiber by a series of proctor compaction tests.

c) Determination of shear strength parameters of natural soil and soil mixed with varying percentage of areca fiber by a series of unconfined compression strength tests.

CHAPTER – 4

METHODOLOGY

4.1 Introduction

This chapter reveals various methods that has been conducted in the dissertation work to investigate the engineering behavior of reinforced soil sample where areca nut husk is distributed randomly within the remoulded soil sample. A series of laboratory tests are carried out that are presented in the chapter.

4.2 Test Programme and sample preparation

The entire test programme is divided into four phases. They are:

• Collection of the soil sample and material.

• Preparation of disturbed samples for laboratory testing.

• Determination of physical properties of soil.

• Determination of shear strength parameters of natural soil and areca fiber mixed soil by using a series of UCS test.

4.2.1 Collection of soil sample and material

Fig 8: Sample collection site

The sample was collected from Assam Engineering College hill region, near GMDA water supply project. A 3 ft.× 3 ft. area was selected and excavated, the first 1.5 ft layer of soil was removed which may contain leaves, organic matter, branches etc and the soil sample was collected.

Dried areca nut husk were collected from Darranggiri, Assam, a small scale industry that produces areca nuts (supari) domestically. The areca nut shells were soaked in water for 2-3 days, until the fibers are loosened. extracted manually and air-dried. The fibers were cut into lengths of 20 mm.

Step 1 Step 2

Step 3 Step 4

Fig 9: Fibers prepared for testing

4.2.2 Preparation of the disturbed samples for laboratory testing

To ensure repeatable results, soil samples taken from the field must first be prepared using a standard procedure. Before testing, the soil sample is often allowed to air dry, then it is ground up and any stones are taken out. The soil is let to dry at room temperature in accordance with the IS Code technique. However, in many practical situations, oven drying at 105°C can be employed. However, in certain soils with high organic matter and heavy clay content, irreversible changes occur during oven drying, leading to unusual test findings. The soil needs to be air dried in these situations.

Fig 10: Air dried sample and Fiber mixed sample

4.2.3 Determination of physical properties of soil

(a) Sieve Analysis

This test was carried out in accordance with IS 2720 (Part 4)-1985, which states that the gradation of the soil samples was determined by wet sieve analysis. There are two main approaches used for sieve analysis: the dry method and the wet method. When the dirt remains on a 4.75mm IS sieve after sifting, the dry sieve method is used. On the other hand, soil that has been kept on a 75-micron IS sieve after passing through a 4.75mm IS sieve is used for wet sieve analysis. The procedure consisted of the following steps:

- Sufficient quantity of 4.75 micron passing soil sample was taken and oven dried at temperature of 105°C - 115°C.
- 100g of soil is taken and transferred into a bowl, water and 2g of sodium hexametaphosphate is added. The sample is soaked overnight.
- The sample is then washed on 75 micron IS sieve. The retained sample is collected and oven dried at temperature of 105°C to 115°C for 24 hours.
- The sample is then passed through a set of sieves: 4.75 mm, 2.36 mm, 1.18 mm, 600 µ, 300 µ, 150 µ, and 75 µ separated into various fractions by sieving.
- The mass of the material retained on each sieve is recorded.
- The gradation curve is obtained by plotting a graph between sieve size (mm) and % finer.

(b) Specific Gravity

Specific gravity measurements are made in accordance with IS-2720 (Part 3)-1980. The mass density of soil at standard temperature of 27℃ is equal to that of distilled water, which is known as the specific gravity of soil particles. It is the mass of a particular volume of soil divided by the mass of a corresponding volume of water. The procedure consisted of the following steps:

- Firstly, the density bottle was cleaned and dried properly before conducting the test.
- The density bottle along with the stopper been weighed and demoted as M1.
- 5-10g of soil sample was taken in the density bottle and weigh the bottle along with the stopper as M2.
- Now add distilled water to the soil in the density bottle upto the soil level and shake gently to mix soil and water.

- Now the stopper of density bottle was removed and placed in the vacuum desiccator and connect the vacuum pump.
- Take out the bottle after attaining constant temperature and dry the outer surface using cloth and weighed the bottle as a total of mass of bottle, soil and water as M3.
- In the last step, bottle was emptied and filled solely with distilled water along with stopper and weighed as M4.

The specific gravity is determined by the following equation,

$$G = \frac{M2 - M1}{(M4 - M1) - (M3 - M2)}$$

(c) Liquid Limit

In compliance with IS specification IS: 2720 (Part 5)-1985, this test was carried out. The water content that corresponds to the arbitrary boundary between the plastic and liquid limits is known as the liquid limit (WL). The lowest water content at which soil retains its liquid condition yet has a minimal shearing power to resist flowing is known as the liquid limit. The procedure for the Liquid limit test consisted of the following steps:

- 250 gm of air dried soil passing through 425 micron sieve is taken, into an evaporating dish. Distilled water is added and mixed thoroughly to form a uniform paste.
- The wet soil paste was then transferred to the cylindrical cup of cone penetrometer apparatus, ensuring that no air was trapped in the process.
- The wet soil was then levelled up to the top of the cup and placed on the base of the cone penetrometer apparatus.
- After that the penetrometer was adjusted so that the cone point just touches the surface of the soil paste in the cup clamped in this position.
- The vertical clamp was then released allowing the cone to penetrate into the soil paste under its own weight.
- The penetration of the cone after 5 seconds to nearest millimeter was then noted. The test was then repeated at least to have four sets of values of penetration in the range of 14 to 28 mm. The exact moisture content of each trial was determined in accordance with IS: 2720 (Part 2)-1973.

- Plotting a graph between cone penetration (x) and water content (y) will reveal the soil's liquid limit. The liquid limit is then determined by taking the water content that corresponds to a cone penetration of 20 mm.

(d) Plastic Limit

In compliance with IS specification IS: 2720 (Part 5)-1985, this test was carried out. The ability of soil to undergo fast deformation without rupture, elastic rebound, or volume change is known as plasticity. The water content that separates the plastic from the semi-solid soil consistency states is known as the plastic limit (WP). It is the lowest water content at which, when rolled into a thread about 3 mm in diameter, the soil will just start to collapse. The procedure consisted of the following steps:

- 30 gm of air dried soil passing through 425 micron sieve is taken into an evaporating dish. Distilled water is added and mixed thoroughly to make it plastic enough to shape into a small ball.
- Take about 8g of the plastic soil and roll it with fingers on a glass plate. The rate of rolling should be about 80 to 90 strokes per minute to form a thread of 3mm diameter.
- The process of alternate kneading and rolling is repeated until the thread crumbles, and the soil can no longer be rolled into thread.
- The pieces of the crumbled soil thread were collected for moisture content determination.
- The test was repeated for 3 times and the average of the test results was calculated to the nearest whole number.

(e) Standard Proctor Test

In accordance with IS: 2720 (Part 7) 1980, the standard Proctor's compaction test was conducted in the lab, and the optimum moisture contest corresponding to the maximum dry density was determined. The procedure consisted of the following steps:

- About 3 kg of soil was obtained.
- Then the soil was passed through the No. 4 sieve.
- The mass of soil and the mold (Wm) without the collar are weighed.
- The soil was placed in the mixer and gradually more water was added to it to reach the desired moisture content (w).

- The collar was then coated with lubricant.
- The soil was taken out of the mixture and added to the mole in three layers in the following phase. The compaction procedure necessitates 25 blows for per layer. After then, the droplets were applied steadily by hand or mechanically. The dirt then fills the mole and reaches, but does not penetrate, the collar by more than 1 cm.
- As the collar was being carefully lifted from the dirt, it was trimmed with a straight edge that had been sharpened so that it extended above the mold.
- Then the weight of the mould and soil (W) was noted.
- In a subsequent stage, a metallic extruder is used to extrude the soil from the mold in a manner that aligns the extruder with the mold.
- The water content of the sample was then measured at the top, middle and bottom.
- The soil was then placed again and water was added to it to achieve a higher water content.

4.2.4 Determination of shear strength parameters of natural soil and areca nut fiber stabilized soil by using a series of unconfined compression strength (UCS) test

The remoulded soil sample and the areca nut fiber mixed soil samples, which were prepared under various conditions, underwent a series of UCS tests in accordance with IS-2720 (Part10) -1991, to determine the compressive strength of all the soil samples, thereby examining the impact of areca nut fiber on the soil. The fibers are mixed in five different percentages 0%, 0.2%, 0.4%, 0.6%, 0.8% & 1% by weight of soil sample respectively.

The procedure for the UCS test consist of the following steps:

(a) The soil specimen is prepared at desired water content and density in the large mould.

(b) The sampling tube is pushed into the mould, and removed gently filled with soil. For undisturbed samples, push the sampling tube into the clay sample.

(c) Coat the split mould lightly with a thin layer of grease. Extrude the sample out of the sampling tube into the split mould, using the sample extractor and knife.

(d) Trim the two ends of the specimen in the split mould, and remove it by splitting the mould into two parts.

(e) Measure the length and diameter of the specimen with Vernier calipers.

(f) Place the specimen on the bottom plate of the UCS testing machine aligning with the upper plate to make contact with the specimen.

(g) Adjust the dial gauge and proving ring to zero and apply the compression load to cause an axial strain at the rate of 0.5 to 2% per minute.

(h) Record the proving ring reading after every 50 seconds of the dial reading.

(i) Continue the test until failure surfaces have clearly developed or until an axial strain of 20% is reached.

(j) Measure the angle between the failure surface and the horizontal.

CHAPTER – 5

RESULTS AND ANALYSIS

5.1 Observations and Calculations

5.1.1 Wet sieve analysis

The grain size distribution was performed by wet method in accordance to IS: 2720 (part 4): 1985.

Total mass of oven dried sample = 200g

Mass retained after washing on 75 micron sieve = 44g

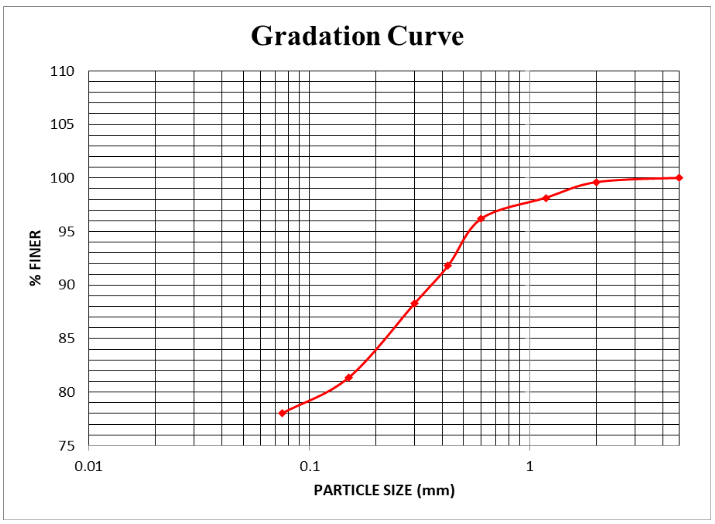

Fig 11: Grain Size Distribution Curve

Table 2: Particle size distribution

Sieve Size	Retained	% Retained	Cumulative % Retained	% Finer
4.75	0	0	0	100
2	0.804	0.402	0.402	99.60
1.18	2.907	1.453	1.855	98.14
0.6	3.917	1.958	3.814	96.19
0.425	8.756	4.378	8.192	91.81
0.3	7.034	3.517	11.709	88.29
0.15	13.935	6.967	18.676	81.32
0.075	6.647	3.323	22	78

Sand = 22%

5.1.2 Liquid limit Test

Determination of liquid limit was performed by cone penetration method according to IS: 2720 (Part 5) 1985.

Table 3: Values for water content determination for liquid limit

Penetration	Cont. Wt.	Cont. + wet soil	Cont. + dry soil	Wt. of water	Wt. of dry soil	Water Content
15	12.648	25.235	21.151	4.084	8.303	49.18
18	9.835	24.196	19.179	5.017	9.344	53.69
20	8.919	25.022	19.252	5.77	10.333	55.84
22	10.149	20.449	16.678	3.771	6.529	57.75
27	9.931	26.113	19.948	6.165	10.017	61.54

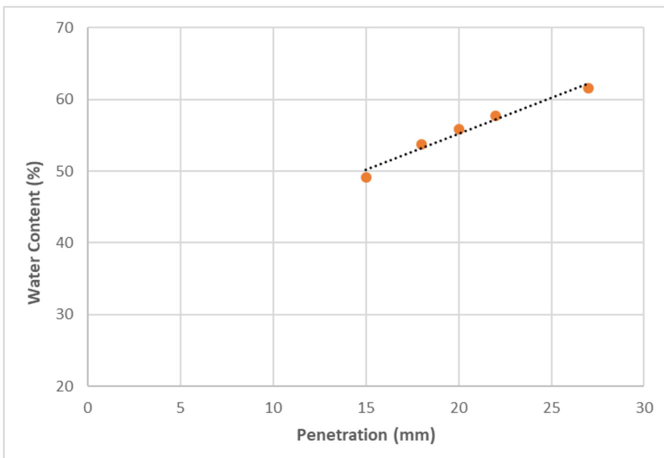

Fig 12: Water content vs penetration graph

Liquid limit is found to be 56%.

5.1.3 Plastic limit test

The plastic limit test was performed in the laboratory according to IS: 2720 (part 5) 1985.

Table 4: Values for water content determination for liquid limit

Cont. Wt.	Cont. + Wet soil	Cont. + Dry soil	Wt. of Water	Wt. of Dry soil	Water Content	Average
9.609	9.985	9.897	0.088	0.288	30.56	29%
9.775	10.346	10.214	0.132	0.439	30.06	
8.469	8.754	8.695	0.059	0.226	26.1	

The value of plastic limit is found to be 29 %.

5.1.4 Specific Gravity Test

Determination of specific gravity was performed with the help of 50 ml density bottle according to IS: 2720 (Part3)1980.

Total mass of sample taken = 5-10 g

Table 5: Specific gravity values

SI No.	Mass of density bottle and stopper, (M1)	Mass of density bottle, stopper and soil, (M2)	Mass of density bottle, stopper, soil and water, (M3)	Mass of density bottle, stopper and water, (M4)	Specific gravity (G)
1	27.22	36.768	84.365	78.101	2.907
2	35.702	45.405	95.484	89.204	2.835
3	35.365	44.795	94.473	89.383	2.173

The average specific gravity is found as 2.638.

5.1.5 Standard Proctor Test

The Standard Proctor's compaction test was carried out in the laboratory and the determination of optimum moisture content corresponding to the maximum dry density was performed according to IS: 2720 (Part 7) 1980.

Weight of Proctor mould (without collar) = 3304g

Height of mould = 12.7 cm

Diameter of mould = 10 cm

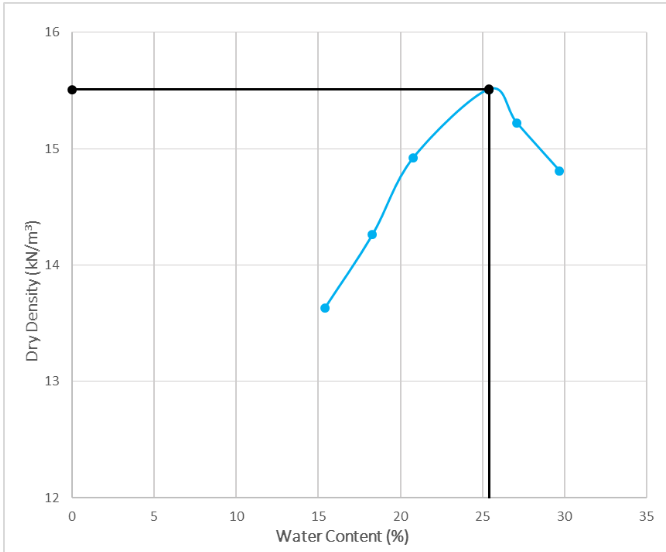

Fig 13: Dry density vs moisture content curve (Soil + 0% fiber)

Results: OMC (Optimum Moisture Content) = 25.4%

MDD (Maximum Dry Density) = 15.51 kN/m^3

5.1.6 Standard Proctor Test of soil with varying percentage of areca fiber

The tests are done as per to IS: 2720 (Part 7) 1980.

(a) Soil + 0.2% (by weight) areca fiber

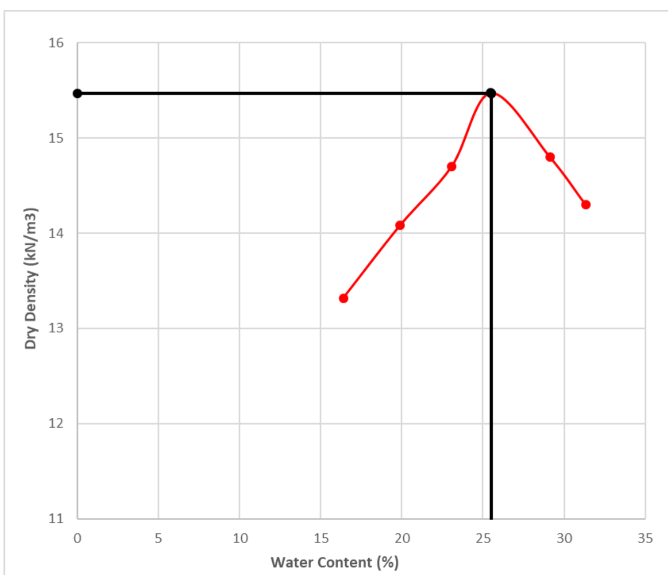

Fig 14: Dry density vs moisture content curve (Soil + 0.2% fiber)

Results: OMC (Optimum Moisture Content) = 25.5%

MDD (Maximum Dry Density) = 15.47 kN/m^3

(b) Soil + 0.4% (by weight) areca fiber

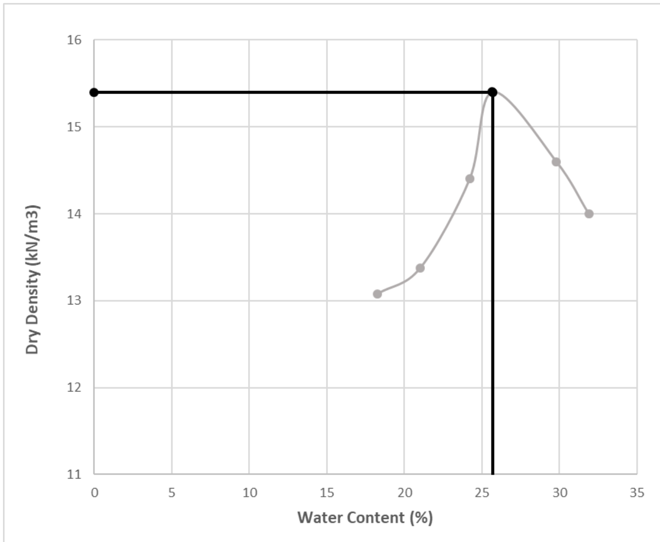

Fig 15: Dry density vs moisture content curve (Soil + 0.4% fiber)

Results: OMC (Optimum Moisture Content) = 25.7%

MDD (Maximum Dry Density) = 15.4 kN/m^3

(c) Soil + 0.6% (by weight) areca fiber

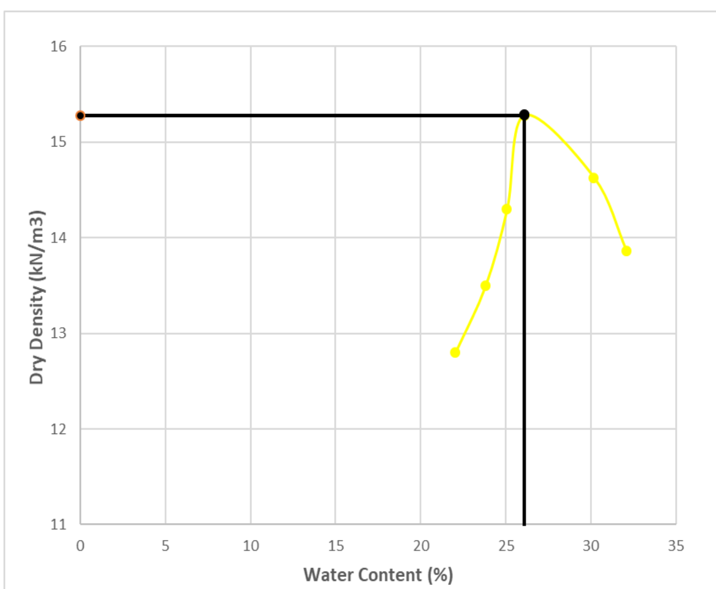

Fig 16: Dry density vs moisture content curve (Soil + 0.6% fiber)

Results: OMC (Optimum Moisture Content) = 26.1%

MDD (Maximum Dry Density) = 15.28 kN/m^3

(d) Soil + 0.8% (by weight) areca fiber

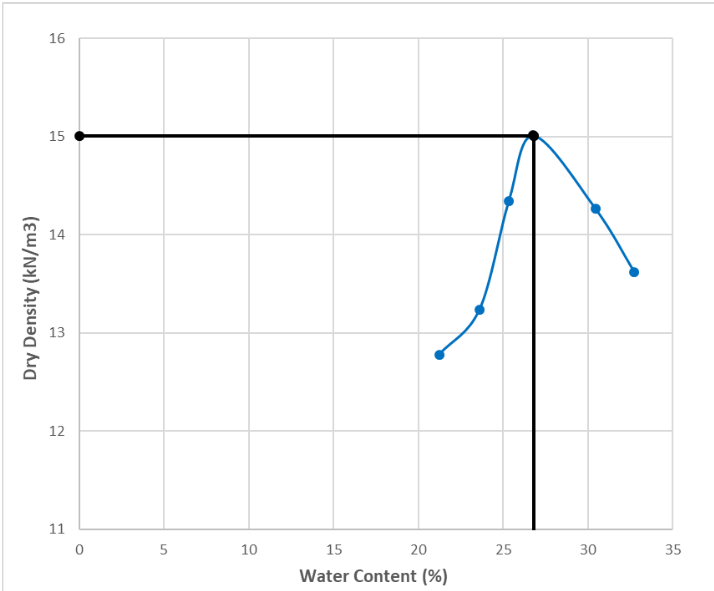

Fig 17: Dry density vs moisture content curve (Soil + 0.8% fiber)

Results: OMC (Optimum Moisture Content) = 26.8%

MDD (Maximum Dry Density) = 15.01 kN/m^3

(e) Soil + 1% (by weight) areca fiber

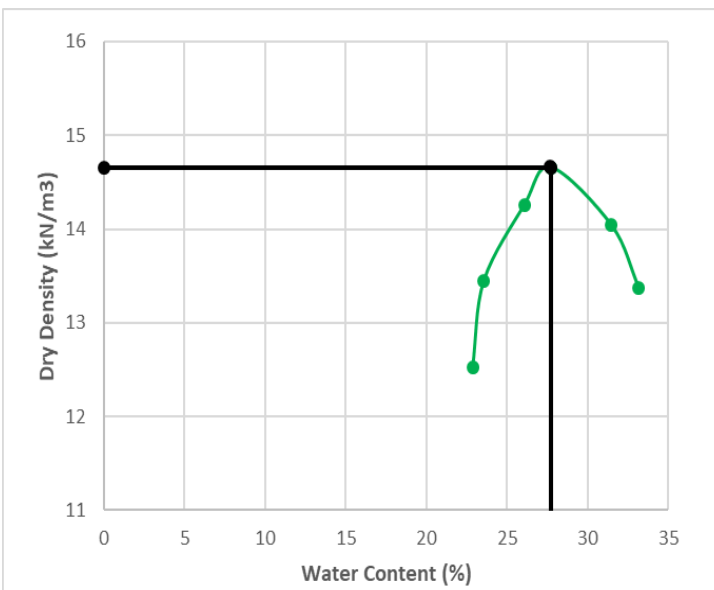

Fig 18: Dry density vs moisture content curve (Soil + 1% fiber)

Results: OMC (Optimum Moisture Content) = 27.6%

MDD (Maximum Dry Density) = 14.82 kN/m^3

5.1.7 Unconfined Compression Strength Test

The UCS test was carried out in the laboratory and the determination of compressive strength was performed at optimum moisture content and maximum dry density according to IS: 2720 (Part 10) 1991.

Test specimen details for all the samples prepared for UCS test :

- Initial Diameter = 38 mm
- Initial length = 76 mm
- Initial area = 11.34 cm2
- Proving ring constant = 0.33 kg/division
- Dial gauge constant = 0.01 mm/division
- Deformation rate = 1.25 mm/minute

The specimen is prepared at MDD = 15.51 kN/m^3 and OMC = 25.4%

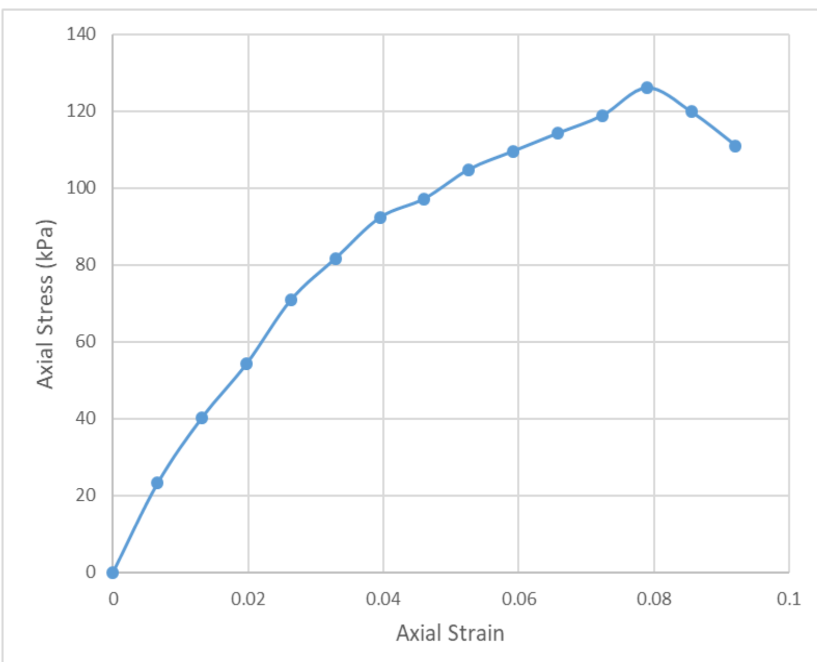

Fig 19: Stress vs Strain curve (soil + 0% fiber)

Fig 20: Failure sample (soil + 0% fiber)

Result: : Unconfined Compressive Strength is found as 126 kPa.

5.1.8 Unconfined Compression Strength Test with varying percentage of areca fiber

(a) Soil + 0.2% (by weight) areca fiber

The specimen is prepared at MDD = 15.47 kN/m^3 and OMC = 25.5%

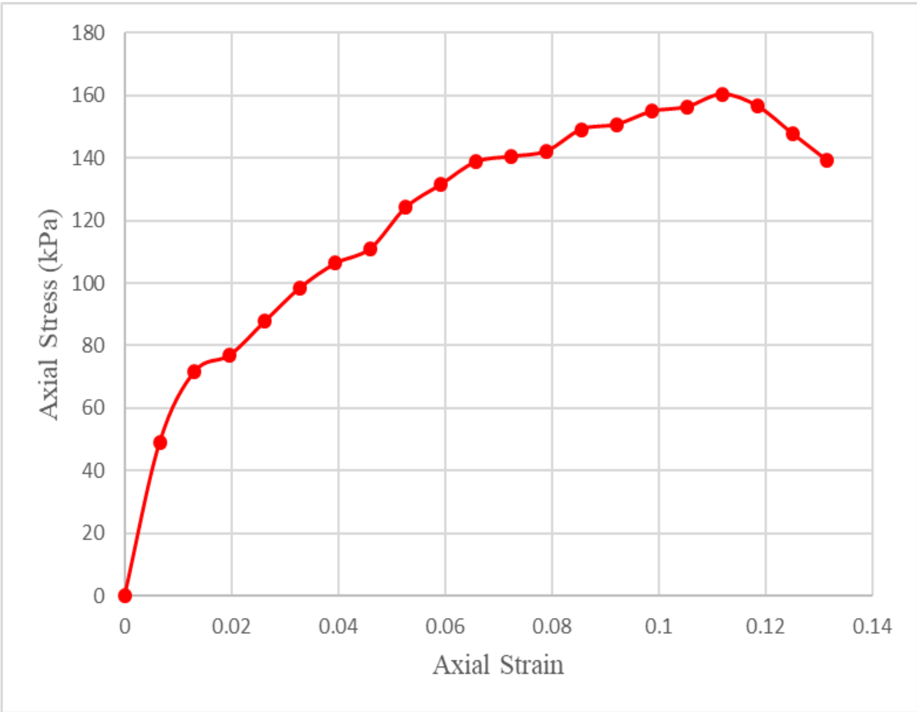

Fig 21: Stress vs Strain curve (Soil + 0.2% fiber)

Fig 22: Failure sample (soil + 0.2% fiber)

Result:: Unconfined Compressive Strength is found as 160 kPa.

(b) Soil + 0.4% (by weight) areca fiber

The specimen is prepared at MDD = 15.4 kN/m^3 and OMC = 25.7%

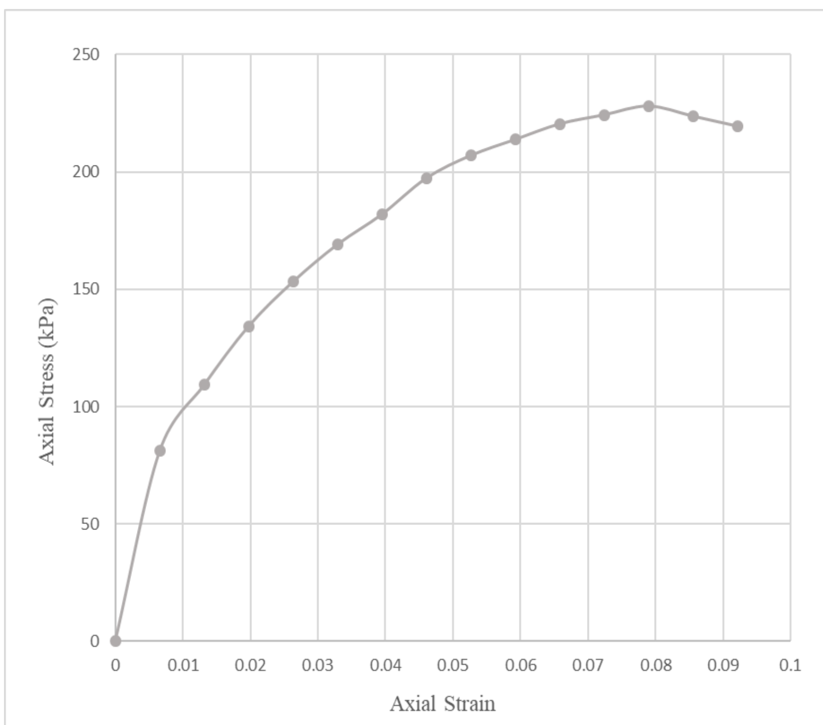

Fig 23: Stress vs Strain curve (Soil + 0.4% fiber)

Fig 24: Failure sample (soil + 0.4% fiber)

Result: Unconfined Compressive Strength is found as 228 kPa.

(c) Soil + 0.6% (by weight) areca fiber

The specimen is prepared at MDD = 15.28 kN/m^3 and OMC = 26.1%

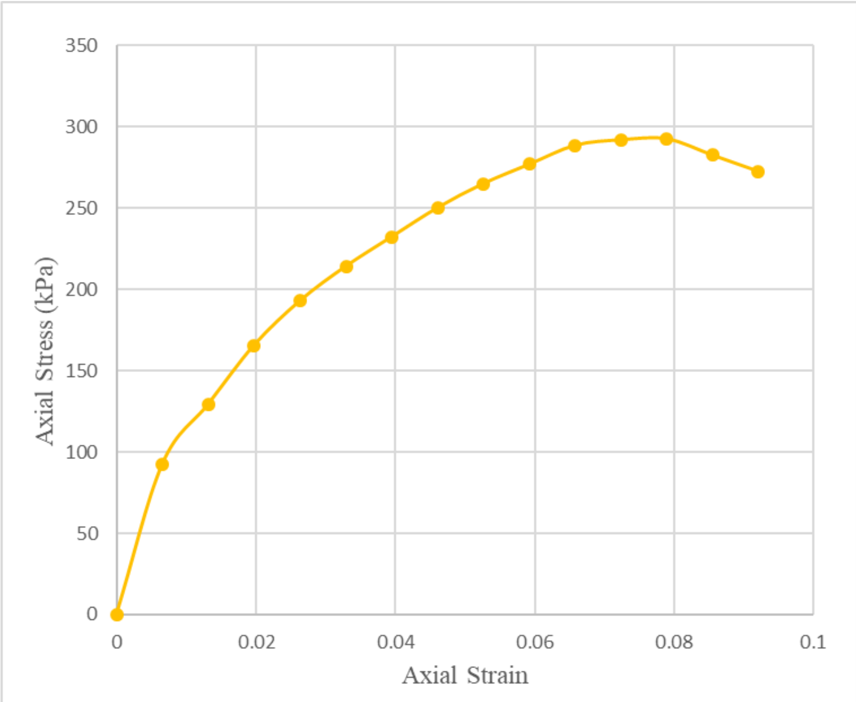

Fig 25: Stress vs Strain curve (Soil + 0.6% fiber)

Fig 26: Failure sample (soil + 0.6% fiber)

Result: Unconfined Compressive Strength is found as 292 kPa.

(d) Soil + 0.8% (by weight) areca fiber

The specimen is prepared at MDD = 15.01 kN/m^3 and OMC = 26.8%

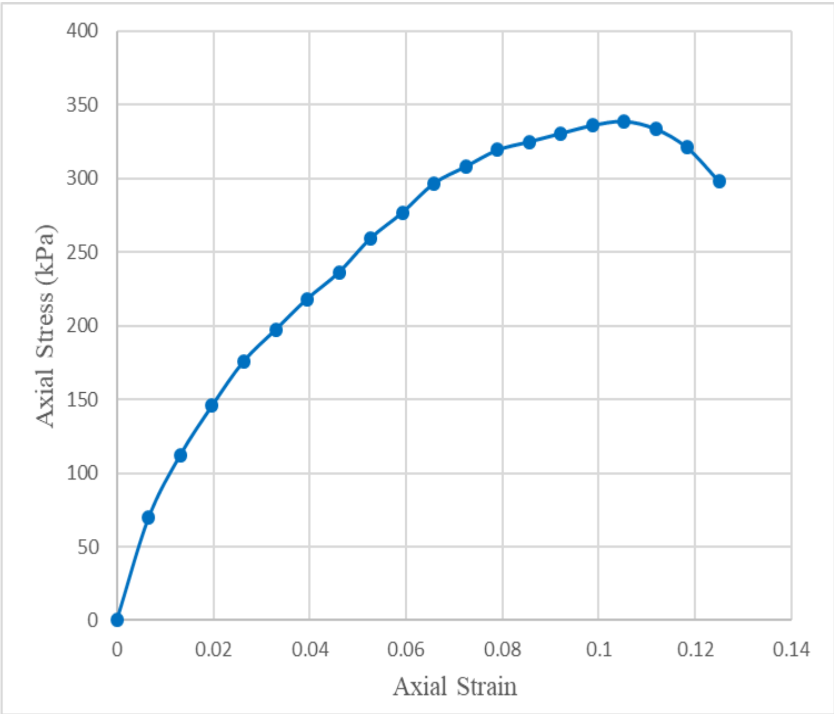

Fig 27: Stress vs Strain curve (Soil + 0.8% fiber)

Fig 28: Failure sample (soil + 0.8% fiber)

Result: Unconfined Compressive Strength is found as 339 kPa.

(e) Soil + 1% (by weight) areca fiber

The specimen is prepared at MDD = 14.66 kN/m^3 and OMC = 27.7%

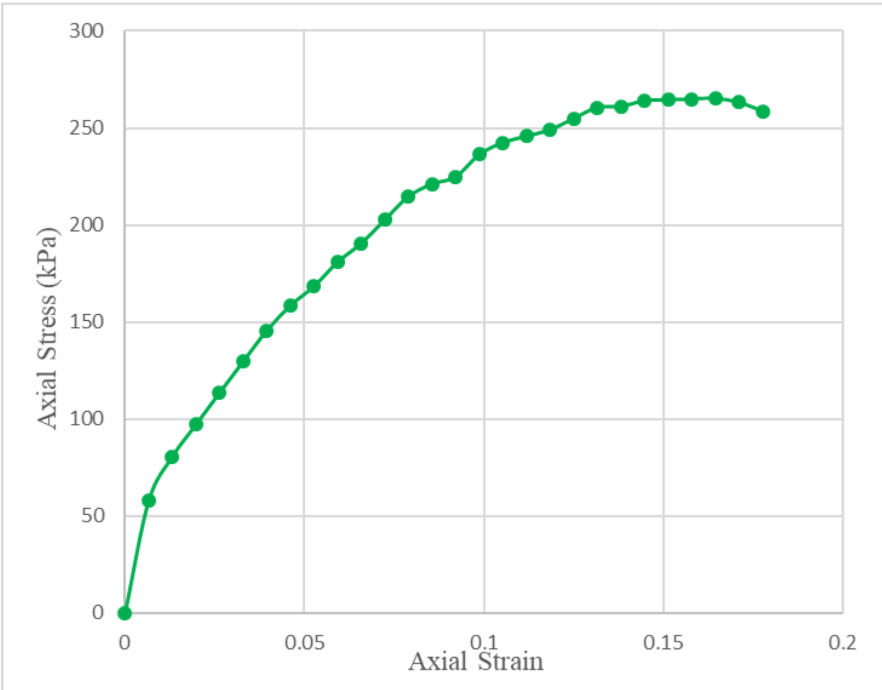

Fig 29: Stress vs Strain curve (Soil + 1% fiber)

Fig 30: Failure sample (soil + 1% fiber)

Result: Unconfined Compressive Strength is found as 265 kPa.

5.2 Analysis of Test Results

5.2.1 Classification of Soil

From the test results, the consistency limits of the sample are calculated as:

Liquid Limit = 56%, Plastic Limit = 29%

Plasticity Index, I_p = 27

To classify the fine-grained soils based on their plasticity, a graph is shown below in Fig. 31 also known as plasticity chart, where it shows the relationship between liquid limit and plasticity index of soil. A-line is the line that is used to separate clays from organic soils and silts. The soil above A-line is clay and below A-line is silt or organic soil.

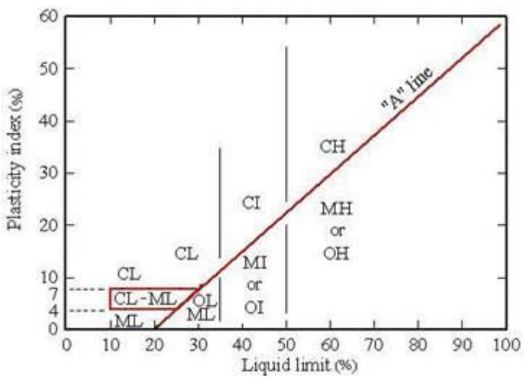

Fig 31: Plasticity Chart

From the plasticity chart, I_p for A-line is given as $0.73(W_l – 20)$ i.e 26.28 < 27. Since I_p for soil is greater than the I_p for A-line, we can classify it as clay type of soil with high compressibility (CH).

5.2.2 Analysis of Experimental Observations in terms of Proctor Compaction Test (when the soil is mixed with areca nut fiber in various percentages)

The values of MDD and OMC obtained from above experiments shows that it varies with inclusion of fibers in the soil. From the test results, the following observations are seen:

- With addition of fibers, there is a marginal decrease in maximum dry density.
- In contrast, the values of optimum moisture content found to increase with increase in percentages of fiber.

The variations may due to following reasons:

- When fibers are added in the soil they interfere with the arrangement of soil particles, making it more difficult to pack tightly together, thereby creating additional pore space within the soil, which reduces the sample's density and contribute to a lower MDD.
- On the other hand, since natural fibers are hydrophilic in nature, that enables them to absorb and retain water. However, the water absorbed by the fibers does not contribute to the lubrication of soil particles, thereby, increases the total water required to achieve optimal compaction, raising the OMC.

Table 6: Percentage change in MDD & OMC w.r.t soil and areca nut fiber mixed soil

Fiber (%)	MDD (kN/m^3)	% change w.r.t original	OMC (%)	% change w.r.t original
0	15.51	0	25.4	0
0.2	15.47	-0.26%	25.5	0.39%
0.4	15.4	-0.71%	25.7	1.18%
0.6	15.28	-1.49%	26.1	2.75%
0.8	15.01	-3.22%	26.8	5.51%
1	14.82	-4.45%	27.6	8.66%

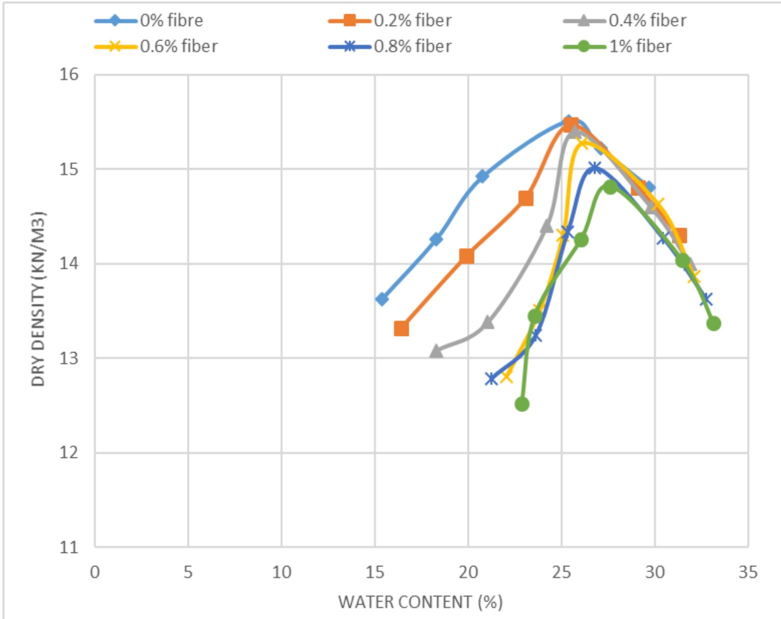

Fig 32: Comparison of compaction curves of soil and areca nut fiber mixed soil in various percentages

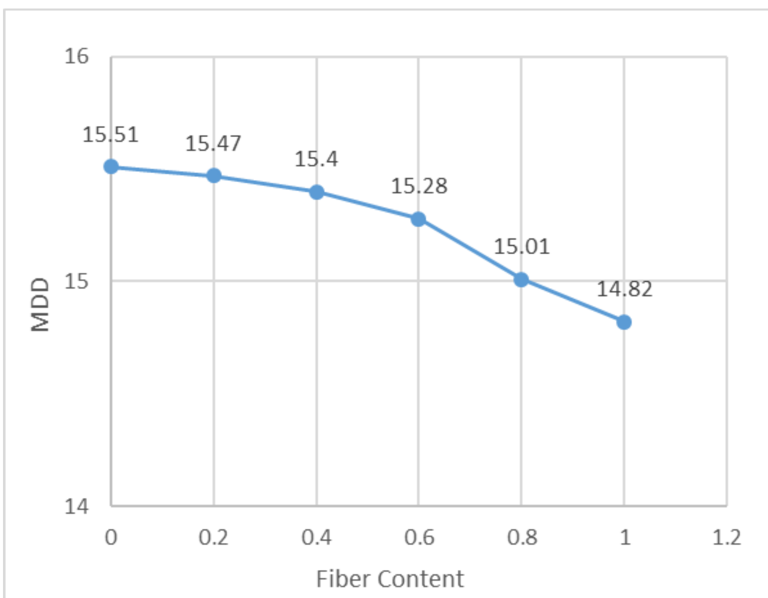

Fig 33: Variation in MDD of fiber reinforced soil w.r.t normal soil

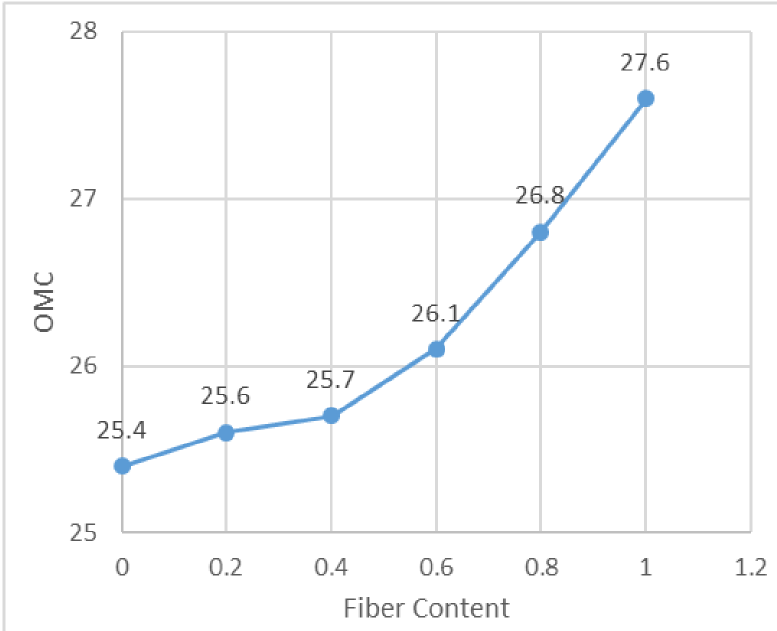

Fig 34: Variation in OMC of fiber reinforced soil w.r.t normal soil

5.2.3 Analysis of Experimental Observations in terms of Unconfined Compression Test (when the soil is mixed with areca nut fiber in various percentages)

The values of compressive strength obtained from above experiments shows that it varies with inclusion of fibers in the soil. From the test results, the following observations are seen:

- The compressive strength for the soil sample has increased when the soil is mixed with 0.2% to 0.8% of areca nut fiber respectively.
- It is found that there is a decrease in strength at 1% fiber content, compared to 0.8% and 0.6%, but greater than the original soil sample. This decrease may due to non-uniform mix of soil fiber composite because of high fiber content, that causes lump formation which is called balling effect. (K.Agarwal et. al 2019). These lumps are highly compressible and make soil more compressible.
- The highest value obtained at 0.8% fiber content i.e 339 kPa contributing 168% of increase compared to original soil.

Table 7: Percentage change in UCS value w.r.t soil and areca nut fiber mixed soil

Fiber (%)	UCS value (kPa)	% change w.r.t original
0	126	0
0.2	160	+ 26.98
0.4	228	+ 80.95
0.6	292	+ 131.74
0.8	338	+ 168.25
1	265	+ 110.31

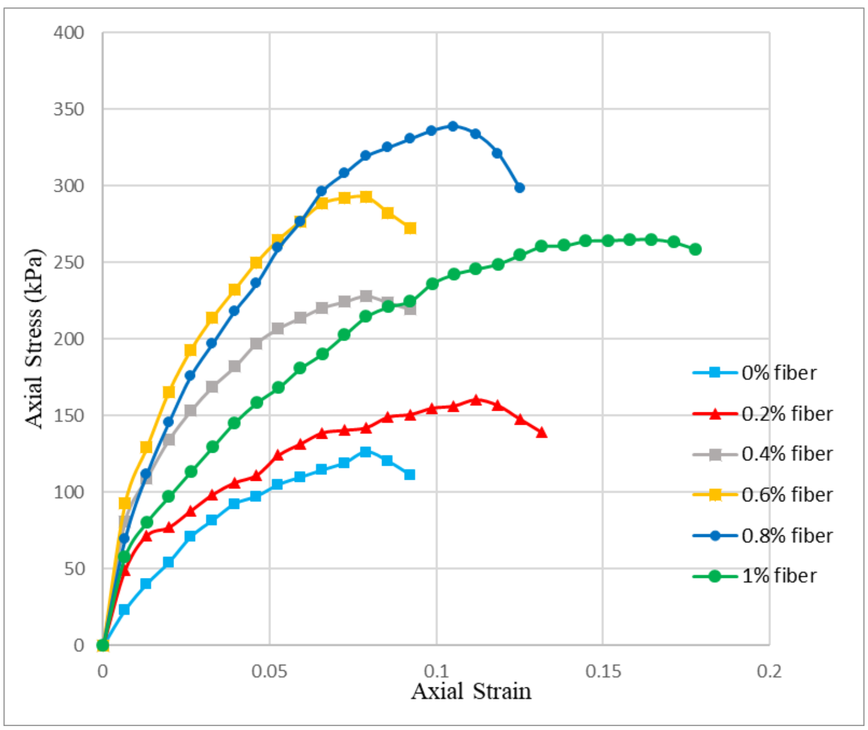

Fig 35: Comparison of stress vs strain curves of soil and areca nut fiber mixed soil in various percentages

CHAPTER - 6

CONCLUSION

The study conducted on the effect of areca nut fiber on soil properties has yielded significant insights, demonstrating the potential of this natural fiber as an eco-friendly and sustainable alternative to traditional synthetic fibers for soil stabilization. The experimental results demonstrate that incorporating areca nut fibers into soil significantly influences its compaction properties, which led to a decrease in maximum dry density and an increase in optimum moisture content. This behavior is attributed to the lower density and water-absorbing nature of the fibers. Moreover, the unconfined compression strength (UCS) tests revealed that the compressive strength of the soil improved with the inclusion of areca nut fibers, reaching optimal performance at 0.8% fiber content by weight of soil. Beyond this percentage, the compressive strength decreases due to the balling effect caused by excessive fiber content, which disrupts the uniform distribution of fibers within the soil matrix. Overall, the findings indicate that areca nut fibers can enhance the strength and stability of soil effectively at optimal fiber content. As a biodegradable and locally available material, areca nut fibers present a sustainable and cost-effective alternative to synthetic fibers in soil stabilization applications. This approach aligns with the goals of sustainable construction practices by reducing reliance on non-renewable materials and minimizing environmental impact. Future research could explore the long-term performance of areca nut fiber-reinforced soil under varying environmental conditions and its application in real-world geotechnical projects.

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