Effect of Different Natural and Synthetic Fiber Reinforcement on the Engineering Characteristics of Sands

A dissertation
submitted in the partial fulfillment of the requirement for the Award of the Degree of

MASTER OF TECHNOLOGY
in
CIVIL ENGINEERING
(*With specialization in Geotechnical Engineering*)
of
Assam Science & Technology University
Session: 2023-2025

Submitted by:

PRIYANGSHU DEKA
Roll No. PG/C/23/13
ASTU Roll No. 230620062010
ASTU Registration No. 312509119

Under the Guidance of
BHASKAR JYOTI DAS
Associate Professor
Assam Engineering College
Department of Civil Engineering

ASSAM ENGINEERING COLLEGE
JALUKBARI, GUWAHATI-13, ASSAM

DECLARATION

I hereby declare that the work presented in this report entitled **"EFFECT OF DIFFERENT NATURAL AND SYNTHETIC FIBER REINFORCEMENT ON THE ENGINEERING CHARACTERISTICS OF SANDS"** in the 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 and Technology University, is a real record of my work carried out in the said college for twelve months under the supervision of Bhaskar Jyoti Das, Associate Professor, Department of Civil Engineering, Assam Engineering College, Jalukbari, Guwahati-13, Assam.

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:

Place:

PRIYANGSHU DEKA

M.Tech 3rd Semester

Roll No: PG/C/23/13

ASTU Registration No: 230620062010

Department of Civil Engineering

Assam Engineering College

Jalukbari, Guwahati- 781013

CERTIFICATE

This is to certify that the work presented in this report entitled "**EFFECT OF DIFFERENT NATURAL AND SYNTHETIC FIBER REINFORCEMENT ON THE ENGINEERING CHARACTERISTICS OF SANDS**" is carried out by Priyangshu Deka , Roll No: PG/C/23/13, a student of M. Tech 3th semester, Department of Civil Engineering, Assam Engineering College, under my guidance and supervision and submitted in the partial fulfillment of the requirement for the award of the Degree of Master of Technology in Civil Engineering with specialization in Geotechnical Engineering under Assam Science and Technology University.

Date:

Place:

BHASKAR JYOTI DAS

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 "**EFFECT OF DIFFERENT NATURAL AND SYNTHETIC FIBER REINFORCEMENT ON THE ENGINEERING CHARACTERISTICS OF SANDS**" has been submitted by PRIYANGSHU DEKA, bearing Roll No: PG/C/23/13, a student of M.Tech 3th Semester, Geotechnical Engineering (Civil Engineering Department), 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. JAYANT A PATHAK

Professor & Head of the Department

Department of Civil Engineering

Assam Engineering College

Guwahati-781013

ACKNOWLEDGEMENT

I would like to extend my sincere appreciation to Bhaskar Jyoti Das, Associate Professor in the Department of Civil Engineering at Assam Engineering College, for his extensive support and encouragement throughout the project. His guidance, constant supervision and provision of necessary information were invaluable to me. Working under him was an inspiring and great experience, and I am highly indebted to him.

This project would not have been possible without the help of my seniors; laboratory assistants and staffs, for their guidance in various ways. Without their guidance and support it would have not been possible for me to prepare and complete this study.

I am also grateful to Dr. Jayanta Pathak, Professor and Head of the Department of Civil Engineering at Assam Engineering College as well as the entire community of the Department of Civil Engineering at Assam Engineering College for providing us with the necessary infrastructure and comfort throughout the course, particularly during my project.

ABSTRACT

This study explores the effect of fiber reinforcement, specifically jute and banana fibers as natural fibers and polypropylene and polyester as synthetic fibers, on the engineering characteristics of sand. Sands, being cohesionless materials, often exhibit poor load-bearing capacity and high susceptibility to deformation under load, making them unsuitable for many geotechnical applications. Traditional soil stabilization methods, such as the use of cement and lime, are effective but contribute to environmental degradation and incur high costs. As a sustainable alternative, natural fibers like jute and banana, known for their high tensile strength, low cost, and biodegradability, offer a promising solution. The research investigates the effects of these fibers on key engineering properties of sands, including compaction behavior, shear strength, permeability and CBR values. Laboratory experiments were conducted by mixing jute and banana fibers into sand at varying percentages (0.5%, 1%, 1.5% by weight). Standard Proctor tests, constant head permeability test, direct shear test and California bearing ratio (CBR) test were used to evaluate the effect of fibers on engineering properties of sand sample. The results demonstrate that both jute and banana fibers significantly enhance the shear strength, permeability and high CBR value indicating improved stability of sands, with notable improvements I angle of internal friction. Despite their biodegradability, jute and banana fibers provided sufficient durability for temporary and semi-permanent geotechnical applications. This research highlights the viability of jute and banana fibers as sustainable reinforcements for sands, offering a cost-effective and environmentally friendly alternative to synthetic fibers and traditional stabilization methods. The findings have significant implications for geotechnical engineering, particularly in regions with abundant natural fiber availability. Future studies are recommended to explore the long-term performance of these fibers under varying environmental conditions. This study highlights the trade-offs between natural and synthetic fibers and provides a comprehensive comparison to guide their application in geotechnical projects. The findings contribute to sustainable and effective soil stabilization techniques, offering practical insights for improving the performance of sands in diverse engineering applications.

LIST OF TABLES

LIST OF FIGURES

CONTENTS

CHAPTER 1

INTRODUCTION

1.1 Background

Sands are widely used in geotechnical engineering projects such as road subgrades, embankments, retaining structures, and foundations. However, their lack of cohesion and low shear strength often necessitate stabilization to ensure structural safety and durability. Among various stabilization techniques, fiber reinforcement has gained significant attention due to its simplicity, effectiveness, and adaptability. By incorporating fibers into the soil matrix, improvements in shear strength, deformation resistance, and stability can be achieved. Fibers, both natural and synthetic, are added to soil matrices to increase cohesion, reduce deformation, and enhance load-bearing capacity.

Reinforcement materials are broadly categorized into natural and synthetic fibers. Natural fibers, such as jute and banana fibers, have gained significant attention due to their availability, cost-effectiveness, and eco-friendly nature. These fibers are biodegradable and derived from renewable sources, making them an excellent alternative to synthetic fibers. In regions with abundant agricultural production, utilizing fibers like jute and banana offers a sustainable solution to improve soil properties while promoting waste management and rural development. Jute fibers are well-known for their tensile strength, biodegradability, and resistance to environmental degradation under controlled conditions. Similarly, banana fibers, extracted from the pseudo-stem of banana plants, possess high specific strength, low density, and excellent mechanical properties, making them ideal for geotechnical applications.

Synthetic fibers, such as polypropylene and polyester, are widely used in soil reinforcement due to their durability, resistance to environmental degradation, and consistent performance. Polypropylene fibers are lightweight, chemically inert, and resistant to moisture, making them suitable for harsh environmental conditions. Polyester fibers, known for their high tensile strength and flexibility, are widely used in applications requiring long-term stability. Despite their advantages, synthetic fibers are non-biodegradable and have a higher environmental impact compared to natural fibers.

However, the effectiveness of these fibers in reinforcing sandy soils requires further exploration to establish their applicability in real-world engineering scenarios. Laboratory testing plays a crucial role in assessing the impact of fiber reinforcement on the engineering characteristics of sands. This study focuses on evaluating the effects of jute and banana fibers on critical properties such as compaction, shear strength, and durability. By performing a series of standardized tests, the research aims to provide a comparative analysis of these fibers, offering insights into their effectiveness and practical applicability in geotechnical engineering.

1.2 Motivation for the study:

Cohesionless sands exhibit poor engineering properties, such as low shear strength, high permeability and susceptibility to deformation under load. While conventional stabilization methods, such as the use of cement or lime, improve these properties, they have significant environmental and economic drawbacks. Fiber reinforcement offers a sustainable alternative, but there is a need for a comparative evaluation of natural and synthetic fibers to determine the optimal choice for reinforcing sands. This research aims to address this gap by systematically investigating the effects of jute, banana, polypropylene, and polyester fibers on the engineering properties of sands through laboratory testing.

CHAPTER 2

LITERATURE REVIEW

2.1 General:

The comprehensive review of literatures have been shown in this chapter related to the fiber reinforced soils , particularly sands emphasizing the effect of use of natural and synthetic fibers on the engineering properties of sand.

2.2 Literature Review:

Ganiev et al. (2021) investigated the effects of fiber reinforcement on the mechanical behavior of sand, particularly focusing on how varying fiber content, confining pressure, and initial relative density influence the shear behavior and critical state line of the sand. The research involved conducting a series of consolidated drained triaxial compression tests to assess these effects under controlled conditions. The results showed that as fiber content increased, both the maximum and residual deviatoric stresses increased, while volumetric expansion decreased. This trend highlights the beneficial role of fiber reinforcement in enhancing the mechanical properties of sand.

Nouri et al. (2019) studied on the effect of polypropylene fiber reinforcement on the shear behavior of sandy soil results indicated that the shear strength of sand increased with the addition of polypropylene fibers. Specifically, the maximum shear strength was observed to improve with higher fiber content, demonstrating a clear relationship between fiber concentration and mechanical performance. The test results showed that both the cohesion and friction angle of the fiber-reinforced samples increased as the fiber content rose. study found that the inclusion of fibers affected the dilatancy behavior of the soil. For loose samples, the fibers decreased dilatancy, while for dense samples, they enhanced the dilation tendency. This behavior is attributed to the interaction between the fiber-sand matrix and the relative density of the samples.

Singh et al. (2022) investigated the behavior of jute fiber-reinforced sand through direct shear tests, focusing on various parameters that influence the engineering properties of the soil.The peak shear stress of the jute-sand (JS) mixes increases with the percentage of jute fiber added, indicating that jute fibers enhance the strength of the soil when mixed appropriately. The study tested fiber contents ranging from 0% to 1.5% by weight of soil, demonstrating a clear correlation between fiber content and shear strength.The optimal fiber length for achieving maximum peak shear stress was found to be 20 mm. The stress-strain response improved with increasing fiber length up to this point, after which the performance declined as the length increased to 40 mm. This suggests that there is a threshold beyond which longer fibers may not contribute positively to the soil's shear strength.The study observed that increasing water content from 0% to 100% led to a significant reduction in peak shear stress. Specifically, at a relative density of 50% and normal stress of 100 kPa, the peak shear stress decreased by approximately 20% with rising water content. This highlights the importance of moisture conditions in the performance of jute-sand mixes.

Hossain et al. (2015) studied that the California Bearing Ratio (CBR) value of the subgrade soil increased with the addition of jute fiber. Specifically, the CBR value improved as the content of jute fiber increased, indicating enhanced load-bearing capacity of the soil. It was observed that longer fibers (30 mm) and larger diameters (8 mm) significantly contributed to higher CBR values, particularly at a fiber content of 1.2%. The Proctor compaction tests indicated that the optimum moisture content (OMC) increased while the maximum dry density (MDD) decreased with the addition of jute fiber. This suggests that while the soil becomes more workable with jute reinforcement, it may also become less dense.

Ahmad et al. (2009): concluded that inclusion of oil palm empty fruit bunch (OPEFB) fibers significantly enhances the peak shear strength of silty sand. The study found that increasing the fiber content leads to greater strain at failure, resulting in more ductile behavior of the soil mixture. Specifically, reinforced silty sand with 0.5% coated fibers of 30 mm length exhibited approximately a 25% increase in friction angle and a 35% increase in cohesion under undrained loading conditions compared to unreinforced silty sand. The findings indicate that both the length and percentage of fiber content play crucial roles in the shear strength of fiber-reinforced soil. The internal friction angle generally increased with fiber length up to 30 mm, after which it began to decrease with longer fibers due to non-uniform distribution and increased horizontal placement of fibers in the soil specimen. The study observed that fiber reinforcement reduces soil dilatancy, which is evident from the stress-strain behavior during triaxial tests. Under undrained conditions, increased fiber content was associated with higher pore water pressure, which positively influenced the shear strength of the soil.

Ibrahim et al. (2006) examined the effects of randomly oriented discrete crimped polypropylene fibers on the mechanical response of very fine sand. Compaction and direct shear tests were performed on sand specimens of different densities, both unreinforced and reinforced with varying proportions of fibers. The results show that the presence of fiber reinforcement provides extra resistance to compaction, leading to a less dense packing as the quantity of fibers increases. The direct shear tests indicate that inclusion of fibers increases the peak shear strength and the strain required to reach the peak. The post-peak strength at large strains was also higher when fibers were included. The presence of fibers leads to more dilative behaviour. A linear failure envelope was observed for all densities and fiber concentrations within the range of effective normal stresses tested. The increase in peak shear strength was almost linear at low effective normal stress and approached a limiting value at higher normal stresses. For the loosest specimens reinforced with the highest percentage of fibers, the relative increase in peak shear strength was more than 50%.

Kumar et al. (2024) presented a numerical investigation into the static and dynamic characterization of fiber-reinforced sand. The study explores the behavior of fiber-reinforced cohesionless soil through numerical simulation of triaxial specimens. The numerical model was validated using existing laboratory triaxial compression testing literature. The effects of fiber content on the static and dynamic stress-strain response of fiber-reinforced soil were examined, including the impact on bulk modulus, shear modulus, and damping values. The results show that increasing fiber content leads to increases in modulus of elasticity, bulk modulus, and shear modulus, while damping coefficients decrease. The authors believe this numerical approach can serve as an alternative to laboratory experiments for determining the dynamic properties of fiber-reinforced soil.

Kalita et al. (2016) presented a comparative study on the use of natural fiber (coconut coir), synthetic fiber (glass fiber), and waste material (cement bag) as soil reinforcement. The study was conducted on red loam soil to investigate the effects of these reinforcement materials on the soil properties and to determine the most effective combination. The key findings include significant improvements in tensile strength, shear strength, and bearing capacity of the reinforced soil, as well as the potential economic benefits of using waste materials like coconut coir and cement bags for soil stabilization.

2.3 Summary and critical appraisal of literature review:

From the reviewed studies, it is evident that both natural (jute, banana, coir) and synthetic (polypropylene, polyester) fibers significantly enhance the engineering properties of sands. Natural fibers offer environmental and cost benefits but face challenges with biodegradability and durability. Synthetic fibers, while durable, have a higher environmental impact. These findings underscore the importance of comparing natural and synthetic fibers under controlled conditions to identify the most suitable option for specific geotechnical applications.

This review highlights the gaps in research, particularly the lack of detailed comparative studies focusing on jute, banana, polypropylene, and polyester fibers for reinforcing sands. While several studies have focused on individual fibers or direct comparisons of one natural and one synthetic fiber, there is limited research that systematically compares multiple fibers (e.g., jute, banana, polypropylene, and polyester) under consistent testing conditions.

2.4 Objective and scope of the work:

The main objective of the work is to study the effect of different natural & synthetic fiber reinforcements on the engineering characteristics of sand. Consequently, the purpose of the research is to assess the impact of these fibers on the shear strength parameter, permeability and CBR characteristics of sands and to finally perform a comparative analysis of natural and synthetic fibers, focusing on their performance, sustainability, and practical feasibility in geotechnical applications.

The scope of the work involves series of laboratory tests to evaluate the performance of natural (jute and banana) and synthetic (polypropylene and polyester) fibers on the engineering properties of sands. The study focuses on the following:

1. Compaction Tests:

Standard Proctor tests are conducted to determine the changes in maximum dry density and optimum moisture content of fiber-reinforced sands.

2. Shear Strength Tests:

Direct shear tests are performed to assess the cohesion and angle of internal friction of sands mixed with different fibers at varying percentages.

3. California Bearing Ratio (CBR) Test:

CBR test to determine the resistance provided by the fiber reinforcement of different percentages with sand to loading.

4. Constant Head Permeability test:

The test was done to determine the effect of fiber reinforcement on the permeability of sand with increasing fiber content.

CHAPTER 3
MATERIALS & METHODOLOGY

3.1 Material used:

The materials used in the work include Sand, Banana Fiber, Jute Fiber, Polypropylene & Polyester Fiber. These are briefly discussed below-

3.1.1 Sand:

Sand is a naturally occurring granular material composed of finely divided rock and mineral particles, predominantly quartz, with traces of feldspar and other minerals. Its abundant availability and versatile nature make it an essential material in various engineering applications. In construction, sand is a key ingredient in concrete, mortar, and asphalt. It is used for laying foundations, as a bedding material for pipes and paving, and in road construction. Sand is also employed in soil stabilization, drainage systems, and as a filler material in earthworks. Beyond construction, sand is vital in glass manufacturing and casting processes.

Fig 3.1 Pure Sand Sample

The advantages of sand as an engineering material include its affordability and widespread availability, making it economically viable for large-scale projects. Sand is easy to handle, mix, and compact, offering excellent workability. Its high permeability ensures effective drainage, making it suitable for use in filters, sub-bases, and retaining walls. Moreover, sand contributes to the stability and strength of concrete and mortar, enhancing the durability of structures. However, sand has its limitations. Its lack of cohesion makes it unsuitable for standalone load-bearing applications without additives or binders. Poorly graded or fine sand can lead to weak foundations and reduced stability. Excessive use of natural sand for construction has also raised environmental concerns, including habitat destruction and resource depletion. Sand is prone to erosion by wind and water, which can cause challenges in certain environments.

The engineering properties of sand further highlight its importance. It has a particle size range of 0.075 to 4.75 mm, with variations classified as fine, medium, or coarse. Its specific gravity ranges between 2.6 and 2.8, while its high permeability makes it ideal for drainage applications. Sand is thermally stable and has good load-bearing capacity when compacted properly. However, it lacks tensile strength and requires stabilization through mixing with cement, lime, or fibers for enhanced performance.

3.1.2 Banana Fiber:

Banana fiber is a natural fiber extracted from the pseudo-stem of the banana plant. Known for its high tensile strength (up to 400 MPa), it is widely used as an eco-friendly reinforcement material. Its moderate elastic modulus allows it to provide flexibility and resistance to deformation when mixed with sand. Banana fiber enhances the load-bearing capacity of sand, improving its ductility and reducing shrinkage.

Fig Banana Fiber mixed with pure sand

However, banana fiber is highly absorbent, which can lead to moisture-related issues and degradation over time. Its thermal insulation properties are beneficial, but its limited resistance to high temperatures restricts its application in certain environments. As a biodegradable material, it offers sustainability and reduces environmental impact, but its susceptibility to decay in wet conditions and variability in quality may limit its long-term performance. Despite these drawbacks, banana fiber is an affordable and renewable option for reinforcing sand in environmentally conscious projects.

Banana fiber has been studied for its potential as a sustainable reinforcement material in sand. Research shows that incorporating banana fiber into sand enhances its shear strength, load-bearing capacity, and ductility. Banana fibers have been used in experimental studies focusing on soil stabilization, where fibers were added to loose sand to improve its stability under load-bearing applications. For example, banana fiber reinforcement has been applied in embankment construction, retaining walls, and foundation beds. The biodegradability of banana fiber has made it particularly attractive for temporary projects or environmentally sensitive applications.

3.1.3 Jute Fiber:

Jute fiber, derived from the bark of the jute plant, is a natural fiber with moderate tensile strength (200–350 MPa) and good elongation properties. Its ability to enhance the shear strength and load-bearing capacity of sand makes it a popular choice for reinforcement in geotechnical applications. Jute fiber is cost-effective, biodegradable, and widely available, making it an eco-friendly option.

Fig Jute Fiber mixed with sand

However, jute fiber's high moisture retention can lead to swelling and degradation over time, especially in wet or humid environments. This limits its long-term durability unless treated with chemicals to improve its resistance to decay. Its thermal insulation properties are beneficial for certain applications, but its lower elastic modulus compared to synthetic fibers restricts its use in high-load scenarios. Jute fiber is an ideal reinforcement material for temporary or short-term projects where sustainability and cost are priorities. Jute fiber has been widely researched as a reinforcement material in geotechnical engineering due to its cost-effectiveness and availability. Studies have demonstrated that jute fiber inclusion in sand improves its shear strength and reduces settlement under loading. Jute fiber has been used in projects such as road construction, where it was mixed with sand to enhance the stability of sub-base layers. Additionally, jute geotextiles have been applied in erosion control and slope stabilization projects, taking advantage of the fiber's biodegradability. However, its use in permanent structures is limited due to its susceptibility to moisture-induced degradation.

3.1.4 Polypropylene Fiber

Polypropylene fiber is a synthetic fiber widely used in sand reinforcement due to its excellent mechanical properties and durability. With tensile strengths ranging from 400 to 700 MPa, polypropylene fiber significantly improves the tensile strength, stability, and durability of sand. It is hydrophobic, meaning it does not absorb water, making it ideal for use in wet environments or applications requiring resistance to water-induced erosion.

Polypropylene fiber is lightweight, resistant to chemicals, UV radiation, and corrosion, and maintains its structural integrity over time. These properties make it a reliable choice for permanent structures and challenging environmental conditions. However, polypropylene is non-biodegradable, raising concerns about its environmental impact. Additionally, it is relatively more expensive than natural fibers like jute and banana fiber. Despite its cost and environmental concerns, polypropylene fiber remains a highly effective material for reinforcing sand in long-term projects. Polypropylene fiber is one of the most extensively used synthetic fibers for sand reinforcement in engineering applications. Its inclusion has been tested in laboratory experiments to improve the tensile strength, compressive strength, and stability of sand. Polypropylene fibers have been used in reinforced soil walls, retaining structures, and pavements. One notable application is in the construction of geosynthetic-reinforced foundations, where polypropylene fibers were added to sand to enhance its load distribution and reduce settlement. The durability and resistance of polypropylene to environmental factors make it a preferred choice in long-term infrastructure projects.

3.1.5 Polyester Fiber:

Polyester fiber is a synthetic fiber known for its exceptional tensile strength (500–900 MPa) and high elastic modulus, which provide rigidity and improve the compressive strength of sand. Its resistance to wear, chemicals, and UV radiation makes it a durable reinforcement material for a wide range of engineering applications. Polyester fiber's minimal water absorption makes it highly suitable for wet or humid environments, as it retains its structural integrity without swelling or degrading.In addition to its durability, polyester fiber exhibits excellent thermal stability, allowing it to perform well under temperature fluctuations. However, it is non-biodegradable and less environmentally friendly than natural fibers. Its relatively higher cost can also be a limiting factor for projects with tight budgets. Despite these drawbacks, polyester fiber is an excellent choice for projects requiring high performance, long-term durability, and resistance to environmental stresses. Polyester fiber has been explored as a reinforcement material in sand to improve its strength and resistance to deformation. Its use has been documented in projects involving geotextiles, where polyester fibers were embedded in sand layers to enhance their load-bearing capacity and reduce erosion. Studies have shown that polyester fiber-reinforced sand exhibits improved compressive strength and reduced strain under dynamic loads, making it suitable for applications in road construction, embankments, and foundation stabilization. The high durability and resistance of polyester fiber to chemical and environmental degradation have made it a reliable option for demanding engineering applications.

3.2 Methodology:

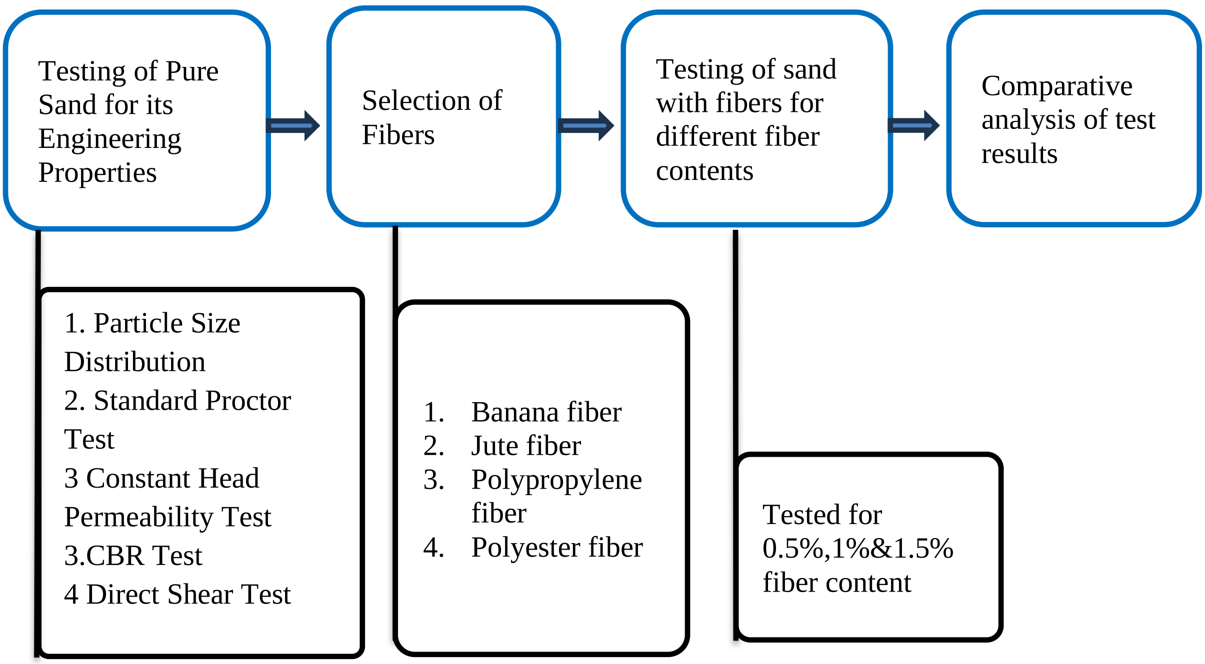


Fig 3.2 Flowchart for Methodology

3.3 Experimental tests performed:

3.3.1 Specific gravity test:

The specific gravity of soil is an important property used in geotechnical engineering. It is defined as the ratio of the weight of soil solids to the weight of an equal volume of water at a specified temperature. The pycnometer method is a standard method to determine the specific gravity of soil and is detailed in IS: 2720 (Part 3/Section 1) – 1980.

3.3.2 Sieve analysis:

Sieve analysis is a fundamental test in civil engineering to determine the particle size distribution of soils, aggregates, or other granular materials. It helps in the classification and assessment of materials for various engineering purposes. The test is conducted as per IS: 2720 (Part 4) – 1985 for soil.

3.3.3 Standard Proctor Compaction Test:

The proctor compaction test is performed as per the IS:2720 (part 7)-1985 guidelines to determine the maximum dry density and optimum moisture content. For the compaction test air dried samples are taken. The dried samples of bentonite-sand(BS) and bentonite-quarry dust (BQ) are then mixed thoroughly with each other in the proposed proportion of 30:70. After that water is added to the soil as prescribed in the code and kept for 24 hours in airtight plastic bags for the uniform distribution of moisture. The process is repeated 3 to 5 times with increasing water content.

3.3.4 Permeability Test:

To determine the hydraulic conductivity the permeability test is conducted as per the IS 2720-(Part-17)-1986 guidelines. In this study the constant head permeability test has been adopted. For the permeability test, the samples are compacted in optimum moisture content (OMC) and maximum dry density (MDD). On the basis of the test results, the permeability of the sample can be calculated as:

$$k = \frac{QL}{Ath}$$

where, k = permeability (cm/s)

Q = volume of water collected (ml)

L = height of soil sample (cm)

A = cross-sectional area of sample (cm^2)

t = time (s)

h = head difference (cm)

3.3.5 California bearing ratio test (CBR):

The California Bearing Ratio (CBR) Test is a penetration test widely used to evaluate the strength and load-bearing capacity of subgrade soil, subbase, and base layers for road and pavement construction. The procedure for conducting the CBR test is outlined in Indian Standard IS 2720-Part 16: Methods of Test for Soils – Laboratory Determination of CBR. This test is essential in determining the suitability of soil for use in road construction and helps in the design of pavement thickness.

3.3.6 Direct shear test (DST) :

The Direct Shear Test is a widely used method to determine the shear strength parameters of soil, namely cohesion () and the angle of internal friction (). According to the guidelines outlined in the Indian Standard (IS 2720-Part 13: Methods of Test for Soils – Direct Shear Test), the test involves shearing a soil sample under controlled conditions to evaluate its response to applied stresses. The test is suitable for both cohesive and non-cohesive soils and can be conducted under drained or undrained conditions, depending on the soil type and the specific requirements of the study.

CHAPTER 4

EXPERIMENTAL PROCEDURE AND RESULTS

4.1 Introduction

The description of different test program with their results which are conducted in the laboratory to examine properties of soil is discussed in this chapter.

4.1.1: Determination of the physical properties of the soils:

4.1.1.1: Specific gravity:

The specific gravity (G) of the sample was determined as per IS: 2720-III (1980) using pycnometer.

Fig 4.1 Specific Gravity using Pycnometer

Average specific gravity was obtained from among the matching results of three trials and the values are listed below-

Table 4.1 Table for Specific Gravity

Specific Gravity	Trail No.
2.77	1
2.52	2
2.55	3

The average specific gravity of the sand sample was **2.62.**

4.1.1.2: Particle size determination:

The particle size distribution of the samples was determined as per IS: 2720- IV (1975).

Fig 4.2 IS Sieve set

The percentage size fractions of the samples are listed below-

Table.4.2 Percentage size fractions of the samples:

Particle size (mm)	Sand Sample (%)
• Coarse sand (4.75-2.00 mm)	2.4
• Medium sand (2-0.425 mm)	92.1
• Fine sand (0.425-0.075 mm)	5.5
• Fines (<0.075 mm)	0

- **Total percentage of sand = 100**
- **The sample do not contain any percentage of fines i.e. clay & silt.**

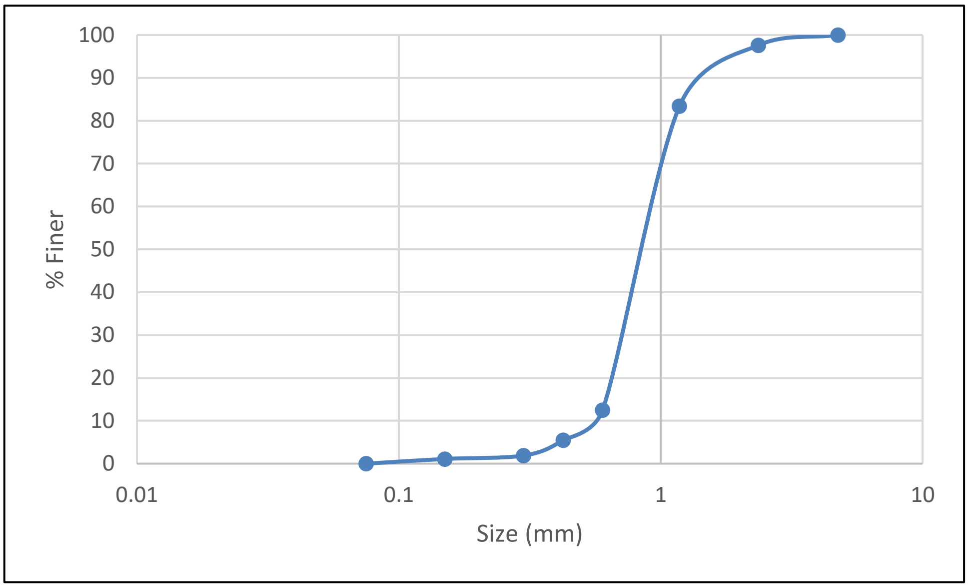


Fig 4.3 Particle size distribution chart for sand sample

4.2 Tests for Engineering Properties of soil sample –

4.2.1 Standard Proctor Compaction Test:

The standard Proctor Compaction test was conducted in the laboratory original sand sample to determine the optimum moisture content corresponding to the maximum dry density in accordance with IS:2720 (Part 7) 1980. The result of the soil sample is presented in table and the Standard Proctor Compaction Curve obtained is shown in figure.

Table 4.3 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test

Maximum Dry Density (MDD) (g/cc)	Optimum Moisture Content (OMC) (%)
1.67	10.87

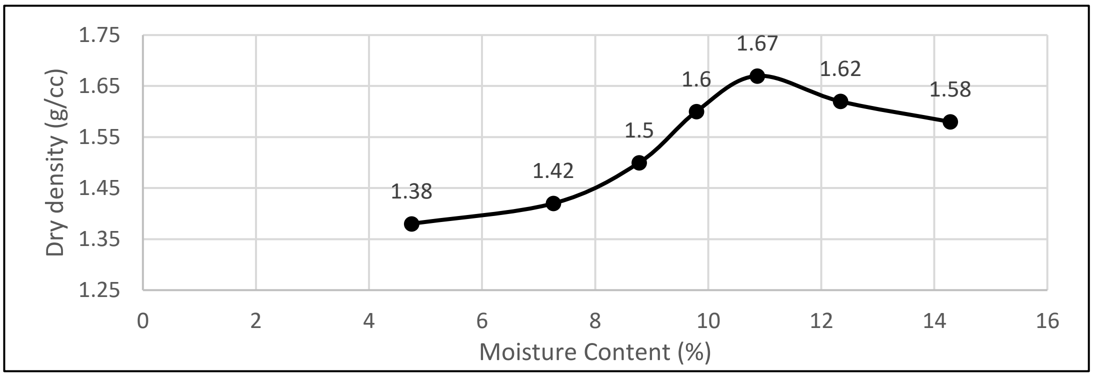


Fig 4.4 Standard Proctor Compaction Curve for Original Sand Sample

4.2.1.1: Standard Proctor Compaction test with Banana Fiber-

The Standard Proctor Compaction test was conducted for a mixture of original sand sample and banana fiber for three different percentages by weight of the sample – namely 0.5% , 1% & 1.5% to obtain their maximum dry density and optimum moisture content in accordance with IS:2720 (Part 7) 1980. The result of the soil sample mixed with banana fiber are presented in tabular form along with their Standard Proctor Compaction Curves –

4.2.1.1.1: Compaction Characteristics for 0.5% banana fiber with sand-

Table 4.4 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test for 0.5% banana fiber + OS

Maximum dry density (MDD) (g/cc)	Optimum moisture content (OMC) (%)
1.55	14.77

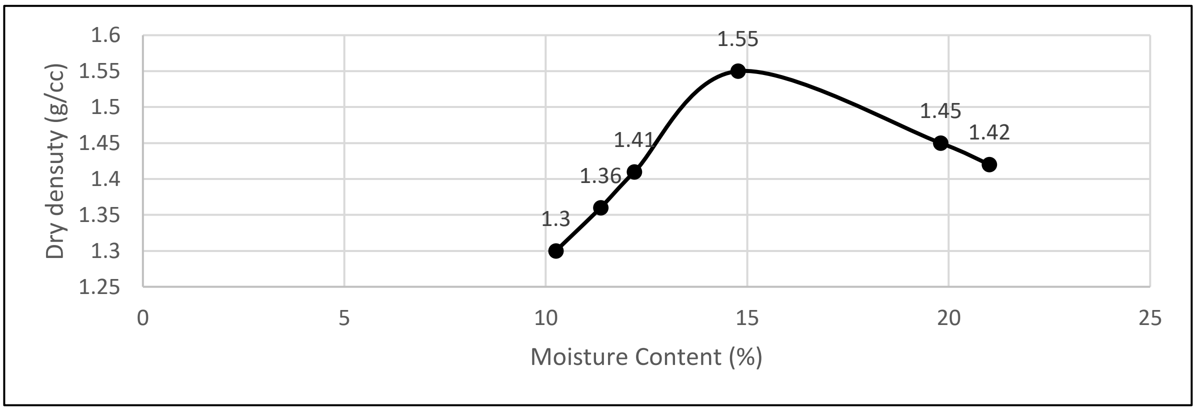


Fig 4.5 Standard Proctor Compaction Curve for Original Sand Sample + 0.5% banana fiber

4.2.1.1.2: Compaction Characteristics for 1% banana fiber with sand-

Table 4.5 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test for 1% banana fiber + OS

Maximum dry density (MDD) (g/cc)	Optimum moisture content (OMC)(%)
1.45	16.66

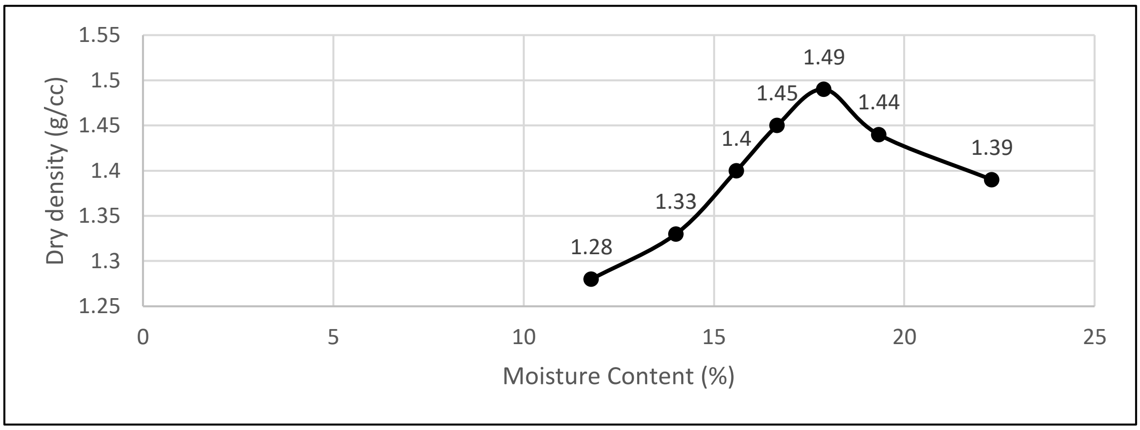


Fig4.6 Standard Proctor Compaction Curve for Original Sand Sample + 1% banana fiber

4.2.1.1.3: Compaction Characteristics for 1.5% banana fiber with sand-

Table 4.6 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test for 1.5% banana fiber + OS

Maximum dry density (MDD) (g/cc)	Optimum moisture content (OMC)(%)
1.39	19.77

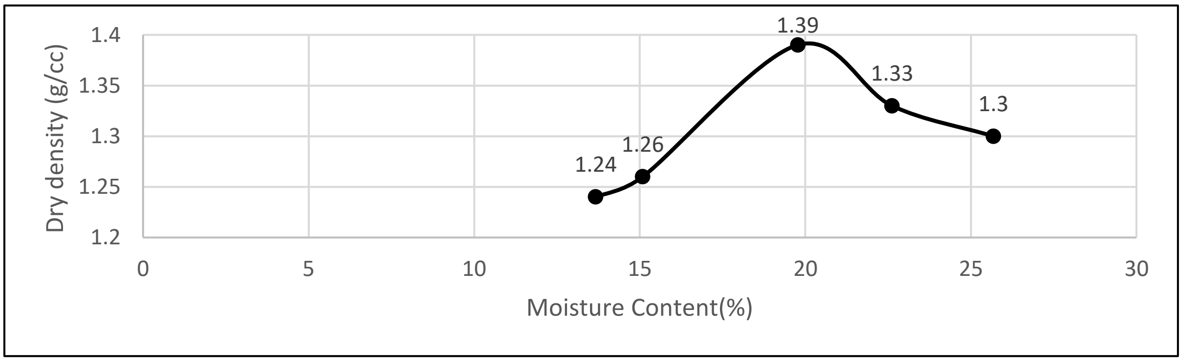


Fig 4.7 Standard Proctor Compaction Curve for Original Sand Sample + 1.5% banana fiber

4.2.1.2: Standard Proctor Compaction test with Jute Fiber-

The Standard Proctor Compaction test was conducted for a mixture of original sand (OS) sample and jute fiber for three different percentages by weight of the sample – namely 0.5% , 1% & 1.5% to obtain their maximum dry density and optimum moisture content in accordance with IS:2720 (Part 7) 1980. The result of the soil sample mixed with banana fiber are presented in tabular form along with their Standard Proctor Compaction Curves –

4.2.1.2.1: Compaction Characteristics for 0.5% jute fiber with sand-

Table 4.7 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test for 0.5% jute fiber + OS

Maximum dry density (MDD) (g/cc)	Optimum moisture content (OMC)(%)
1.61	17.77

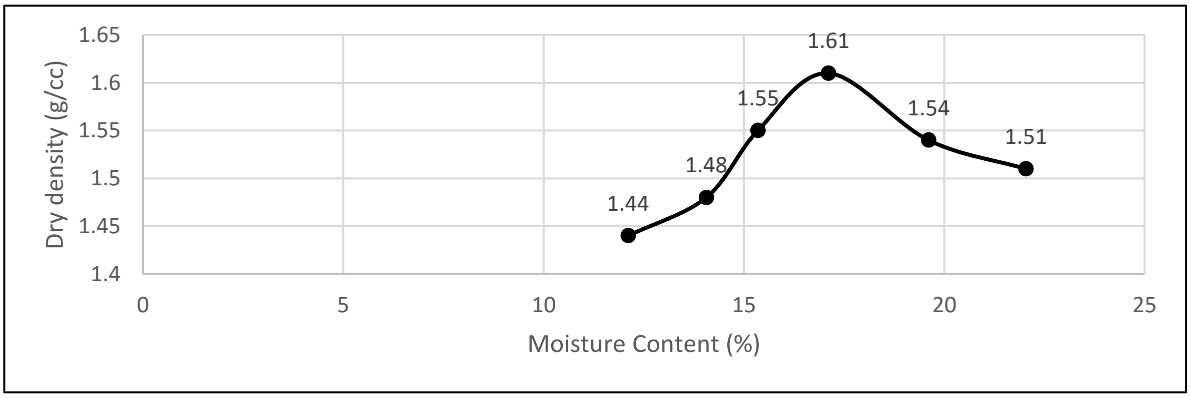


Fig 4.8 Standard Proctor Compaction Curve for OS + 0.5% jute fiber

4.2.1.2.2: Compaction Characteristics for 1% jute fiber with sand-

Table 4.8 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test for 1% jute fiber + OS

Maximum dry density (MDD) (g/cc)	Optimum moisture content (OMC)(%)
1.53	21.98

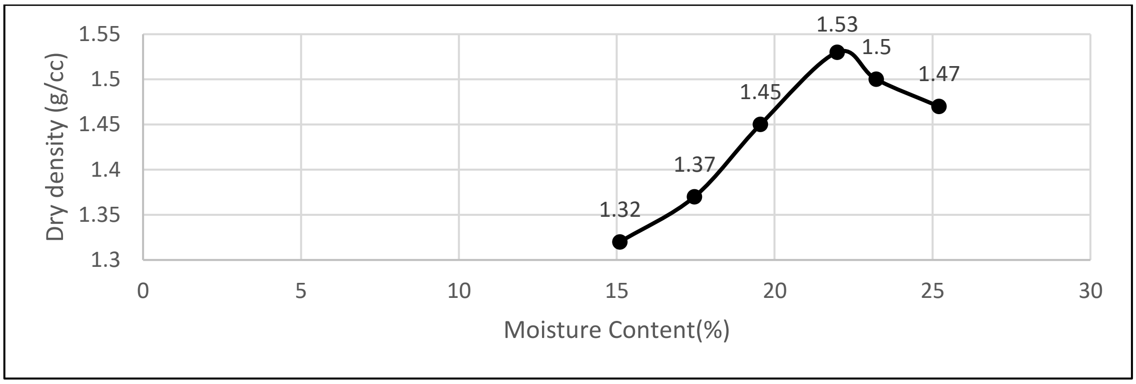


Fig 4.9 Standard Proctor Compaction Curve for OS + 1% jute fiber

4.2.1.2.3: Compaction Characteristics for 1.5% jute fiber with sand-

Table 4.9 Maximum dry density and Optimum moisture content by Standard Proctor Compaction test for 1.5% jute fiber + OS

Maximum dry density (MDD) (g/cc)	Optimum moisture content (OMC)(%)
1.46	**23.22**

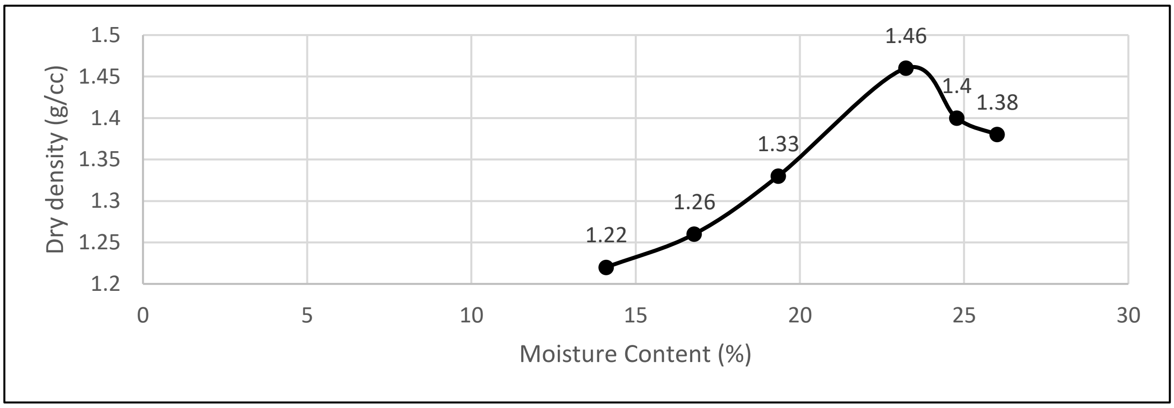


Fig 4.10 Standard Proctor Compaction Curve for OS + 1.5% jute fiber

4.2.2 Constant Head Permeability Test

The Constant Head Permeability Test was conducted in the laboratory original sand sample to determine its average permeability. The test was carried out in accordance with IS 2720 (Part 36) :1987.

4.2.2.1 Constant Head Permeability Test on Original Sand Sample-

The result of the soil sample for constant head permeability test is presented in table –

Table 4.10 Constant Head Permeability test for Original Sand Sample

Head difference (h) (cm)	Volume (Q) (cm^3)	Time (t) (s)	Permeability (k) (cm/s)
97.73	24	10	0.00398
97.73	22	10	0.00360
97.73	19	10	0.00315
97.73	15	10	0.00248
97.73	12	10	0.00199

The average Permeability of pure sand sample was found to be **3.05 x 10^{-3} cm/s.**

Fig 4.11 Constant Head Permeability Test Apparatus

4.2.2.2 Constant Head Permeability Test with Banana Fiber

The Constant Head Permeability Test was conducted for a mixture of original sand (OS) sample and banana fiber for three different percentages by weight of the sample – namely 0.5%, 1% & 1.5% to obtain their average permeability. The test was carried out in accordance with IS 2720 (Part 36) :1987.

4.2.2.2.1 Constant Head Permeability Test with 0.5 % Banana Fiber with sand

Table 4.11 Constant Head Permeability test for 0.5% banana fiber + Original Sand Sample

Head difference (h) (cm)	Volume (Q) (cm^3)	Time (s)	Permeability (k) (cm/s)
87.73	18	10	0.00332
87.73	16	10	0.00295
87.73	14	10	0.00258
87.73	13	10	0.00240
87.73	10	10	0.00184

The average Permeability of pure sand + 0.5% banana fiber was found to be **2.62 x $\mathbf{10^{-3}}$cm/s.**

4.2.2.2.2 Constant Head Permeability Test with 1 % Banana Fiber with sand

Table 4.12 Constant Head Permeability test for 1% banana fiber + Original Sand Sample

Head difference (h) (cm)	Volume (Q) (cm^3)	Time (s)	Permeability (k) (cm/s)
89.73	17	10	0.00307
89.73	15	10	0.00270
89.73	12	10	0.00216
89.73	11	10	0.00198
89.73	9	10	0.00162

The average Permeability of pure sand + 1% banana fiber was found to be **2.31 x $\mathbf{10^{-3}}$ cm/s.**

4.2.2.2.3 Constant Head Permeability Test for 1.5 % Banana Fiber with sand

Table 4.13 Constant Head Permeability test for 1.5% banana fiber + Original Sand Sample

Head difference (h) (cm)	Volume (Q) (cm^3)	Time (s)	Permeability (k) (cm/s)
82.73	14	10	0.00274
82.73	13	10	0.00254
82.73	10	10	0.00195

82.73	9	10	0.00176
82.73	8	10	0.00156

The average Permeability of pure sand + 1.5% banana fiber was found to be **2.11 x 10^{-3}cm/s.**

4.2.2.3 Constant Head Permeability Test with Jute Fiber

The Constant Head Permeability Test was conducted for a mixture of original sand (OS) sample and jute fiber for three different percentages by weight of the sample – namely 0.5%, 1% & 1.5% to obtain their average permeability. The test was carried out in accordance with IS 2720 (Part 36) :1987.

4.2.2.3.1 Constant Head Permeability Test for 0.5% Jute Fiber with Sand

Table 4.14 Constant Head Permeability test for 0.5% jute fiber + Original Sand Sample

Head difference (h) (cm)	Volume (Q) (cm^3)	Time (s)	Permeability (k) (cm/s)
95.73	19	10	0.00321
95.73	17	10	0.00287
95.73	15	10	0.00254
95.73	12	10	0.00203
95.73	11	10	0.00186

The average Permeability of pure sand + 0.5% jute fiber was found to be **2.51 x 10^{-3}cm/s.**

4.2.2.3.2 Constant Head Permeability Test for 1% Jute Fiber with Sand

Table 4.15 Constant Head Permeability test for 1% jute fiber + Original Sand Sample

Head difference (h) (cm)	Volume(Q) (cm^3)	Time (s)	Permeability (k) (cm/s)
88.73	21	15	0.00255
88.73	19	15	0.00231
88.73	18	15	0.00219
88.73	17	15	0.00207
88.73	15	15	0.00182

The average Permeability of pure sand + 1% jute fiber was found to be **2.19 x 10^{-3}cm/s.**

4.2.2.3.3 Constant Head Permeability Test for 1.5% Jute Fiber with Sand

Table 4.16 Constant Head Permeability test for 1.5% jute fiber + Original Sand Sample

Head difference (h) (cm)	Volume (Q) (cm^3)	Time (s)	Permeability (k) (cm/s)
82.73	14	10	0.00274
82.73	12	10	0.00235
82.73	10	10	0.00195
82.73	9	10	0.00176
82.73	7	10	0.00137

The average Permeability of pure sand + 1.5 % jute fiber was found to be **2.04 x 10^{-3}cm/s.**

4.2.3 California Bearing Ratio Test (CBR)

The **CBR Test** was conducted in the laboratory original sand sample to determine its CBR value. The test was carried out in accordance with IS 2720 (Part 16) :1987.

Fig 4.12 CBR Test Apparatus

4.2.3.1 CBR test for Original Sand Sample-

Table 4.17 CBR test on Original Sand Sample

Load (kg)	Penetration (mm)
0	0
29.4	0.5
44.3	1
68.8	1.5
88.1	2
112.5	2.5
125.5	3
161.7	4
190.4	5
222.9	7.5
285.5	10
334.2	12.5

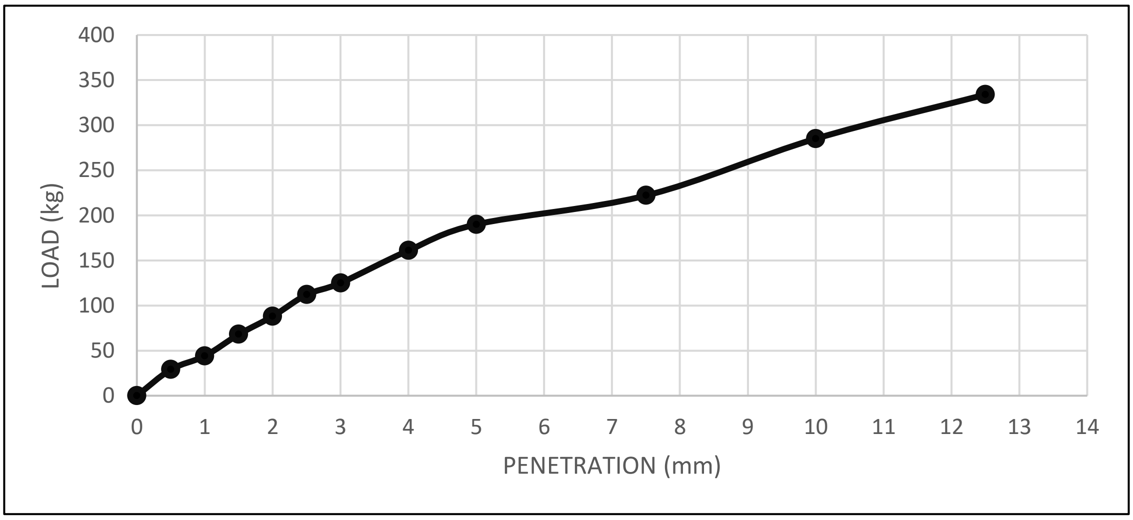


Fig 4.13 CBR Curve for Original sand sample

The CBR value for the original sand sample is **9.24%.**

4.2.3.2 CBR Test with Banana Fiber

The CBR Test was conducted for a mixture of original sand (OS) sample and Banana fiber for three different percentages by weight of the sample – namely 0.5% , 1% & 1.5% to obtain their CBR values. The test was carried out in accordance with IS 2720 (Part 16) :1987.

4.2.3.2.1 CBR test for 0.5% Banana fiber with Sand-

Table 4.18 CBR test on Original Sand Sample with 0.5% banana fiber

Load (kg)	Penetration (mm)
0	0
38.6	0.5
59.4	1
99.1	2
128.6	2.5
137.4	3
171.9	4
209.3	5
252.4	7.5
303.5	10
401.2	12.5

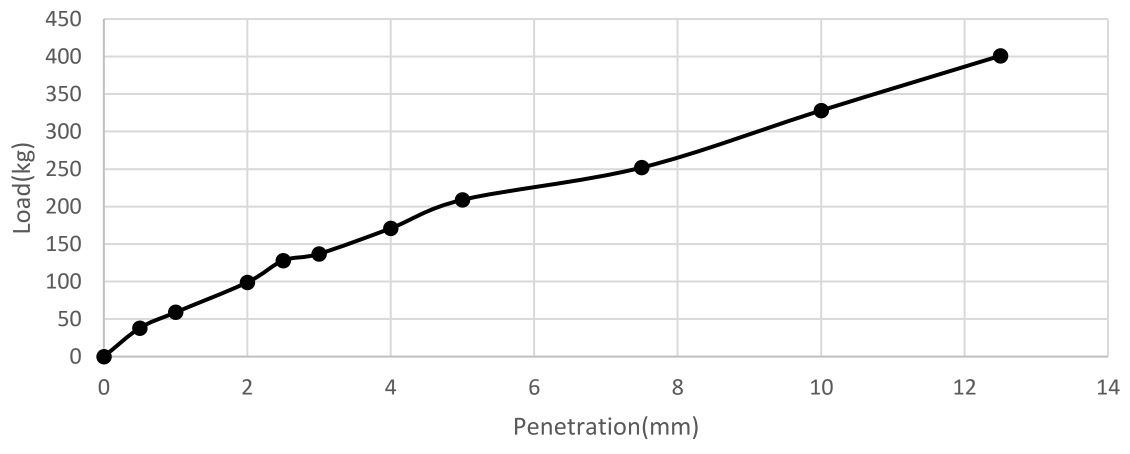


Fig 4.14 CBR Curve for Original sand sample with 0.5% banana fiber

The CBR value for the original sand sample with 0.5% banana fiber is **10.17%.**

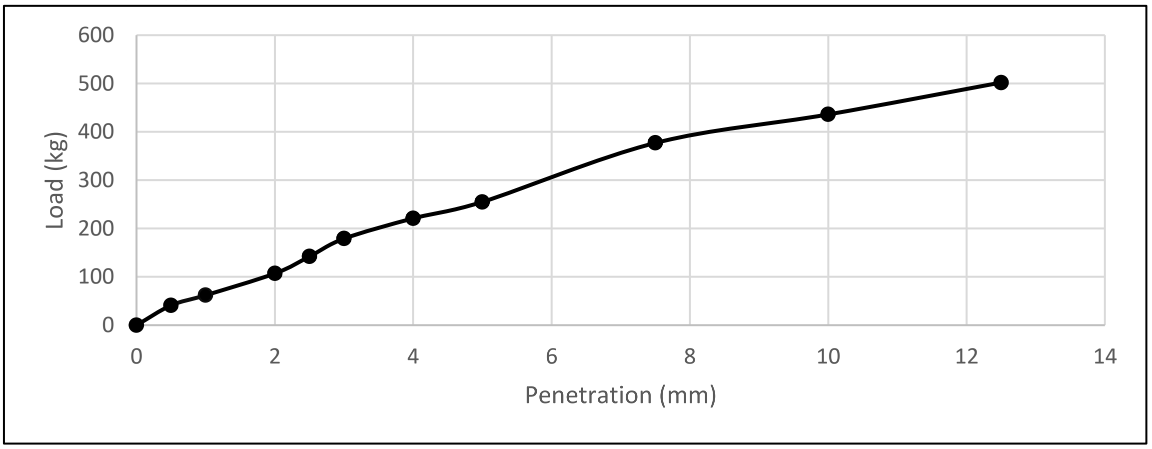
4.2.3.2.2 CBR test for 1% Banana fiber with Sand:

Table 4.19 CBR test on Original Sand Sample with 1% banana fiber

Load (kg)	Penetration (mm)
0	0
41.4	0.5
62.9	1
107.6	2

142.1	2.5
179.1	3
221.5	4
255.8	5
377.4	7.5
436.3	10
502.2	12.5

Fig 4.15 CBR Curve for Original sand sample with 1% banana fiber



The CBR value for the original sand sample with 1% banana fiber is **12.4 % .**

4.2.3.2.3 CBR test for 1.5% Banana fiber with Sand-

Table 4.20 CBR test on Original Sand Sample with 1.5% banana fiber

Load (kg)	Penetration (mm)
0	0
69.6	0.5
90.2	1
135.5	2
170.5	2.5
207.7	3
249.8	4
283.9	5
405.3	7.5
464.5	10
530.5	12.5

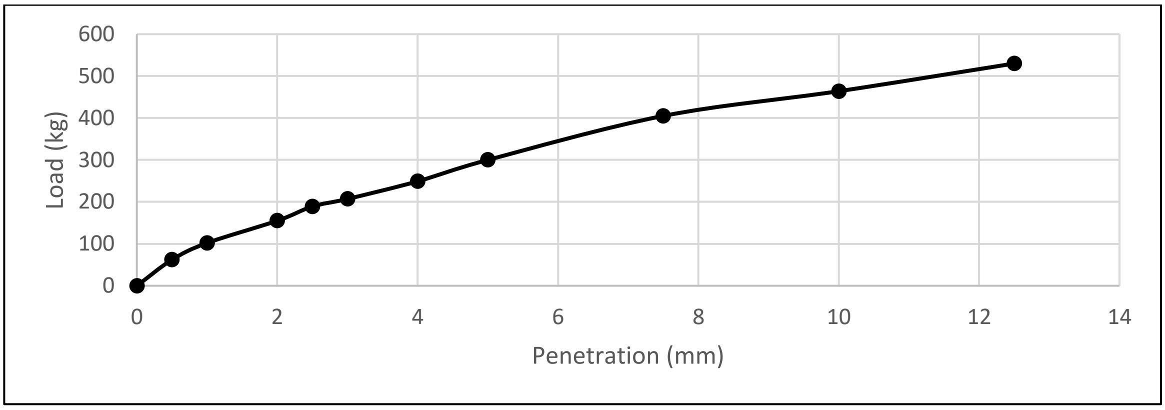


Fig 4.16 CBR curve for original sand sample with 1.5% banana fiber

The CBR value for the original sand sample with 1% banana fiber is **13.77 % .**

4.2.3.3 CBR Test with Jute Fiber

The CBR Test was conducted for a mixture of original sand (OS) sample and Jute fiber for three different percentages by weight of the sample – namely 0.5% , 1% & 1.5% to obtain their CBR values. The test was carried out in accordance with IS 2720 (Part 16) :1987.

4.2.3.3.1 CBR test for 0.5% Jute fiber with Sand-

Table 4.21 CBR test on Original Sand Sample with 0.5% Jute fiber

Load (kg)	Penetration (mm)
0	0
57.3	0.5
78.4	1
118.2	2
147.5	2.5
156.9	3
190.6	4
228.5	5
271.4	7.5
322.8	10
420.1	12.5

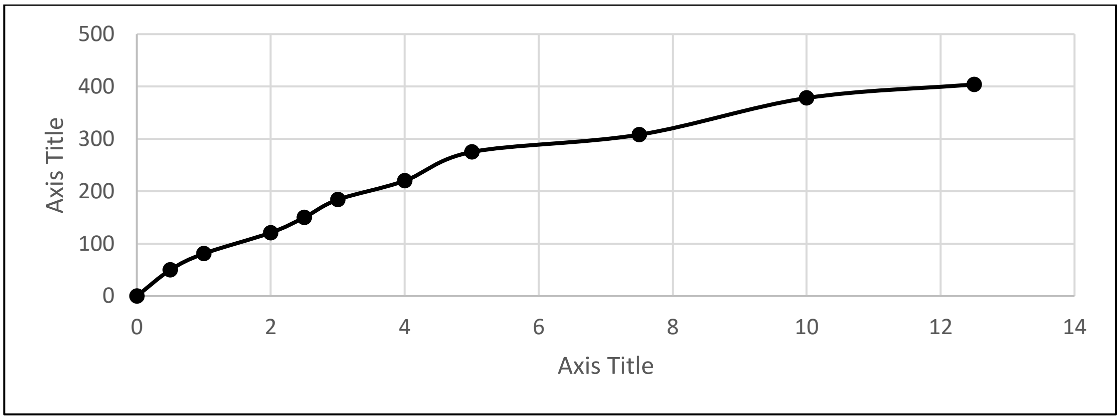


Fig 4.17 CBR Curve for Original sand sample with 0.5% jute fiber

The CBR value for the original sand sample with 0.5% Jute fiber is **11.09% .**

4.2.3.3.2 CBR test for 1% Jute fiber with Sand-

Table 4.22 CBR test on Original Sand Sample with 1% Jute fiber

Load (kg)	Penetration (mm)
0	0
50.8	0.5
81.9	1
121.3	2
150.4	2.5
184.2	3
220.5	4
275.8	5
308.6	7.5
378.1	10
404.4	12.5

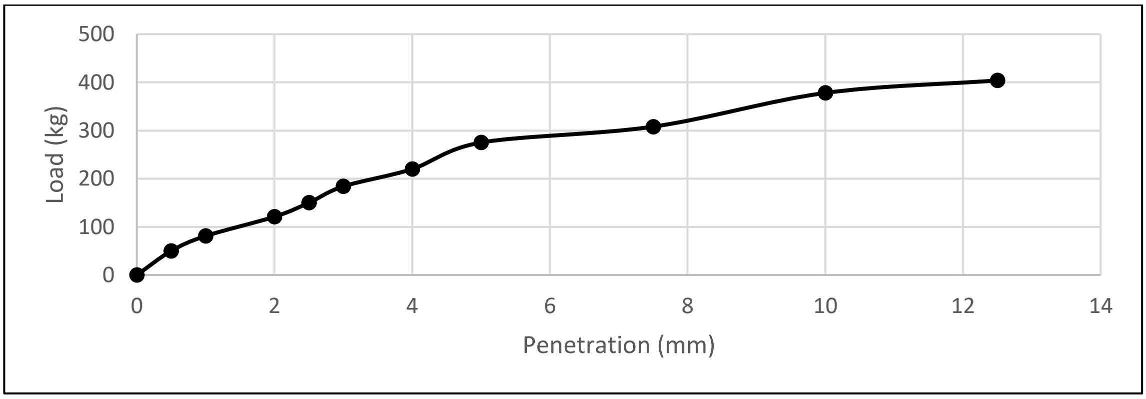


Fig 4.18 CBR Curve for Original sand sample with 1% jute fiber

The CBR value for the original sand sample with 0.5% Jute fiber is **13.38%.**

4.2.3.3.3 CBR test for 1.5% Jute fiber with Sand-

Table 4.23 CBR test on Original Sand Sample with 1.5% Jute fiber

Load (kg)	Penetration (mm)
0	0
62.2	0.5
102.8	1
155.2	2
189.9	2.5
207	3
249	4
300.3	5
405	7.5
464	10
530	12.5

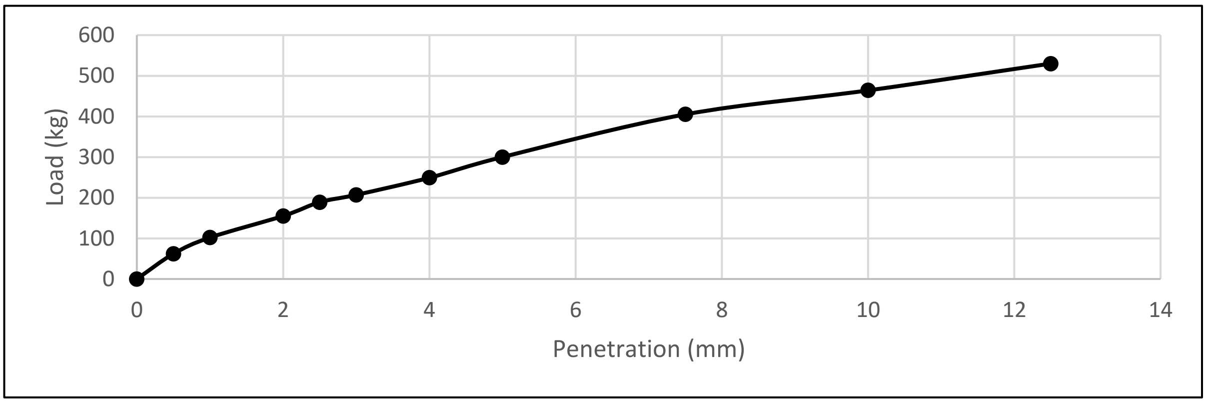


Fig 4.19 CBR Curve for Original sand sample with 1.5% jute fiber

The CBR value for the original sand sample with 1.5% Jute fiber is **14.59%**

4.2.4 Direct shear test (DST):

The DST was conducted in the laboratory original sand sample to determine its angle of internal friction(ϕ). The test was carried out in accordance with IS 2720 (Part 13) :1987.

Fig 4.20 DST apparatus

4.2.4.1 Direct Shear Test on Original Sand Sample-

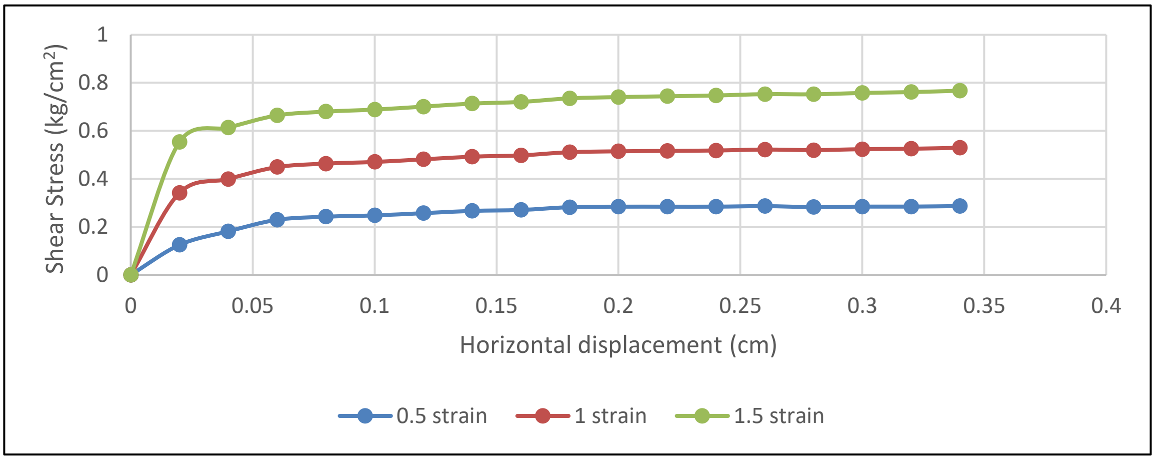


Fig 4.21 Displacement v/s shear stress graph for pure sand

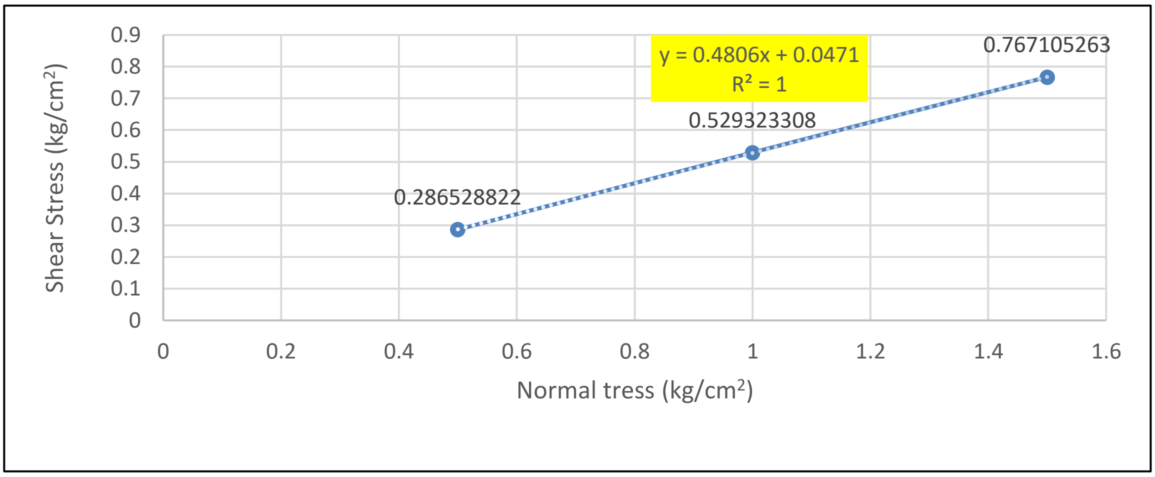


Fig 4.22 Normal stress v/s shear stress for pure sand sample

Table 4.24 Normal stress v/s shear stress for pure sand sample

NORMAL STRESS (kg/cm^2)	MAXIMUM SHEAR STRESS (kg/cm^2)
0.5	0.286
1	0.529
1.5	0.767

The angle of internal friction for pure sand sample was found to be **25.64º &** unit cohesion was 0.04 kPa.

4.2.4.2 Direct shear test (DST) with Banana Fiber with sand:

The DST was done for different content of banana fiber namely 0.5%, 1% & 1.5% by weight mixed with pure sand sample to determine its angle of internal friction(ϕ). The test was carried out in accordance with IS 2720 (Part 13) :1987.

4.2.4.2.1 Direct shear test (DST) with 0.5% Banana Fiber with sand:

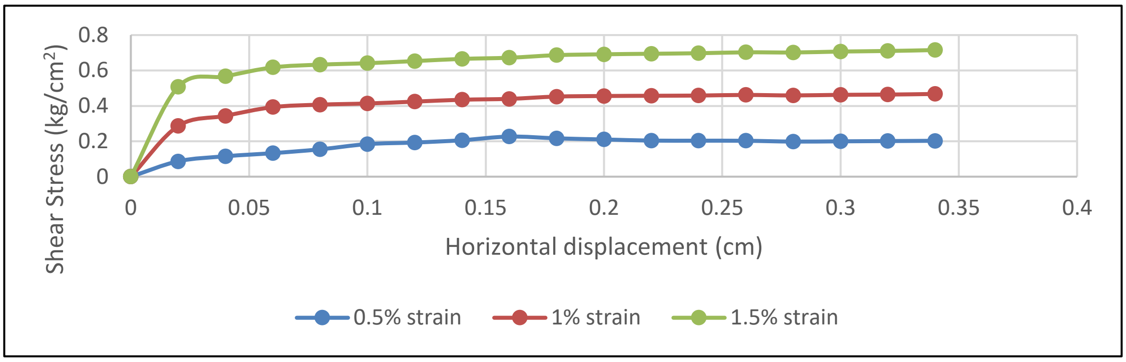


Fig 4.23 Displacement v/s shear stress graph for pure sand with 0.5% banana fiber

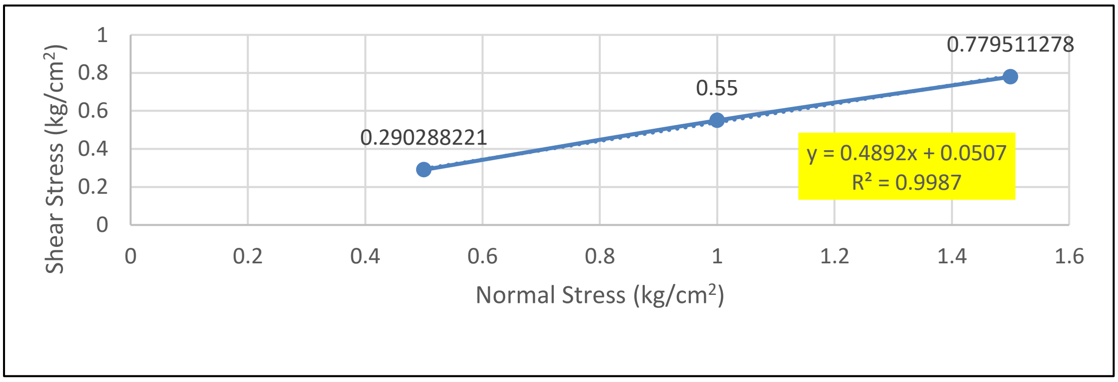


Fig 4.24 Normal stress v/s shear stress for pure sand sample with 0.5% banana fiber

Table 4.25 Normal stress v/s shear stress for pure sand sample with 0.5% banana fiber

NORMAL STRESS (kg/cm^2)	MAXIMUM SHEAR STRESS (kg/cm^2)
0.5	0.290
1	0.550
1.5	0.779

The angle of internal friction for pure sand sample with 0.5% banana fiber was found to be **26.01^o &** unit cohesion was 0.050 kPa.

4.2.4.2.2 Direct shear test (DST) with 1% Banana Fiber with sand:

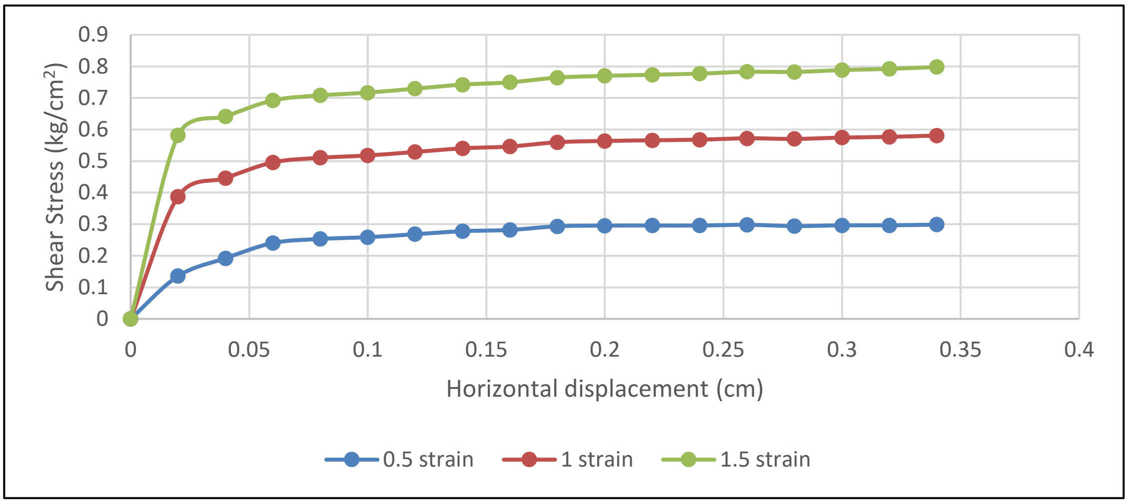


Fig 4.25 Displacement v/s shear stress graph for pure sand with 1% banana fiber

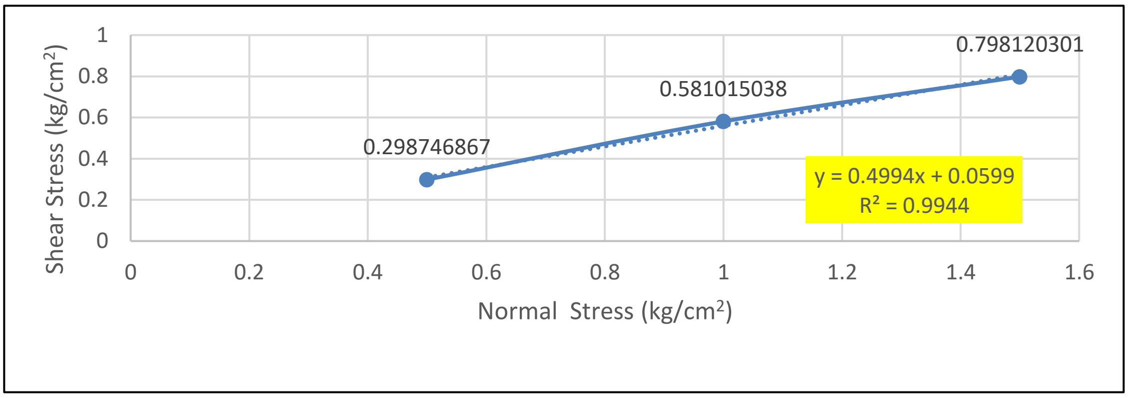


Fig 4.26 Normal stress v/s shear stress for pure sand sample with 1% banana fiber

Table 4.26 Normal stress v/s shear stress for pure sand sample with 1% banana fiber

NORMAL STRESS (kg/cm^2)	MAXIMUM SHEAR STRESS (kg/cm^2)
0.5	0.298
1	0.581
1.5	0.798

The angle of internal friction for pure sand sample with 1% banana fiber was found to be **26.51º &** unit cohesion was 0.059 kPa.

4.2.4.2.3 Direct shear test (DST) with 1.5% Banana Fiber with sand:

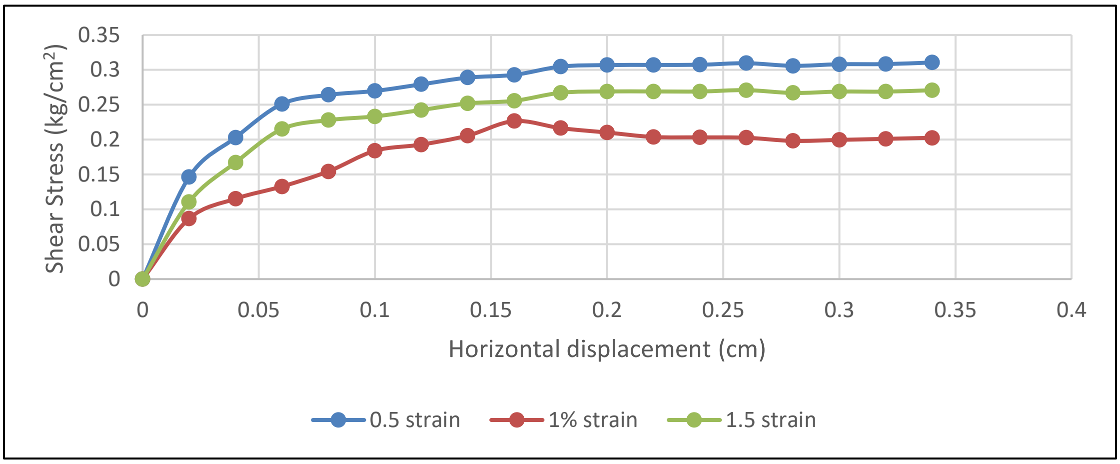


Fig 4.27 Displacement v/s shear stress graph for pure sand with 1.5% banana fiber

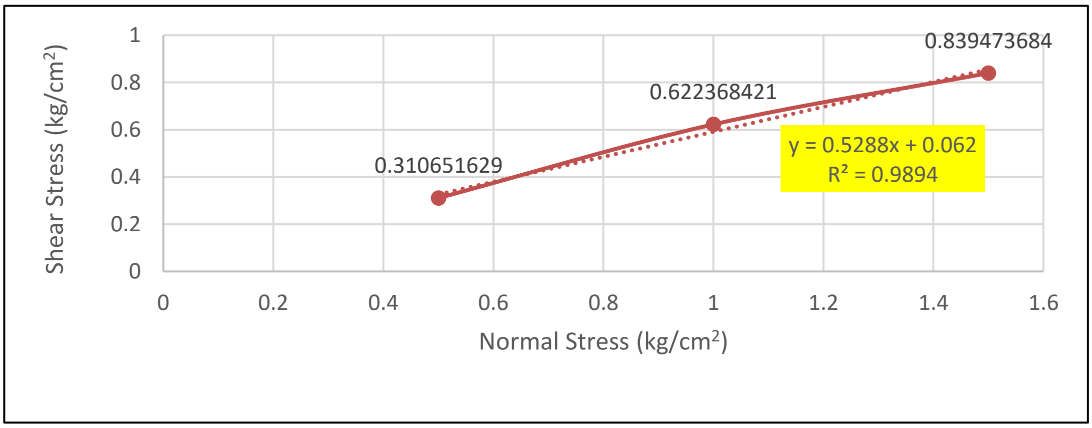


Fig 4.28 Normal stress v/s shear stress for pure sand sample with 1.5% banana fiber

Table 4.27 Normal stress v/s shear stress for pure sand sample with 1.5% banana fiber

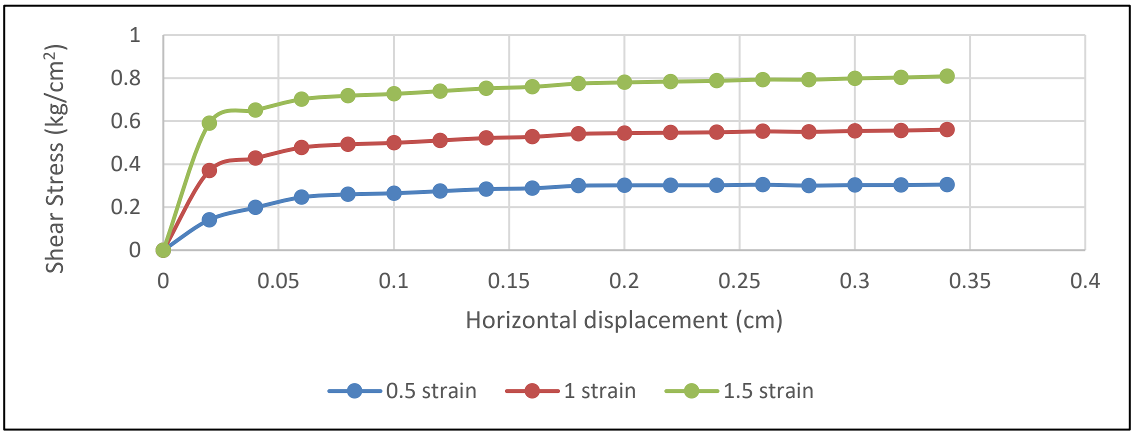
NORMAL STRESS (kg/cm^2)	MAXIMUM SHEAR STRESS (kg/cm^2)
0.5	0.310
1	0.622
1.5	0.839

The angle of internal friction for pure sand sample with 1.5% banana fiber was found to be **27.83^o &** unit cohesion was 0.062kPa.

4.2.4.3 Direct shear test (DST) of sand with Jute fiber:

The DST was done for different content of jute fiber namely 0.5%, 1% & 1.5% by weight mixed with pure sand sample to determine its angle of internal friction(ϕ). The test was carried out in accordance with IS 2720 (Part 13) :1987.

4.2.4.3.1 Direct shear test (DST) of sand with 0.5% Jute fiber:



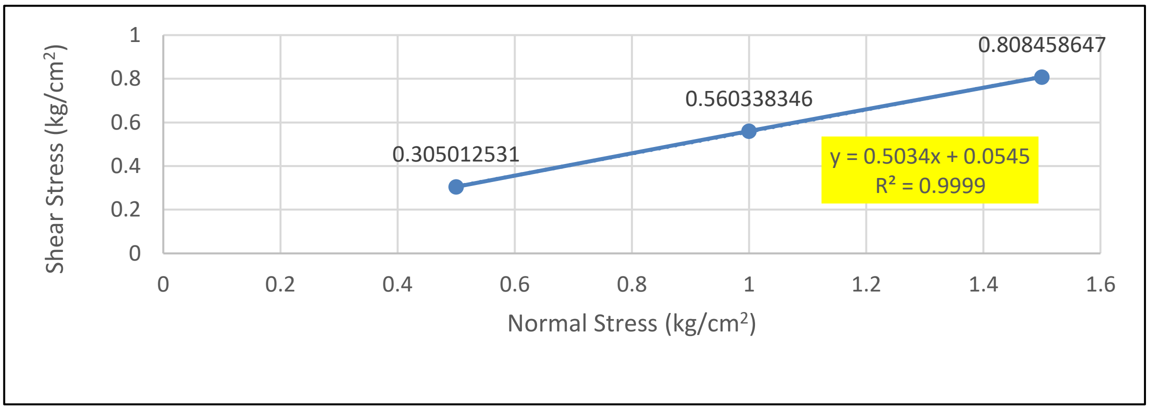


Fig 4.30 Normal stress v/s shear stress for pure sand sample with 0.5% jute fiber

Table 4.28 Normal stress v/s shear stress for pure sand sample with 0.5% jute fiber

NORMAL STRESS (kg/cm^2)	MAXIMUM SHEAR STRESS (kg/cm^2)
0.5	0.305
1	0.560
1.5	0.808

The angle of internal friction for pure sand sample with 0.5% jute fiber was found to be **26.70º &** unit cohesion was 0.0545kPa.

4.2.4.3.2 Direct shear test (DST) of sand with 1% Jute fiber:

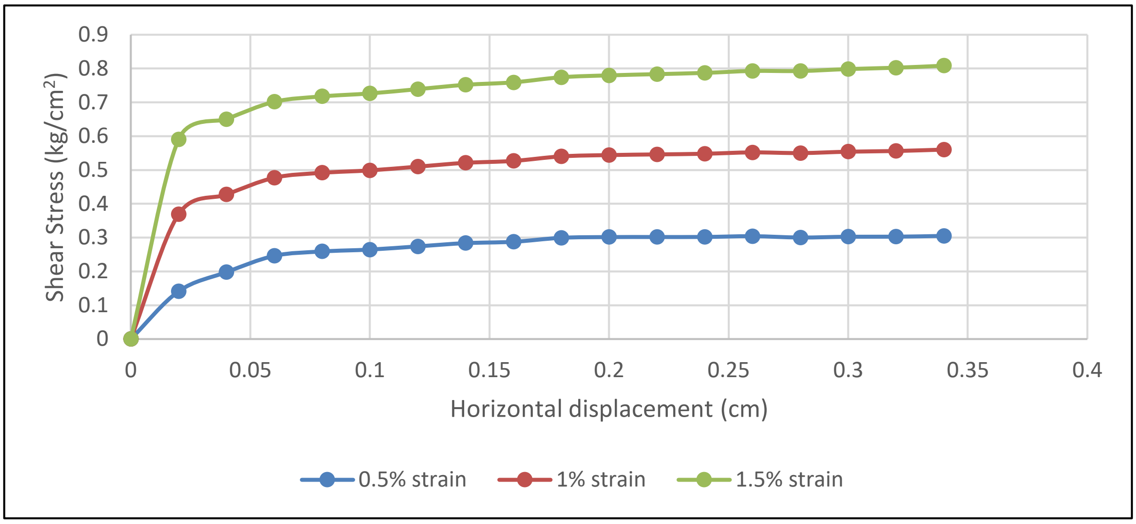


Fig 4.31 Displacement v/s shear stress graph for pure sand with 1% jute fiber

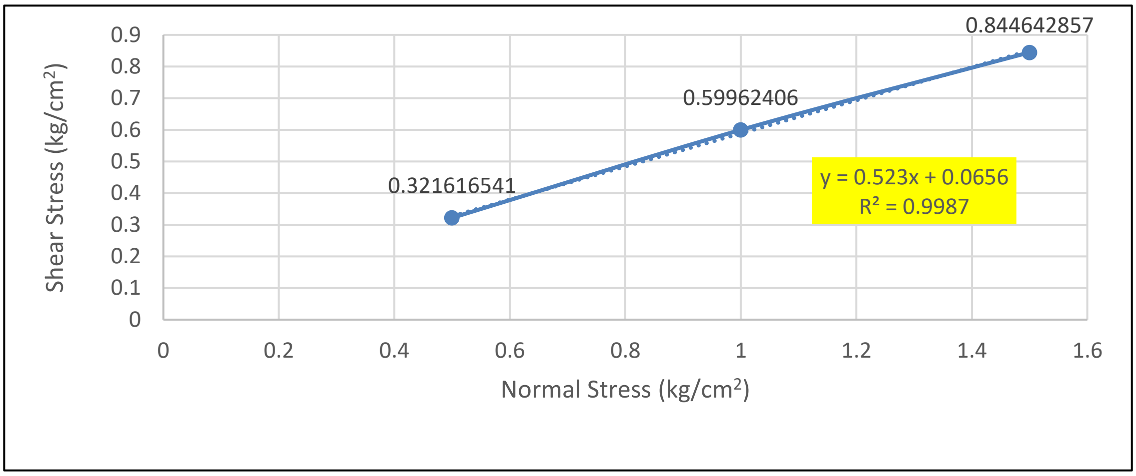


Fig 4.32 Normal stress v/s shear stress for pure sand sample with 1% jute fiber

Table 4.29 Normal stress v/s shear stress for pure sand sample with 1%jute fiber

NORMAL STRESS (kg/cm^2**)**	MAXIMUM SHEAR STRESS (kg/cm^2**)**
0.5	0.321
1	0.599
1.5	0.844

The angle of internal friction for pure sand sample with 1% jute fiber was found to be **27.60º &** unit cohesion was 0.065 kPa.

4.2.4.3.3 Direct shear test (DST) of sand with 1.5% Jute fiber:

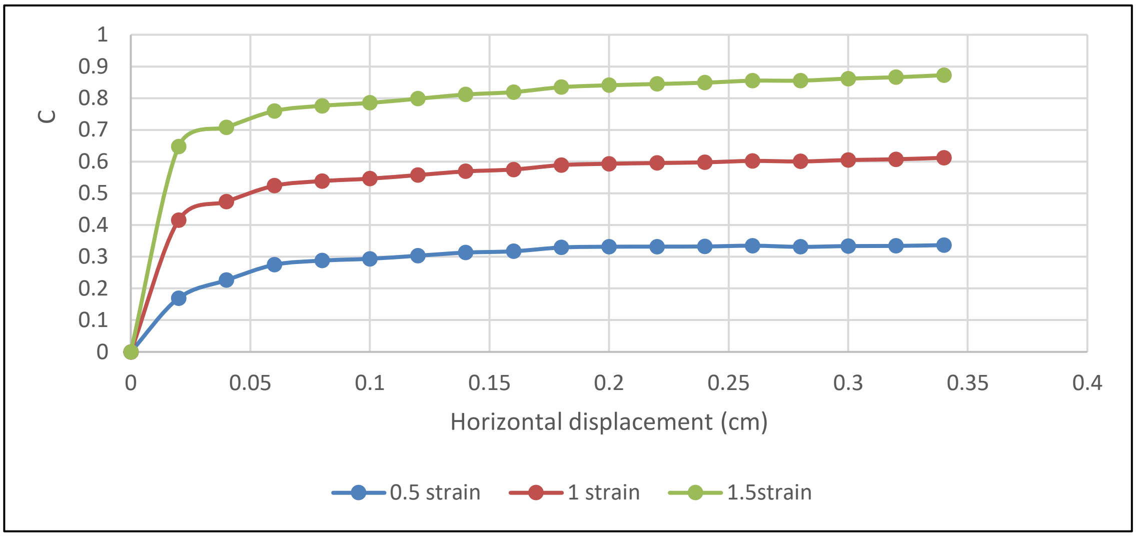


Fig 4.33 Displacement v/s shear stress graph for pure sand with 1.5 % jute fiber

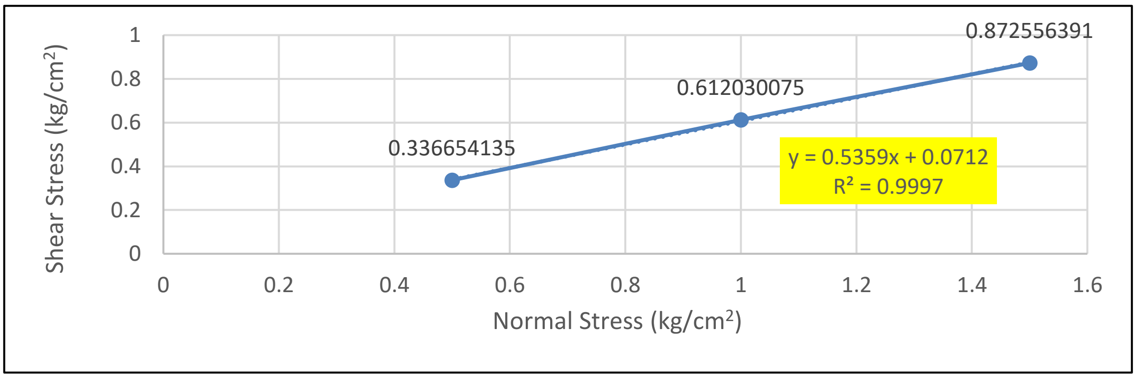


Fig 4.34 Normal stress v/s shear stress for pure sand sample with 1.5% jute fiber

Table 4.30 Normal stress v/s shear stress for pure sand sample with 1.5% jute fiber

NORMAL STRESS (kg/cm^2**)**	MAXIMUM SHEAR STRESS (kg/cm^2**)**
0.5	0.336
1	0.612
1.5	0.872

The angle of internal friction for pure sand sample with 1% jute fiber was found to be **28.14º &** unit cohesion was 0.071kPa.

CHAPTER 5

ANALYSIS OF TEST RESULTS

5.1 Introduction

The chapter contains a comparative analysis of the test results obtained in the previous chapter. The test results are compared & analyzed for each test and each percentage of fiber i.e. 0.5% , 1% & 1.5% respectively. Both Banana Fiber and Jute Fiber are compared for their effect in the engineering properties of the sand sample.

The tests covered in the comparison are-

Standard Proctor Test

Constant Head Permeability Test

California Bearing Ratio (CBR) Test

Direct Shear Test (DST)

5.2 Standard Proctor Test

5.2.1 Comparative analysis of Standard Proctor Test results for Banana Fiber with Sand

A comparative plot is prepared for the Standard Proctor Test performed on sand with different percentages of banana fiber that shows a decrease in maximum dry density (MDD) values with increase in percentage of fiber with sand. The plot also shows increase in optimum moisture content (OMC) for corresponding MDD values with increase in fiber percentage.

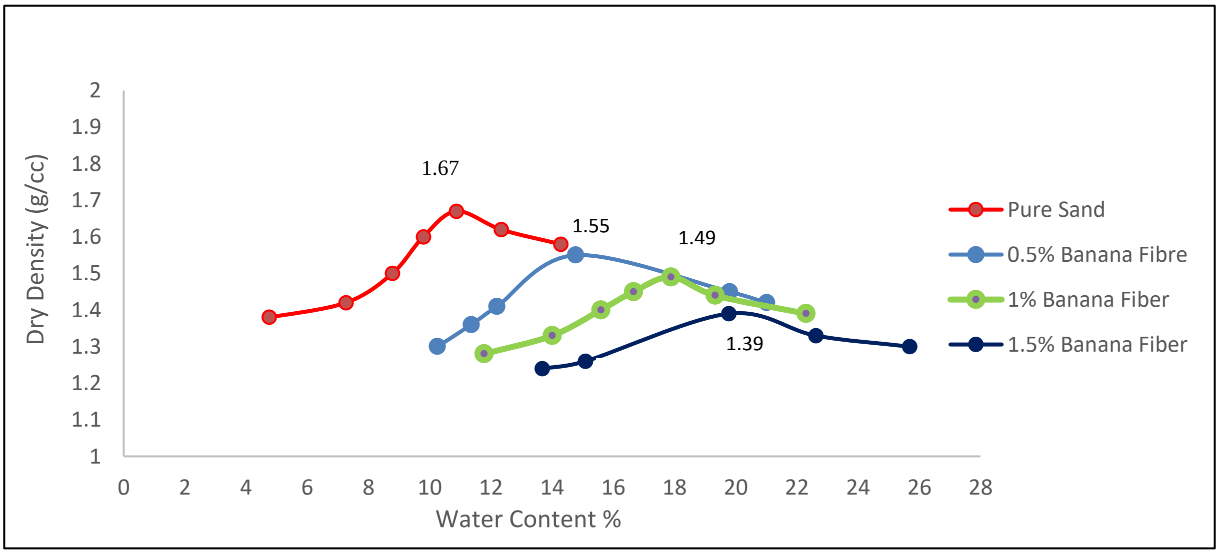


Fig 5.1 Comparative analysis of standard proctor test results for banana fiber mixed with sand

Table 5.1 MDD & OMC values for Sand with Banana Fiber for different fiber percentages

Sample	PURE SAND	0.5% BANANA FIBER	1% BANANA FIBER	1.5% BANANA FIBER
MDD (g/cc)	1.67	1.55	1.45	1.39
OMC (%)	10.87	14.77	16.66	19.77

5.2.2 Comparative analysis of Standard Proctor Test results for Jute Fiber with Sand

A similar comparative plot is prepared for the Standard Proctor Test performed on sand with different percentages of jute fiber that shows a decrease in maximum dry density (MDD) values with increase in percentage of fiber with sand. The plot also shows increase in optimum moisture content (OMC) for corresponding MDD values with increase in fiber percentage.

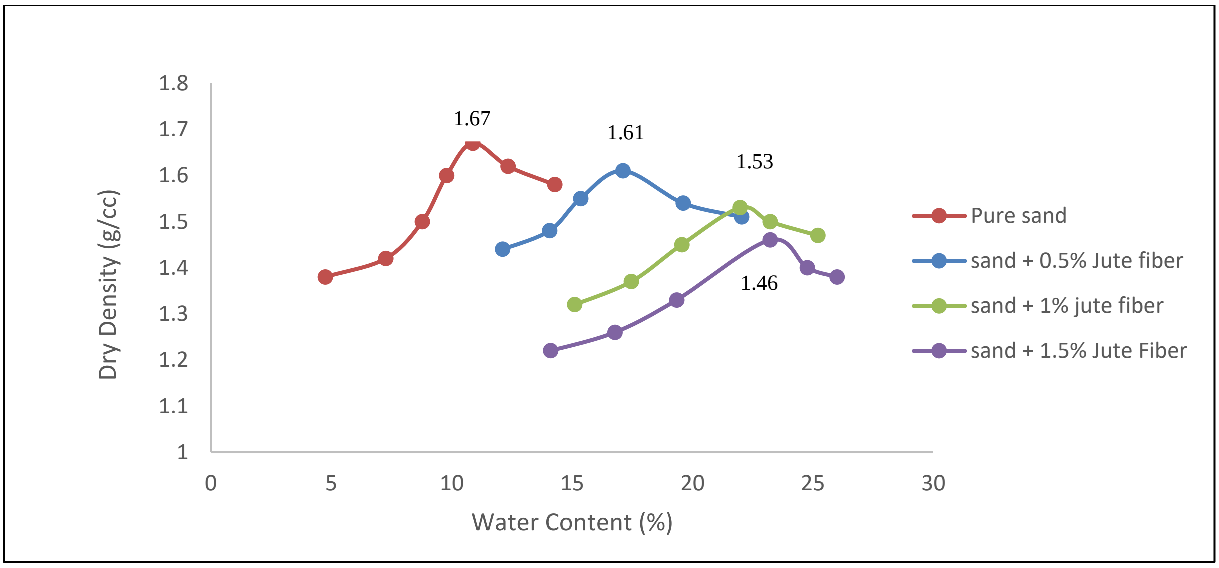


Fig 5.2 Comparative analysis of standard proctor test results for jute fiber mixed with sand

Table 5.2 MDD & OMC values for Sand with Jute Fiber for different fiber percentages

SAMPLE DESCRIPTION	PURE SAND	0.5% JUTE FIBER	1% JUTE FIBER	1.5% JUTE FIBER
MDD (g/cc)	1.67	1.61	1.53	1.46
OMC %	10.87	17.77	21.98	23.22

5.2.3 Comparative analysis of MDD & OMC values for both Banana Fiber & Jute Fiber with Sand

A collective comparison is drawn out for MDD & OMC values of sand sample mixed with different percentages of Banana & Jute fibers. The comparisons suggest that MDD value achieved with jute fiber is greater compared to that of banana fiber for corresponding fiber percentages.

5.2.3.1 Comparative analysis of MDD for both Banana & Jute Fiber

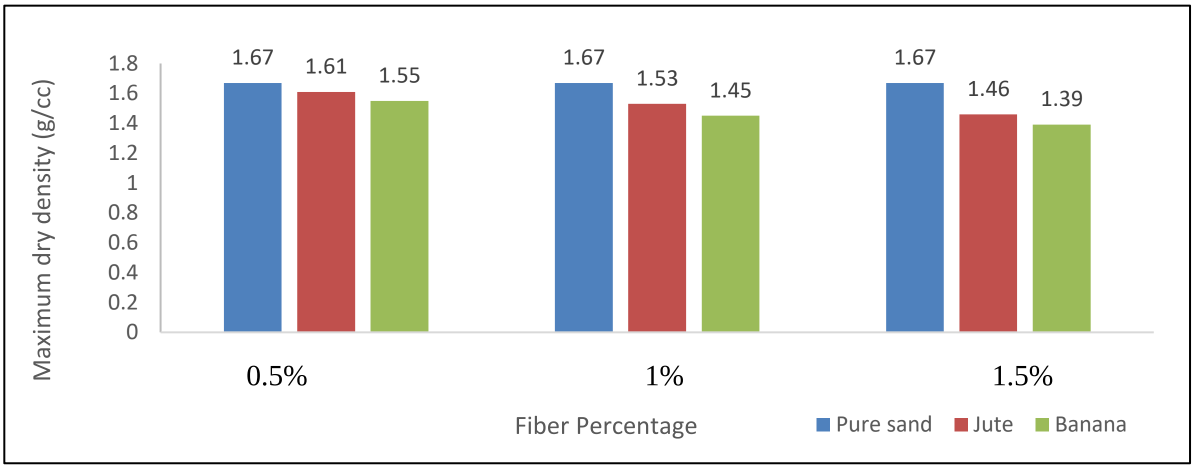


Fig 5.3 MDD values comparison for banana & jute fiber with sand

Table 5.3 MDD values for different percentages of banana and jute fibers with sand

Maximum dry density (MDD)			
Fiber Percentage	0.50%	1%	1.50%
Jute	1.61	1.53	1.46
Banana	1.55	1.45	1.39

5.2.3.2 Comparative analysis of OMC for both Banana & Jute Fiber

Table 5.4 OMC values for different percentages of banana and jute fibers with sand

Optimum Moisture Content (%)			
Fiber Percentage	0.50%	1%	1.50%
Jute	17.77	21.98	23.22
Banana	14.77	16.66	19.77

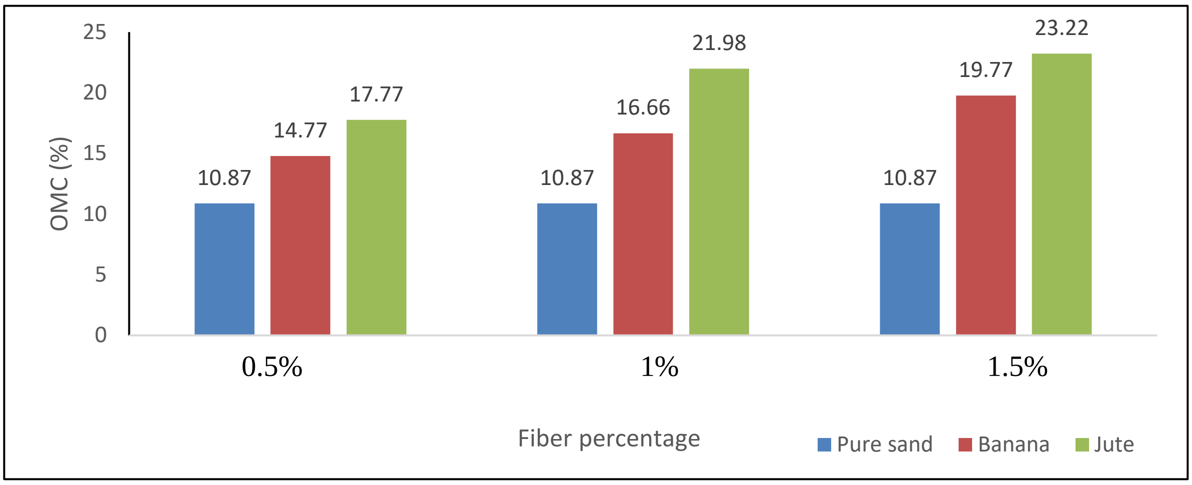


Fig 5.4 OMC values comparison for banana & jute fiber with sand

The comparison for OMC shows that jute fiber achieved its MDD at a comparatively greater water content than banana fiber, i.e. the OMC for jute fiber is greater than banana fiber for corresponding fiber percentage.

5.3 Constant Head Permeability Test-

5.3.1 Analysis of average permeability for banana fiber mixed with sand

The average permeability of sand mixed with banana fiber decreases with increase in percentage of banana fiber.

Table 5.5 Average permeability for sand mixed with banana fiber

Fiber Percentage	0.50%	1%	1.50%
Permeability (k) (cm /s)	2.62×10^{-3}	2.31×10^{-3}	2.11×10^{-3}

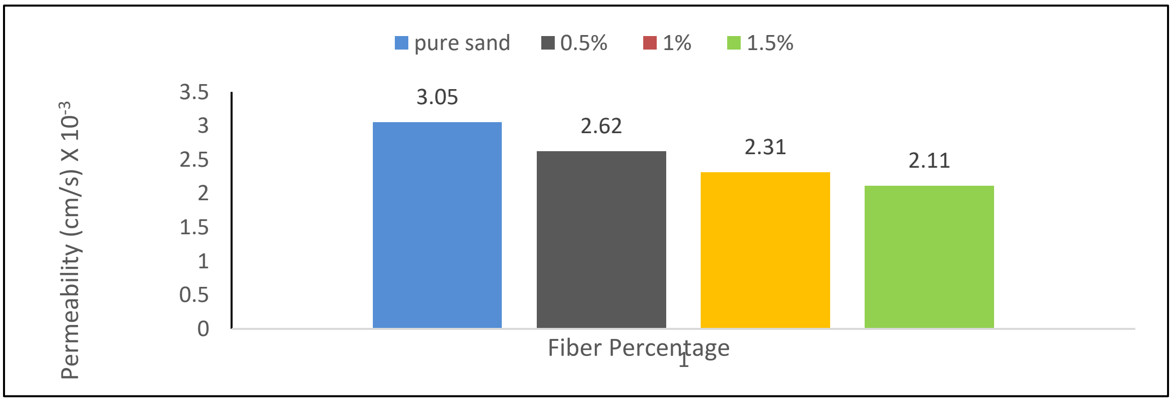


Fig 5.5 Comparison of average permeability of sand mixed with banana fiber

5.3.2 Analysis of average permeability for jute fiber mixed with sand

Table 5.6 Average permeability for sand mixed with jute fiber

Fiber Percentage	0.50%	1%	1.50%
Permeability (k) (cm/s)	2.5×10^{-3}	2.19×10^{-3}	2.05×10^{-3}

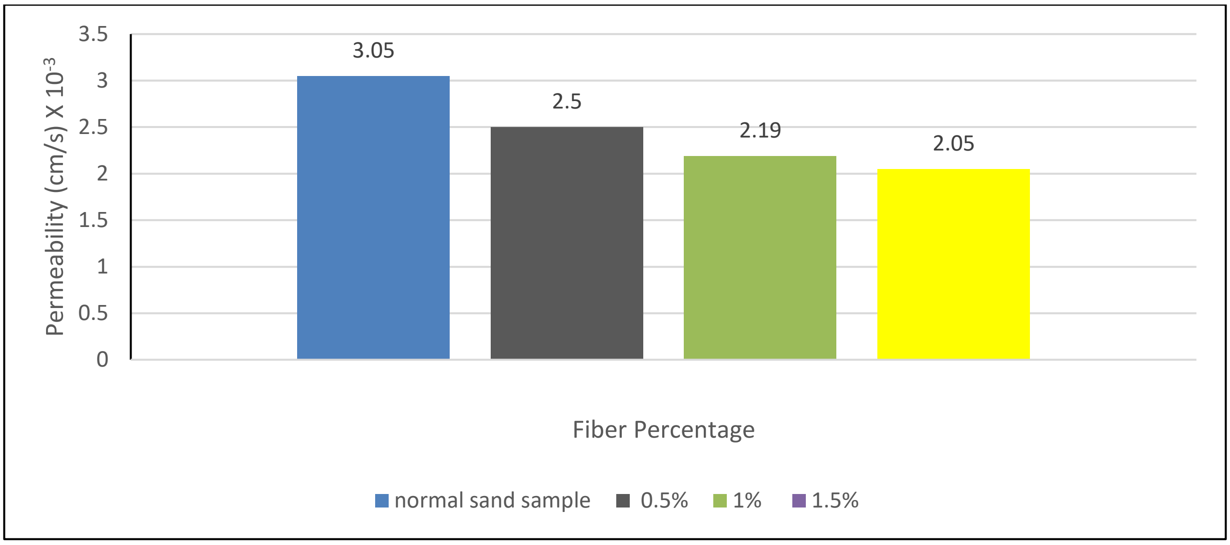


Fig 5.6 Comparison of average permeability of sand mixed with jute fiber

5.3.3 Comparative analysis of Permeability results for both Banana Fiber & Jute Fiber with Sand

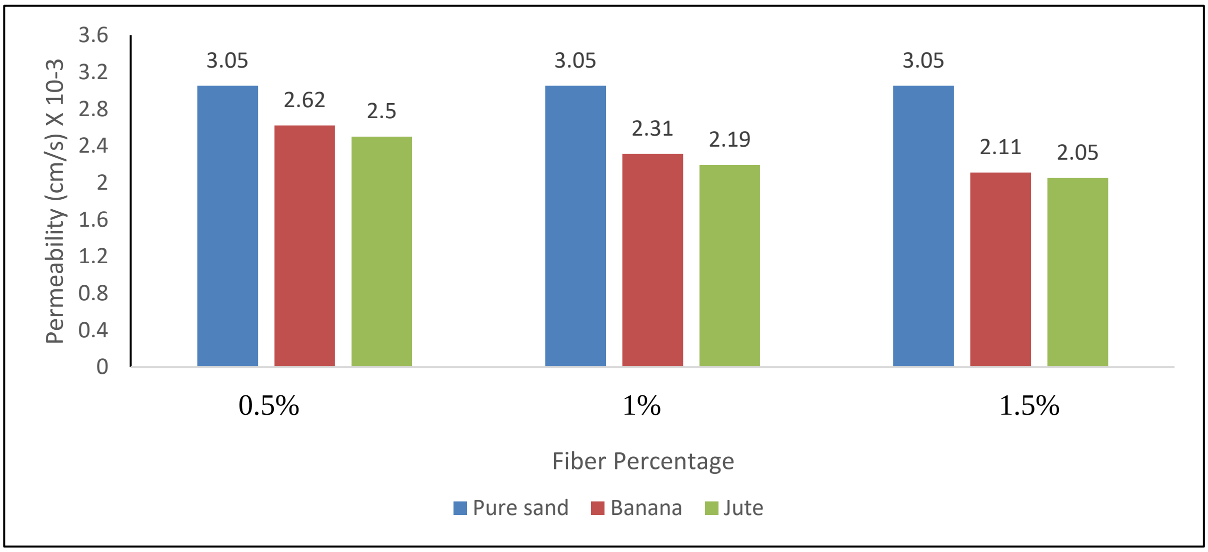


Fig 5.7 Comparative analysis of Permeability for both Banana Fiber & Jute Fiber with Sand

Table 5.7 Comparative analysis of Permeability for both Banana Fiber & Jute Fiber with Sand

Permeability (k) (cm/s)			
Fiber Percentage	0.50%	1%	1.50%
Banana	2.62 x 10^{-3}	2.31 x 10^{-3}	2.12 x 10^{-3}
Jute	2.5 x 10^{-3}	2.19 x 10^{-3}	2.04 x 10^{-3}

The analysis shows that the average permeability of sand mixed with banana fiber is greater than that of jute fiber for respective fiber percentages .Thus, jute fiber is more effective in regulating permeability of sand.

5.4 California Bearing Ratio (CBR) Test:

5.4.1 Analysis of CBR test results for Banana Fiber with sand

The analysis of CBR values for sand mixed with banana fiber shows an increase in CBR values with increase in fiber percentage.

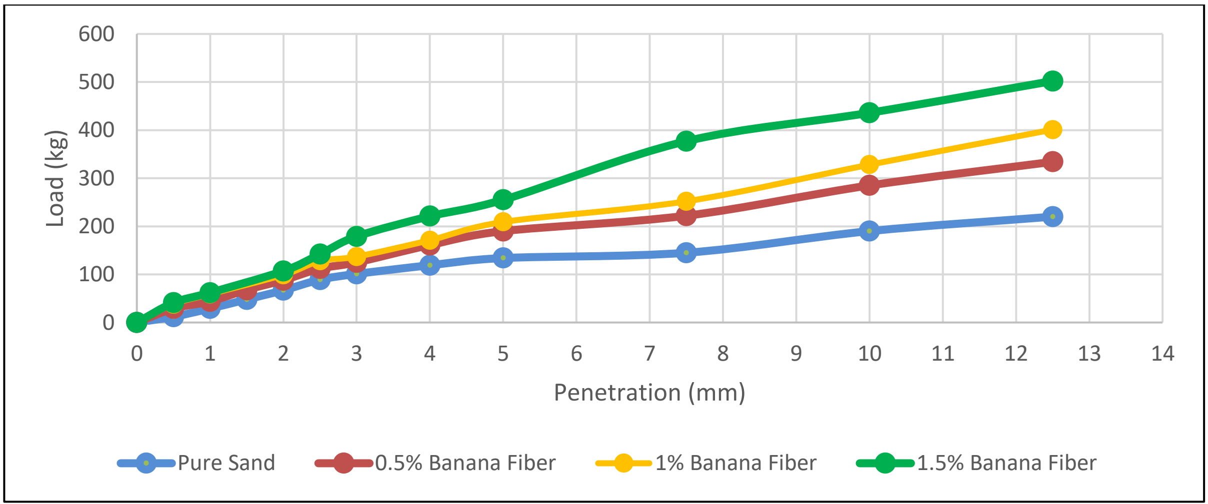


Fig 5.8 Comparison of CBR values for banana fiber mixed with sand

Table 5.8 Comparison of CBR values for banana fiber with sand

Fiber Percentage	0.50%	1%	1.50%
CBR (%)	10.17	12.40	13.77

5.4.2 Analysis of CBR test results for Jute Fiber with sand

The analysis of CBR values for sand mixed with jute fiber shows an increase in CBR values with increase in fiber percentage.

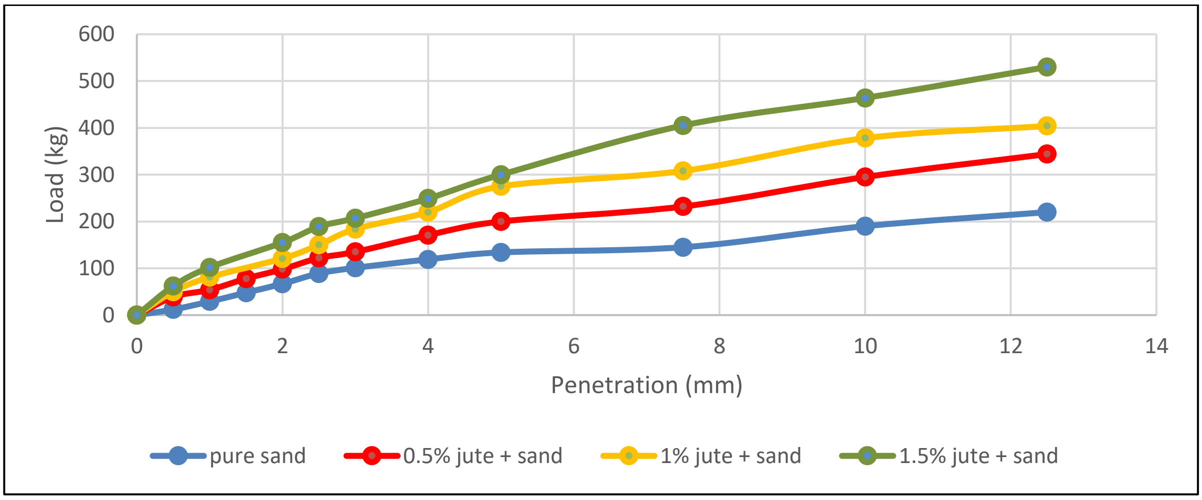


Fig 5.9 Comparison of CBR values for jute fiber mixed with sand

Table 5.9 Comparison of CBR values for jute fiber mixed with sand

Fiber Percentage	0.50%	1%	1.50%
CBR (%)	11.09	13.38	14.59

5.4.3 Comparative analysis of CBR values for Banana Fiber & Jute Fiber with sand

The addition of both banana & jute fibers with sand increased the CBR values with increase in fiber percentage. However, the increase in CBR value for jute fiber is comparatively more than that of banana fiber for corresponding fiber percentages.

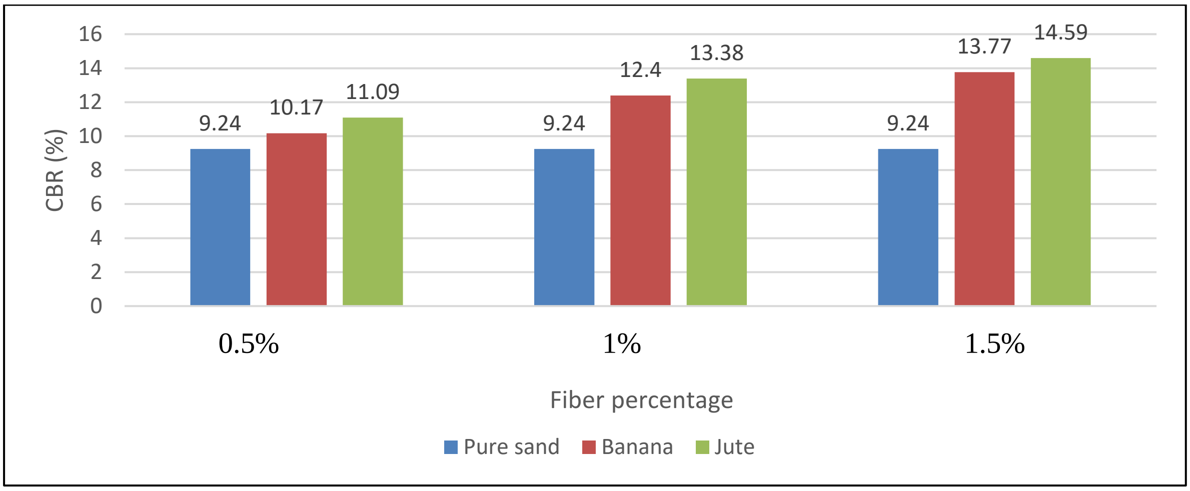


Fig 5.10 Comparison of CBR values for banana fiber & jute fiber mixed with sand

Table 5.10 Comparison of CBR values for banana fiber & jute fiber mixed with sand

CBR (%)			
Fiber Percentage	0.50%	1%	1.50%
Pure sand	9.24	9.24	9.24
Banana	10.17	12.40	13.77
Jute	11.09	13.38	14.59

5.5 Direct shear test (DST):

The results of DST show an increase in the angle of internal friction (ϕ) & unit cohesion values for both banana & jute fiber with increase in fiber content.

5.5.1 Comparative analysis of angle of internal friction(ϕ) for Banana fiber with sand:

The DST results show that with increase in fiber content with sand increases the angle of internal friction (ϕ) & unit cohesion.

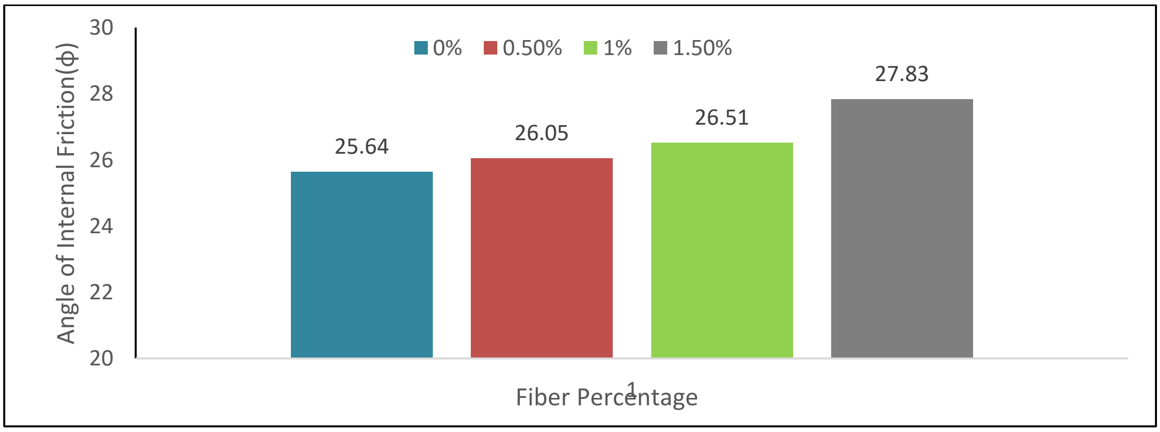


Fig 5.11 Comparison of angle of internal friction(ϕ) for sand with banana fiber

Table 5.11 Comparison of angle of internal friction(ϕ) for sand with banana fiber

Fiber content	0%	0.5%	1%	1.5%
Angle of internal friction(ϕ)	25.64	26.05	26.51	27.83

5.5.2 Comparative analysis of angle of internal friction(ϕ) for Jute fiber with sand:

The DST results show that with increase in fiber content with sand increases the angle of internal friction (ϕ) & unit cohesion.

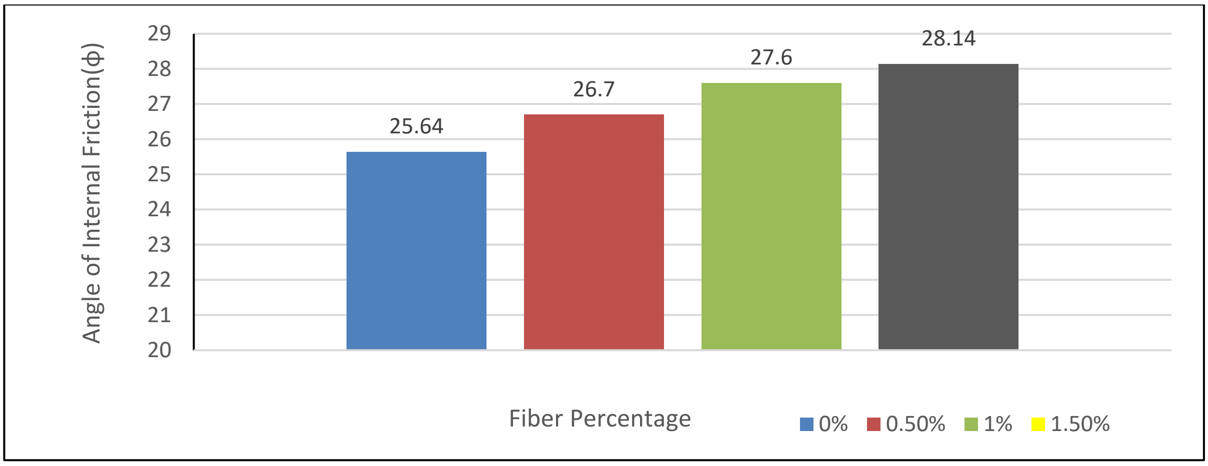


Fig 5.12 Comparison of angle of internal friction(ϕ) for sand with jute fiber

Table 5.12 Comparison of angle of internal friction(ϕ) for sand with banana fiber

Fiber content	0%	0.5%	1%	1.5%
Angle of internal friction(ϕ)	25.64	26.70	27.60	28.14

5.5.3 Comparative analysis of angle internal friction (ϕ) for both banana &jute fiber with sand:

The comparison shows that the increase in angle of internal friction and unit cohesion values is more fore jute fiber compared to banana fiber. The results are tabulated below & depicted in figure below.

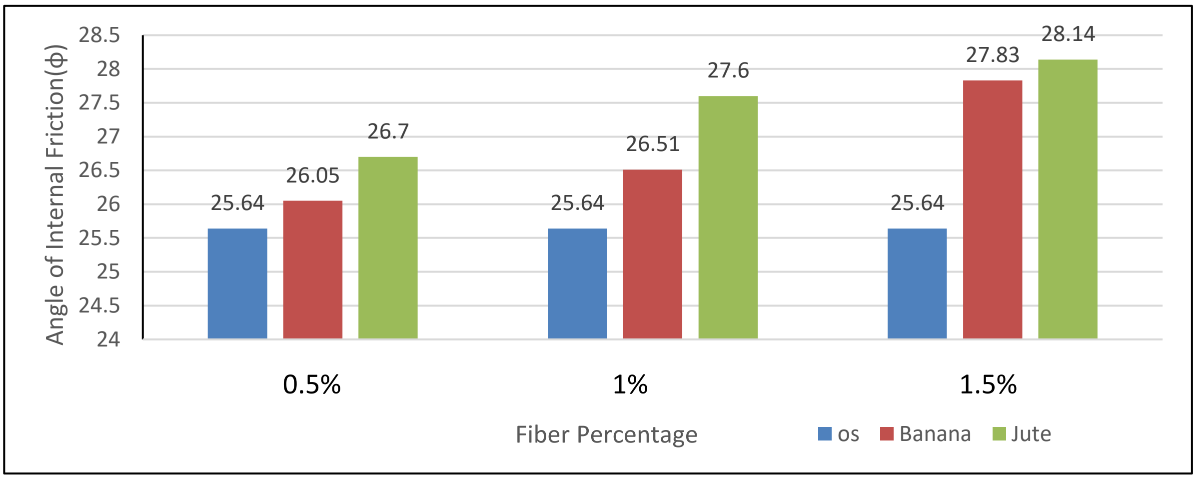


Fig 5.13 Comparative analysis of angle internal friction (ϕ) for both banana &jute fiber with sand

Table 5.13 Comparative analysis of angle internal friction (ϕ) for both banana &jute fiber with sand

FIBER PERCENTAGE	0.5	1	1.5
PURE SAND	25.64	25.64	25.64
BANANA FIBER	26.05	26.51	27.83
JUTE FIBER	26.7	27.6	28.14

CHAPTER 6

CONCLUSIONS

6.1 Introduction

Based on the analysis of the test results including Permeability, CBR & Direct shear test (DST) on sand mixed with varied percentages of fibers including banana & jute fibers suggested an enhancement of its engineering characteristics and geotechnical viability.

6.2 Standard Proctor Test:

1. The test results suggests that the maximum dry density (MDD) value for both banana & jute fiber mixed with sand decreased with increase in fiber content. Alternatively, the optimum moisture content (OMC) increased with increase in fiber content for both banana & jute fibers.
2. It is seen that although the MDD values decreased for both the fibers but jute fiber shows a comparatively more MDD value than banana fiber. On the other hand, jute fiber had greater OMC values than jute fiber for corresponding fiber contents.

Overall, jute fiber had greater MDD than banana fiber but also had a greater OMC value than banana fiber.

6.3 Constant Head Permeability Test:

1. Both banana & jute fibers showed a decrease in permeability values with increase in fiber content with sand..
2. Jute fiber shows slightly lesser permeability than banana fiber that could be due to jute fiber being more water absorbent than banana fiber.

6.4 California Bearing Ratio test (CBR):

1. The addition of fiber to sand increased the CBR value for both banana & jute fibers. This could be due to more resistance provided by the fiber reinforcement to the loading.
2. The CBR value increased with increasing the fiber percentage with sand. Results shows that jute fiber had comparatively higher CBR value than banana fiber.

6.5 Direct Shear Test (DST):

1. The addition of fiber to sand increased the angle of internal friction (ϕ) & unit cohesion value for both banana & jute fibers with increase in fiber content.
2. However, the increase in internal friction (ϕ) & unit cohesion value for jute was comparatively more than banana fiber.

REFERENCES

1. Ahmad, F., Bateni, F., & Azmi, M. (2009b). Performance evaluation of silty sand reinforced with fibers. *Geotextiles and Geomembranes*, *28*(1), 93–99. https://doi.org/10.1016/j.geotexmem.2009.09.017
2. Bureau of Indian Standards (1980) Methods of test for soils: Grain size analysis IS- 2720-4, New Delhi, India.
3. Bureau of Indian Standards (1980) Methods of test for soils: Determination of specific gravity, IS 2720-3, New Delhi, India.
4. Bureau of Indian Standards (1980) Methods of test for soils: Determination of water content-Dry density relation using light compaction, IS 2720-7, New Delhi, India.
5. Bureau of Indian Standards (1987) Methods of test for soils: Laboratory determination of CBR, IS 2720-16, New Delhi, India.
6. Bureau of Indian Standards (1980) Methods of test for soils: Direct shear test, IS 2720-13, New Delhi, India.
7. Bureau of Indian Standards (1980) Methods of test for soils: Laboratory determination of permeability, IS 2720-17(reaffirmed 2021), New Delhi, India.
8. C.N.V. Satyanarayana Reddy G. Sireesha Professor (2014). Effect of Randomly Distributed Synthetic Fiber in Fine Sand and Fly Ash *Department of Civil Engineering, College of Engineering, Andhra University, Visakhapatnam.*
9. Ganiev, J., Yamada, S., Nakano, M., & Sakai, T. (2021). Effect of fiber-reinforcement on the mechanical behavior of sand approaching the critical state. *Journal of Rock Mechanics and Geotechnical Engineering*, *14*(4), 1241–1252. https://doi.org/10.1016/j.jrmge.2021.10.003
10. Hossain, M. A. (2015). Application of jute fiber for the improvement of subgrade characteristics. *American Journal of Civil Engineering*, *3*(2), 26. https://doi.org/10.11648/j.ajce.20150302.11
11. Ibraim, E., Fourmont, S., & University of Bristol. (2006). Soil Stress-Strain Behavior: Measurement, Modeling and analysis. In *Geotechnical Symposium in Roma*.
12. Himadri Baruah, Indrani Mili, Dimpa Moni Kalita, Injamamul Islam(2016). Comparative Study of Soil Reinforced With Natural Fiber, Synthetic Fiber And Waste Material. *International Journal of Latest Trends in Engineering and Technology*.
13. Jin Liu, Yuxia Bai, Zezhuo Song, Debi Prasanna Kanungo, Ying Wang, Fan Bu, Zhihao Chen, Xiao Shi (2020). Stabilization of sand using different types of short fibers and organic

polymer. *Construction and Building Materials 253, 119164.*

14. Kumar, S., Jat, M. K., Sarkar, R., & Alsabhan, A. H. (2021). Static and dynamic characterization of fiber reinforced sand: A numerical investigation. Journal of King Saud University Engineering Sciences, 36(7),517-523.
15. Mahdi Ghasemi Nezhad, Alireza Tabarsa, Nima Latifi. Effect of natural and synthetic fibers reinforcement on California bearing ratio and tensile strength of clay. *Journal of Rock Mechanics and Geotechnical Engineering* 13 (3), 626-642.
16. Mona Bayoumy, Mostafa El Sawwaf, Ahmed Nasr, Ahmed Elsawwaf (2024). Strength characteristics of clayey sand stabilized using polypropylene fiber or Portland cement.*Transportation Infrastructure Geotechnology 11 (3), 1249-1271.*
17. Sayyed Mahdi Hejazi, Mohammad Sheikhzadeh, Sayyed Mahdi Abtahi, Ali Zadhoush(2012). A simple review of soil reinforcement by using natural and synthetic fibers*.* *Construction and building material*s 30, 100-116.
18. Singh, S., & Kumar, S. S. (2022). Behavior of Jute Fiber-Reinforced sand using direct shear test for ground engineering application. In *Lecture notes in civil engineering* (pp. 157–170). https://doi.org/10.1007/978-981-19-6727-6_15
19. Stuti Maurya, AK Sharma, PK Jain, Rakesh Kumar (2015). Review on stabilization of soil using coir fiber. *International Journal of Engineering Research 4 (6), 296-299, 2015.*
20. Ying Wang, Jin Liu, Yadong Chen, Yun Dong, Zejun Liu, Zezhuo Song, Xiaofan Ma (2024). Strength assessment of sand stabilized with synthetic polymer and natural fibers. *Bulletin of Engineering Geology and the Environment* 83 (6), 1-17, 2024.