STRENGTH ANALYSIS OF GEOTEXTILE REINFORCED SUBGRADE

MAJOR-II PROJECT REPORT

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CANDIDATE'S DECLARATION

I, Pradeep Kumar, Roll no. 2K21/GTE/13 student of M.Tech., Geotechnical Engineering, hereby declare that the Project Dissertation titled "**Strength Analysis Of Geotextile Reinforced Subgrade**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

Place: Delhi **(PRADEEP KUMAR)**

Dated: 30/05/2023

CERTIFICATE

I hereby certify that the Project Dissertation titled "**Strength Analysis of Geotextile Reinforced Subgrade**" which is submitted by Pradeep Kumar, Roll no. 2K21/GTE/13 [Civil Engineering], Delhi Technological University, Delhi in the partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this University or elsewhere.

Place: Delhi **(Prof. ASHUTOSH TRIVEDI)**

Dated: 30/05/2023 **SUPERVISOR**

ABSTRACT

Geotextiles are an excellent solution for reinforcing subgrades in road projects, as they effectively address the common challenge of poor subgrade strength. In this comparative study, the strengths of subgrades reinforced with jute textile and polypropylene (PP) geotextile are investigated. The direct shear test (DST) and California bearing ratio (CBR) tests are conducted on both reinforced and non-reinforced soil samples. The positioning of geotextiles is crucial to the overall strength of the subgrade. The test results reveal that jute textile, a natural fibre, increases the shear strength of the soil samples. Conversely, the shear strength of the soil decreases when reinforced with polypropylene geotextile, a synthetic fiber. The study explores the placement depths of D/2, D/3, and D/4 from the top surface for the geotextile. For the CBR test, a single, double, and triple layer of geotextile is used to reinforce the soil samples. The double layer reinforcement at depths D/3 and D/4 demonstrates optimal strength. The focus of the study is on cohesionless pavement geomaterial reinforced with multi-layers of jute fibers. The research aims to evaluate the strength and stiffness capacity of the pavement geomaterial using the CBR test. The study optimizes the embedment depth of jute fiber at D/2, D/3, and D/4 in single, double, and triple layers based on CBR values. A novel concept of stiffness capacity, along with the penetration factor, is introduced to assess the strength of unreinforced and jute-reinforced geomaterial. The test results indicate that incorporating jute fibre in single, double, and triple layers increases the stiffness capacity of the soil at the optimum depth of D/4.The stiffness capacity varies from 0.378 to 0.682 at the maximum penetration factor, representing an 80.42% enhancement in the strength of pavement geomaterial. The findings of this study offer a cost-effective solution for improving the strength of cohesionless soils in embankment, subgrade, and pavement construction technologies.

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Chapter 1

Introduction

The subgrade is a vital layer that supports the pavement structure of a road, whether it is composed of natural soil or engineered fill material. A weak subgrade can give rise to a range of problems during road construction and maintenance, such as pavement cracking, rutting, settlement, and uneven road surfaces. To ensure the road's long-term performance, it is crucial to evaluate the subgrade's strength prior to construction and implement appropriate measures for its improvement, if necessary.

Various techniques can be employed to strengthen the subgrade, including soil stabilization, geotextile reinforcement, and subgrade replacement. In this research, the strength of jute textile and polypropylene geotextile is analyzed and compared to determine their effectiveness. Additionally, investigations are conducted to enhance the strength of the subgrade itself.

Stiffness capacity is a fundamental parameter that evaluates a soil specimen's ability to withstand deformation when exposed to external forces, such as the weight exerted by structures like buildings or pavement. It is influenced by various factors, including the composition of the soil, its density, moisture content, and the presence of reinforcement materials. The composition of the soil refers to its mineral and organic content, which can significantly impact its stiffness capacity. Soils with higher clay or silt content tend to have lower stiffness capacity compared to those with higher proportions of sand or gravel, which are generally more stable. Density plays a crucial role in determining the stiffness capacity of the soil. Compacted soils with higher density typically exhibit greater stiffness capacity and better resistance to deformation. Adequate compaction during construction helps improve the soil's stiffness and overall performance.

1.1 Motivation

The choice to focus on and work on the strength analysis of geotextile reinforced subgrade in transportation engineering is motivated by several key factors. First and foremost, the subgrade is a critical component of pavement structures, and its strength and stability directly impact the overall performance and longevity of the pavement. By conducting strength analysis of geotextile reinforced subgrade, engineers aim to enhance the subgrade's mechanical properties, such as its load-bearing capacity and resistance to deformation. This analysis ensures that the subgrade can effectively support the applied loads and maintain its structural integrity over time.

Additionally, the strength analysis allows for the optimization of pavement design. Geotextile reinforcement is a widely used technique to enhance subgrade strength and performance. By conducting in-depth strength analysis, engineers can assess the effectiveness of different geotextile types, configurations, and installation methods. This analysis enables the selection of optimal design parameters, such as geotextile strength and spacing, to achieve the desired level of subgrade improvement. Ultimately, this optimization leads to more efficient and cost-effective pavement designs. Furthermore, the strength analysis of geotextile reinforced subgrade ensures long-term sustainability of the pavement system. By understanding how geotextile reinforcement affects the subgrade's strength, engineers can make informed decisions regarding the design life, maintenance requirements, and rehabilitation strategies. This analysis helps ensure that the pavement system remains resilient, capable of withstanding anticipated traffic loads and environmental conditions over its service life.

Another significant motivation for working on the strength analysis of geotextile reinforced subgrade is quality control and assurance during the construction phase. Geotextile reinforcement is a widely adopted technique for improving subgrade strength. By studying the strength properties of geotextile-reinforced subgrade, engineers can evaluate the effectiveness of different reinforcement strategies, such as varying geotextile types, configurations, and installation methods. This analysis allows for the optimization of design parameters, resulting in more efficient and cost-effective pavement designs. By testing and evaluating the subgrade's strength, engineers can verify if the geotextile installation and construction processes meet the required specifications and standards. This analysis serves as a valuable tool to ensure that geotextile reinforcement is correctly implemented, leading to reliable and consistent performance of the pavement.

Lastly, choosing to work on the strength analysis of geotextile reinforced subgrade contributes to the advancement of knowledge and research in transportation engineering. By conducting rigorous analysis, engineers expand the understanding of the behavior and effectiveness of geotextile reinforcement in various soil conditions, loading scenarios, and environmental factors. This research can lead to the development of improved design guidelines, construction practices and innovative geotextile materials for future projects, further enhancing the field of transportation engineering.

1.2 Objectives of the study

The objectives of this strength analysis are to compare the performance of unreinforced subgrade versus geotextile reinforced subgrade and to determine the optimum depth of the geotextile layer for improved subgrade performance. The investigation also attempts to compare soil samples with and without geotextile reinforcement in terms of their strength and stiffness.

The first objective is to compare the performance of unreinforced subgrade and geotextile reinforced subgrade. This involves evaluating the strength characteristics and overall behavior of both types of subgrades under applied loads. We may evaluate the success of geotextile reinforcement in improving the subgrade's capacity to bear loads and resist deformations by analyzing the differences in performance.

The second objective is to determine the optimum depth of the geotextile layer for better subgrade performance. The depth of the geotextile layer plays a crucial role in providing reinforcement to the soil. By studying different depths of the geotextile layer, we can identify the depth that offers the best balance between strength improvement and cost-effectiveness. This analysis will provide insights into the most efficient use of geotextiles in subgrade reinforcement.

Lastly, the analysis aims to determine the strength and stiffness capacity of soil samples with and without geotextile reinforcement. This involves conducting tests such as the California Bearing Ratio (CBR) test on soil samples both with and without geotextile reinforcement. By comparing the results, we can quantify the improvements in strength and stiffness provided by the geotextile reinforcement. This information will be valuable in understanding the performance benefits of geotextiles and their influence on subgrade behavior.

Overall, these objectives will contribute to a comprehensive understanding of the advantages and optimal utilization of geotextile reinforcement in subgrade construction. The findings can be applied in practical engineering applications to enhance the durability, stability, and long-term performance of pavement structures.

1.3 Experiments perform

A. Sieve analysis

A 1000-gram sample of oven-dried soil was passed through a set of sieves with sizes ranging from 4.75 mm to 75 µm. The full set of sieves was placed on an electric sieve shaker machine and run for ten minutes. The percentage finer after this particle size on the X-Axis and percentage finer on the Y-Axis are computed and plotted on the particle size distribution curve, which depicts the distribution of particles of different sizes in the soil mass. The weight of soil fractions retained via each sieve is recorded. The curve is used to specify how soil is graded based on its effective size, uniformity coefficient, and curvature coefficient. The definitions of the curvature (C_c) and uniformity (C_u) coefficients are as follows:

$$C_u = \frac{D_{60}}{D_{10}} \quad (1)$$

$$C_c = \frac{D_{30}^2}{D_{60}D_{10}} \quad (2)$$

Where D_{10} is the particle diameter at a 10 % finer level, D_{30} is the particle diameter at a 30 % finer level, and D_{60} is the particle diameter at a 60 % finer level. A soil must have C_c between 1 and 3 and C_u more than 4 for gravels and greater than 6 for sands in order to be considered well graded. The soil is said to be badly graded if neither of these conditions is met.

B. Liquid and plastic limit test

At certain minimum water content, soil has a tendency to flow. Soil changes from the plastic to the liquid state, and vice versa, at the liquid limit. In this test, distilled water was used to make a uniform paste out of 120 grams of soil material that had gone through a 425 µm sieve. Some of the paste was put in the cup of a liquid limit device. The paste was cut to create a groove, and the machine was spun at a speed of two revolutions per second until the two soil sections reached the bottom of the groove, which was separated from the top by 12 mm. The number of droplets was then determined. Not to mention, the moisture content equivalent to 25 blows was chosen as the liquid limit.

When tested for plasticity, the soil must contain a certain amount of water in order to behave like plastic. In soil, the plastic limit marks the point at which the consistency changes from plastic to semi-solid. 20 grams of soil that had passed through a sieve with a mesh size of 425 µm was taken for the plastic limit test, and it was thoroughly combined with distilled water to make it plastic enough. Then 8 grams of soil were taken from 20 grams of moist soil to make a ball. The palm of the hand was used to roll the ball on the glass plate, producing a thread that was uniformly 3 mm in diameter. The rolling procedure was repeated until the thread's diameter reached 3 mm, at which point it simply crumbled. Then, the thread's moisture content was used to calculate the plastic limit.

C. Specific gravity test

It computes the ratio of the weight of water in a given volume to the weight of solids in that volume. Additionally, it is described as the relationship between the unit weights of water and solids. The specific gravity is calculated using a pycnometer, a 500 ml flask, or a 50 ml density bottle. The specific gravity of a particle that has gone through a 4.75 mm IS sieve was determined using a density bottle. The density bottle approach is the most precise and works with all kinds of soil in the lab.

D. Standard proctor test

This experiment used a 4.75 mm sieve to separate 3 kg of air-dried soil. Less than 20% of the soil was retained on the 4.75 mm sieve; hence a 100 mm diameter mould had to be used. The mould could hold 1000 ml, and the rammer weighed 2.6 kg. For sandy soils, the samples were diluted with water to 4 %, and for clayey soils, to 8%. The moist samples were packed into the mould in three layers and subjected to 25 blows from a 310 mm drop height on each layer. It was determined how much water was in the compacted soils and how densely it was dry. Additionally, the soil's water content was increased and it was compressed. There were calculated values for dry density and water content.

E. Direct shear test (DST)

The direct shear test is a typical experimental technique used in geotechnical engineering to determine the shear strength of soil materials. Shear strength is the maximum degree of a material's resistance to shearing forces. This test, which may be carried out on either undisturbed or remoulded soil samples, is regarded as both common and simple. The three different drainage conditions under which the direct shear test can be performed are unconsolidated-undrained, consolidated-undrained, and consolidated-drained. Each condition provides valuable insights into the behavior of the soil. Cohesionless soils, typically devoid of any significant binding forces, are commonly tested in the consolidated-drained condition. Engineers can get crucial data from the direct shear test, including the soil's cohesiveness and angle of internal friction. These parameters play a crucial role in various engineering designs, including foundations and retaining walls. Calculations and forecasts relating to soil stability, bearing capacity, and overall structural safety can be made with greater accuracy by understanding cohesion and the angle of internal friction.

F. California bearing ratio (CBR) test

The California Bearing Ratio (CBR) test is a widely used method for evaluating a material's resistance to penetration by a standard plunger under controlled density and moisture conditions. The California Division of Highways originally developed this test to allow for the classification and evaluation of the base course and subgrade soil materials for flexible pavements. Both remoulded and undisturbed soil samples can be used for the CBR test. Using a cylindrical plunger with a diameter of 50 mm, the technique involves regulated 1.25 mm/min material penetration. During the test, the loads needed for penetrations of 2.5 mm and 5 mm are noted. The recorded load is represented as a percentage of the standard load value at the associated deformation level to derive the CBR value. This value provides a measure of the material's strength and suitability for pavement applications. Higher CBR values indicate greater resistance to penetration and are desirable for achieving stable and durable pavements.

1.4 Organisation of report

Chapter 1 It gives a general overview of the subgrade's strength, stiffness capability, and available strengthening techniques. The kind of soil, its density, the amount of moisture in the soil, and the presence of reinforcing materials are just a few of the variables that affect how it behaves. Moreover, the project work is described in this chapter.

Chapter 2 The methods and procedures used by famous researchers over the past few decades to ascertain subgrade strength and stiffness capability are reviewed in-depth in this chapter. The review highlights the advancements and findings in this field, providing valuable insights for further research and understanding of subgrade behavior.

Chapter 3 This section describes the proposed experimental approach for the strength analysis of geotextile subgrade. It outlines the test methods and procedures to be followed, including sample preparation, laboratory testing, and data collection. The report emphasizes the importance of conducting comprehensive and accurate tests to obtain reliable results.

Chapter 4 This section discusses the practical implications of the study findings, highlighting the benefits of jute reinforcement in pavement systems, such as improved structural performance and load-bearing capacity. It also addresses sustainability and cost-effectiveness aspects, along with challenges related to implementation and suggestions for mitigating them.

Chapter 5 This chapter presents the results and discussion of the present work, highlighting the key findings and their corresponding analysis. The study revealed significant improvements in various aspects due to the implemented interventions. Detailed examination of the results provides valuable insights into the effectiveness of the methods employed. These results contribute to a better understanding of the topic and may have ramifications for future study as well as real-world use.

Chapter 6 This chapter incudes the conclusion part of the project works.

CHAPTER 2

REVIEW OF LITERATURE

To improve the performance and durability of pavement structures, geosynthetic reinforcing layers are frequently used. The California bearing ratio (CBR), which is used to evaluate the performance of unpaved roads, is an important consideration. It serves as an indicator of subgrade soil strength for both paved and unpaved road applications. In current construction practices, geosythetic layers are frequently utilized to improve weak or unsuitable soil subgrades for both paved and unpaved roads. Unpaved roads built on soft soil subgrades can be strengthened successfully with geosynthetic reinforcements, extending their lifespan. **(Singh et al; 2019)**.

By using geotextile and jute fibre have improved the bearing capacity of granular subgrade soil was discussed by **(Hossain et al; 2015)**.

The usage of natural geotextiles for improving unpaved roads and examine their combination with biaxial geogrid. SEM (Scanning electron microscope) photos showed that soil particles and the surface of the geogrid were bonded together during the soaked CBR and UCS testing **(Sudarsanan et al; 2015, Mittal et. al; 2019 and Viveka et al; 2021).**

In one such study, experimental and computational assessments were conducted to determine how geotextile reinforcement affected the bearing capacity of granular soils **(Rashidian et al; 2018)**.

Another study described, Soft soil that had been strengthened with a non-woven geotextile functioning as a separator and covered in sand was used for the CBR tests **(Bergado et al; 2001)**.

In classical literature, **(Singh et al; 2020)** introduced the dynamic cone penetrometer is a widely used pavement evaluation technique. Unpaved roads on weak soil require regular maintenance due to severe damage. Geosynthetics like geotextiles and geogrids are effective in reinforcing and improving the serviceability of these roads.

To gain a deeper understanding and analysis of the test results FE analysis using PLAXIS software was conducted. Researchers have studied the impact of jute, geogrids and geosynthetics on the performance of geomaterial **(Singh et al; 2020, 2020)**.

A paper presents laboratory California bearing ratio (CBR) test results on unreinforced and reinforced soil-aggregate composites. It evaluates the strength improvement of the subgrade-aggregate system using CBR values. Geotextile, geogrid, and geomat were used as reinforcing layers, and their impact on the load-penetration curve and relative performance were analyzed **(Singh et al; 2020)**.

Giroud et al; (2004) suggest a technique for figuring out the base course's thickness in unpaved roads. The approach takes into account geosynthetic stiffness, interlock with geosynthetics, stress distribution, and base course material strength. Additionally considered for determining failure modes are the volume of traffic, wheel loads, tyre pressure, subgrade strength, rut depth, and the effect of reinforcing geosynthetics.

Another study focuses on the use of woven treated DW Twill Jute Geotextile (JGT) for subgrade soil reinforcement in flexible pavement. Both laboratory investigation and field trial were conducted. The results of laboratory tests demonstrate a 1.5 times increase in CBR value when jute geotextiles are applied in the subgrade soil. The study also looks at how geotextile reinforcement affects how much subgrade pumping occurs on highway pavements at the subgrade-subbase interface **(Khan et al; 2009 and Alobaidi et al; 1998)**.

Nonwoven geotextiles offer two primary benefits when used in unpaved roads: separation and reinforcement functions. These contributions effectively reduce rutting, minimize maintenance costs, and significantly enhance the overall performance of reinforced unpaved roads **(Al-Refeai et al; 2000)**.

Lee et al; (2021) evaluate the stiffness and strength properties of a compacted subgrade, a crosshole dynamic cone penetrometer (DCP) were utilized. The proposed paper suggests optimizing stiffness and damping of structural systems simultaneously by minimizing sum of mean square responses to stationary random excitations and ensuring constraints on total stiffness and damper capacity. The best design for a constant total stiffness and damper capacity is found in the first phase of a two-step optimization approach, and a number of best designs for changing total stiffness and damper capacity are found in the second step **(Takewaki et al; 1999, 2000)**.

A study uses stiffness measurements to estimate the compactness of granular geomaterials used in road sub-base and base courses **(Kazemi et al; 2018)**.

CASM-n, a unified critical state model for bonded geomaterial that extends an existing model for reconstituted geomaterial (CASM). In order to more accurately characterize bonded geomaterial, CASM-n takes into account pre-yield greater strength and stiffness as well as the cohesivefrictional shearing mode in the post-yield zone **(Yu et al; 2007)**.

Geogrids improve pavement performance, increase bearing capacity, and reduce cracking and damage. This paper presents a case study on geogrid application in an airport runway, evaluating static behavior and conducting non-destructive testing. A numerical study compares geogrid-reinforced runway behavior to experimental results **(Abdesssemed et al; 2015).**

Inverse analysis of multi-layered flexible pavement constructions subjected to dynamic stress is presented in this research using an adaptive-network-based fuzzy inference system (ANFIS) in conjunction with finite element modelling (FEM). Non-destructive tests (NDTs) are used to assess the structural health, bearing capacity, and spot damage over the service life of the pavement **(Gopalakrishnan et al; 2010).**

CHAPTER 3

STRENGTH ANALYSIS OF GEOTEXTILE REINFORCED SUBGRADE

3.1 Introduction

The subgrade, which acts as the foundation for the pavement structure of a road, comprises natural soil or engineered fill material. However, if the subgrade has inadequate strength, it can lead to significant challenges in road construction and maintenance. A weak subgrade is unable to withstand the weight of the pavement and traffic load, resulting in various distresses such as cracking, rutting, and other pavement failures. Additionally, uneven settlement caused by a weak subgrade can lead to bumps or depressions in the road surface. Given these possible problems, it is essential to carefully evaluate the subgrade's strength before beginning road construction operations. Through conducting thorough and comprehensive strength evaluations, engineers can identify potential weaknesses in the subgrade and implement appropriate measures to enhance its strength, if deemed necessary. Neglecting to address subgrade deficiencies can lead to premature pavement failures, escalated maintenance expenses, and disruptions to the smooth flow of traffic. Several techniques can be employed to strengthen the subgrade and ensure the long-term performance of the road. To improve the engineering properties of the subgrade soil, stabilizing agents like cement, lime, or chemical additives are added to the soil. This process improves the load-bearing capacity, reduces settlement, and increases overall stability. Geotextile reinforcement is another effective technique where geotextile materials are placed within the subgrade layers. These materials act as reinforcement by distributing the load more evenly and reducing the potential for differential settlement. Geotextiles also aid in controlling soil erosion and improving overall soil strength. In cases where the subgrade is too weak to support the intended road structure, subgrade replacement may be necessary. This involves excavating and removing the inadequate subgrade material and replacing it with stronger engineered fill materials that meet the required specifications. To provide insights into enhancing subgrade strength, this paper conducts comparative studies on the strength analysis of polypropylene (PP) and jute geotextiles. The ability of these materials in enhancing the subgrade's engineering qualities is being studied.

3.2 Experimental set-ups

3.2.1 Materials

This study specifically selected a single type of soil as its focus. To examine the influence on shear strength and CBR (California Bearing Ratio) of the soil, two different types of geotextiles were employed: woven jute textile, consisting of natural fibres, and woven polypropylene geotextile, composed of synthetic fibres. This study's objective is to evaluate the effects of these two geotextiles on the selected soil type's shear strength and CBR properties. By comparing the performance of the natural fibre-based geotextile (jute) with the synthetic fibre-based geotextile (polypropylene), the study aims to provide valuable insights into the suitability and effectiveness of these geotextiles for soil stabilization applications.

3.2.2 Soil testing

An area nearby was chosen to collect a soil sample for this study. A soil sample is subjected to the sieve analysis test in order to determine the type of soil, and the results of this test produce a particle size distribution curve, as shown in Fig. 3.1. The soil can be categorized as poorely graded sand containing silt, abbreviated as SP-SM according to IS: 2720 Part-4 (1985). An IS: 2720 Part-7 (1980) compliant soil sample is subjected to a conventional proctor test, also known as a light compaction test, to determine the maximum dry density (MDD) and optimal moisture content (OMC) of soil. In this test, the soil sample is compacted using a 2.6 kg rammer with 25 blows, each having a 31 cm free fall height, to create three equal layers in a 1000 cc mould. The MDD and OMC achieved from the standard proctor test are 1.899 gm/cc and 12.94 % respectively and shown in Fig. 3.2. To accurately determine the shear parameters of soil, direct shear test (consolidated drained) is performed on remoulded soil by preparing soil sample on its maximum dry density by adding optimum moisture content. This test yields the normal stress (σ) and shear stress (τ) curves. Additionally, laboratory studies are carried out on the geotechnical properties of soil, such as its specific gravity and consistency limits, as shown in Table 3.1.

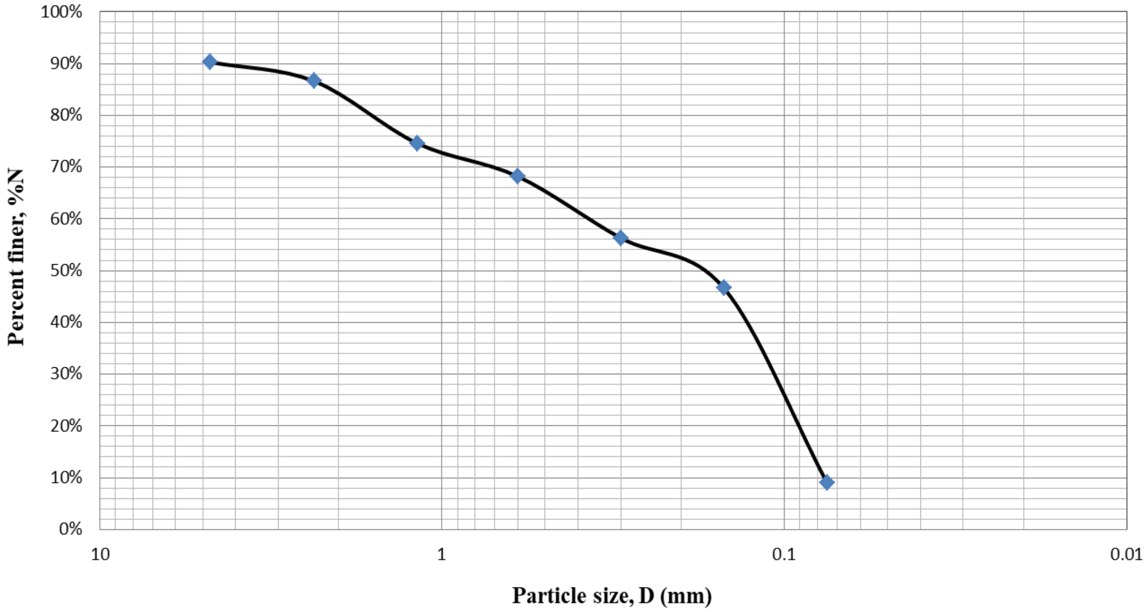


Figure 3.1: Particle size distribution curve of soil

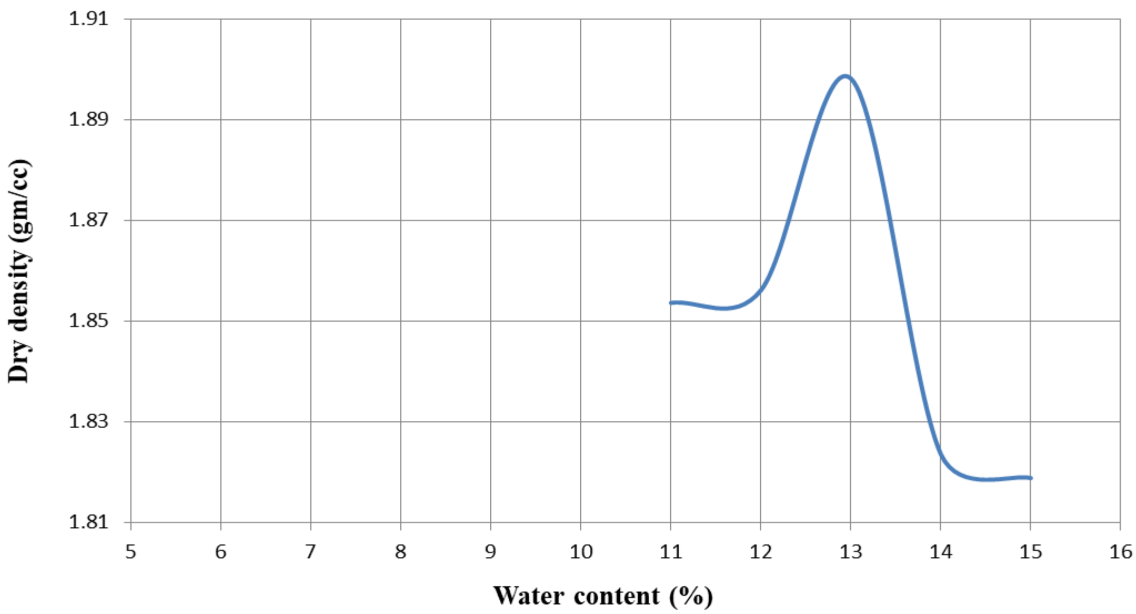


Figure 3.2: Compaction curve of soil

Table 3.1: Geotechnical properties of soil

Serial No.	Properties	Values
1.	Gravel content (%)	9.7
2.	Sand content (%)	81.3
3.	Silt and clay content (%)	9
4.	Uniformity coefficient (C_u)	4.9032
5.	Coefficient of curvature (C_c)	0.39606
6.	Specific gravity (G)	2.63
7.	Liquid limit (%)	30.5
8.	Plastic limit (%)	25
9.	Plasticity index (%)	5.5
10.	$\gamma_{dmax.}$ (gm/cc)	1.899
11.	OMC (%)	12.94

3.2.3 Geotextile

Geotextiles, which are permeable textiles, offer a wide range of benefits in various civil engineering and environmental applications and used to improve the soil characteristics. It has ability to separate, drain, protect, reinforce and filter when used in contact with soil. Two types of woven geotextiles i.e. jute textile (natural fibre) and polypropylene geotextile (synthetic fibre) are used here as depicted in Figs. 3.3 (a) and 3.3 (b), respectively. Woven type geotextiles are manufactured by interlocking two or more sets of yarns, filaments or other elements. These threads are generally woven straight and parallel to each other.

(a)

(b)

Figure 3.3: Geotextiles materials (a) Jute textile and (b) Polypropylene (PP) geotextile

3.3 Placement of geotextiles

Several unreinforced soil samples with various geotextile layers have been made and investigated in order to identify the best reinforcing material for the California Bearing Ratio (CBR) test and Direct Shear Test (DST). The test results were then compared to identify the most effective reinforcing material. By analyzing the CBR values and direct shear strengths of the samples, we can evaluate the performance and suitability of each geotextile layer in enhancing soil stability and shear resistance. These comparisons will ultimately guide the selection of the best reinforcing material for the desired application.

Samples tested are as follows:

1. Samples without any geotextile were tested to establish a baseline for comparison against the reinforced samples. These samples allowed us to assess the natural behavior of the soil under testing conditions.
2. For the direct shear test, both jute and polypropylene geotextiles were used individually as reinforcing materials. The unreinforced soil sample was combined with one layer of each geotextile. As a result, we were able to assess the soil's shear strength and performance after being reinforced with distinct geotextiles made of jute and polypropylene.
3. Jute and polypropylene geotextiles were used to strengthen the soil samples during the CBR test. As depicted in Fig. 3.4, the reinforcement arrangement used single layer at depths of D/2, D/3, and D/4, double layers at combinations of D/2, D/3 and D/3, D/4 and D/2, D/4, and triple layers at D/2 and D/3 and D/4. We were able to evaluate the impact of various reinforcement configurations on the California Bearing Ratio (CBR) of the soil sample thanks to this thorough setup. These studies outcomes gave us important information about the efficacy and suitability of jute and polypropylene geotextiles for soil reinforcing.

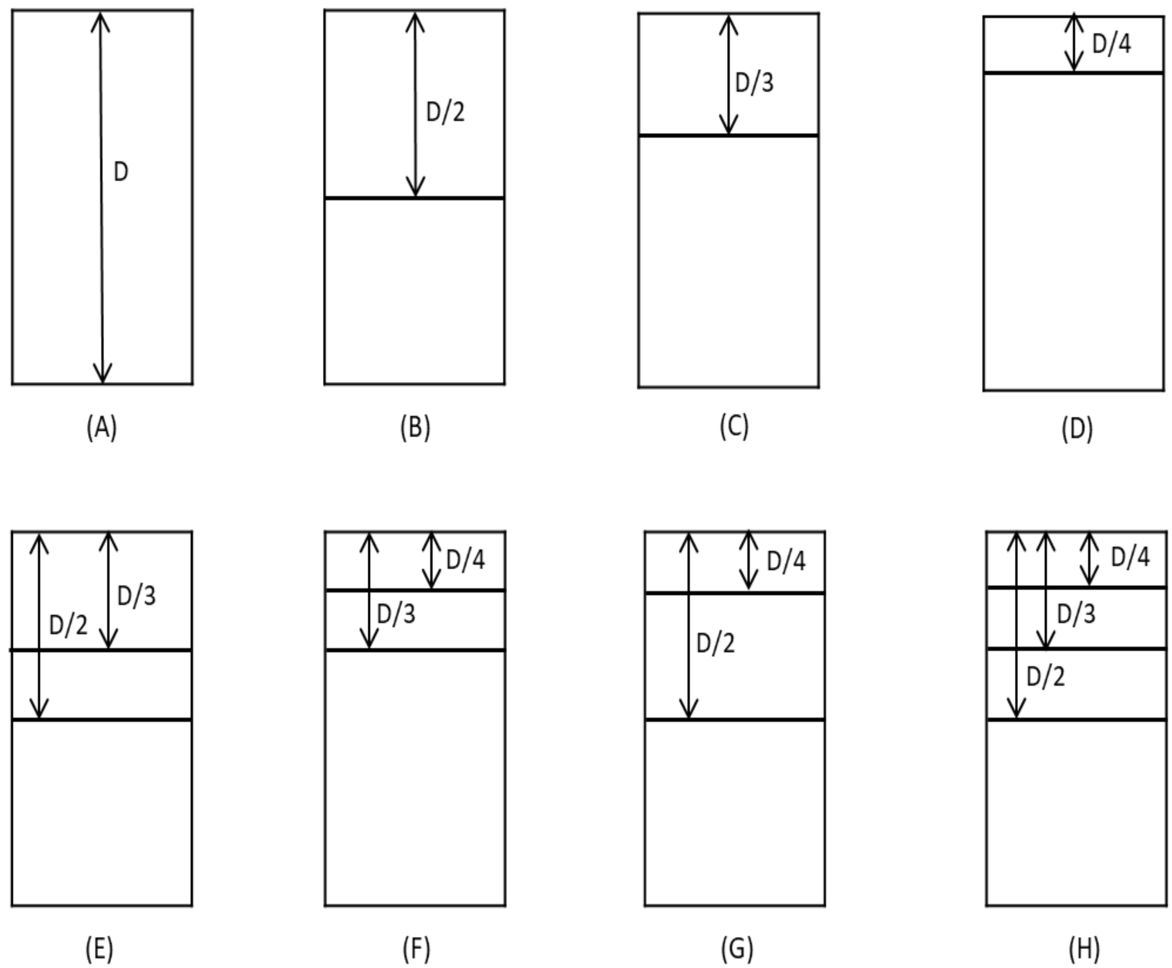


Figure 3.4 Placement of geotextiles in CBR mould

CHAPTER 4

INFLUENCE OF JUTE-REINFORCEMENT ON THE STIFFNESS CAPACITY OF COHESIONLESS PAVEMENT GEO-MATERIALS

4.1 Introduction

Soil stiffness capacity is a critical measure of a soil specimen's ability to withstand external forces and maintain its shape and stability. It serves as a fundamental parameter in assessing the soil's capability to support applied loads, such as the weight of structures like buildings or pavements, without experiencing excessive settlement or deformation.

A higher stiffness capacity indicates a stronger and more stable soil, capable of bearing greater loads and stresses without significant deformation. It implies that the soil can effectively distribute the applied loads, minimizing settlements and maintaining the structural integrity of the supported structures. Researchers have extensively studied the stiffness capacity of soil to better understand its behavior under various loading conditions. These studies involve investigating the effects of different soil properties, testing methodologies, and engineering techniques to enhance the stiffness capacity. The findings from these studies have contributed to the development of design guidelines and construction practices aimed at optimizing the performance of soil in various geotechnical applications. Several factors contribute to the stiffness capacity of soil, including its composition, density, moisture content, and the presence of reinforcement materials. These factors collectively determine the soil's resistance to deformation when subjected to external loads.

4.2 Materials and test procedure

4.2.1 Soil

In this research, a soil sample was collected from nearby local places and subjected to sieve analysis test to determine the particle size distribution curve as shown in Fig. 4.1. Based on the test results, the soil was categorized as SP-SM (Poorely graded sand with silt) in accordance with the IS: 2720 Part-4 (1985) standard. A soil's liquid limit (LL) refers to the moisture content on which the soil exhibits characteristics similar to that of a liquid yet displays minimal shear strength. This can be determined by using Casagrande's liquid limit device which involves closing a groove in the soil sample by repeatedly striking it with a standard sized cup. The logarithm of the number of blows is plotted against the water content in a semi-log plot to determine the soil's liquid limit. The moisture content corresponding to 25 blows is then calculated as the liquid limit using the figure presented in Fig. 4.2. A conventional proctor test (mild compaction) was carried out in accordance with IS: 2720 Part-7 (1980) to assess the maximum dry density (MDD) and optimal moisture content (OMC) of the soil. Using a 2.6 kg rammer and a free fall height of 31 cm, the soil sample was compacted in three equal layers using 25 blows each in a 1000 cc mould. The MDD and OMC achieved from this test were 18.63 KN/m^3 and 12.94 % respectively as shown in Fig. 4.3. In addition, other geotechnical characteristics of the soil, including consistency limits and specific gravity, were examined in the lab and are shown in Table 4.1.

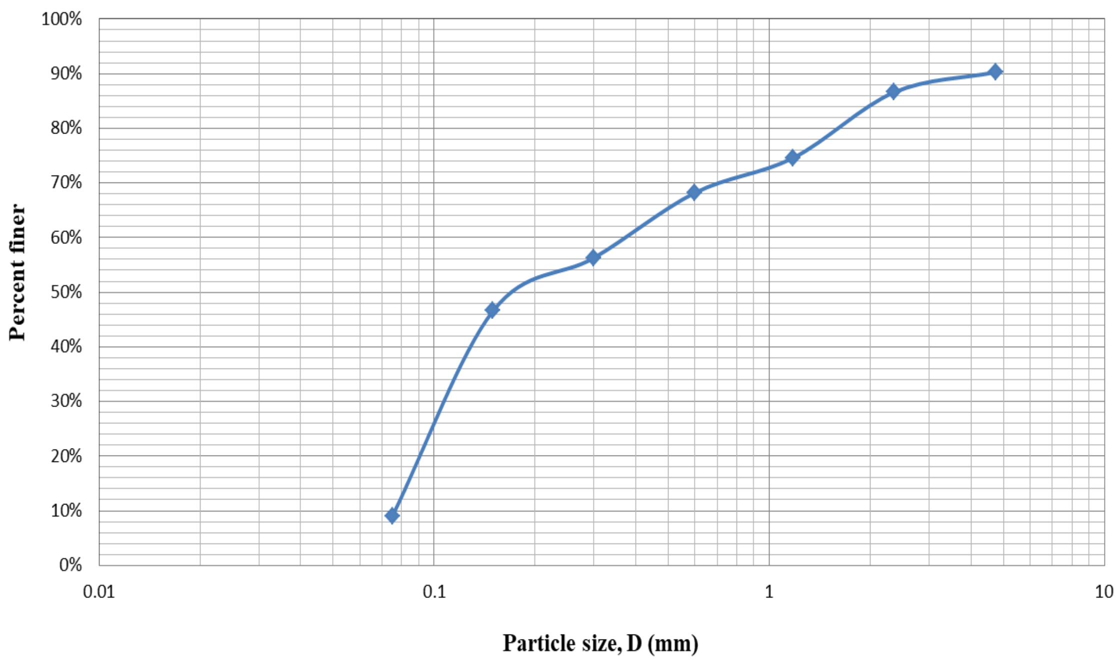


Figure 4.1: Grain size distribution curve of soil

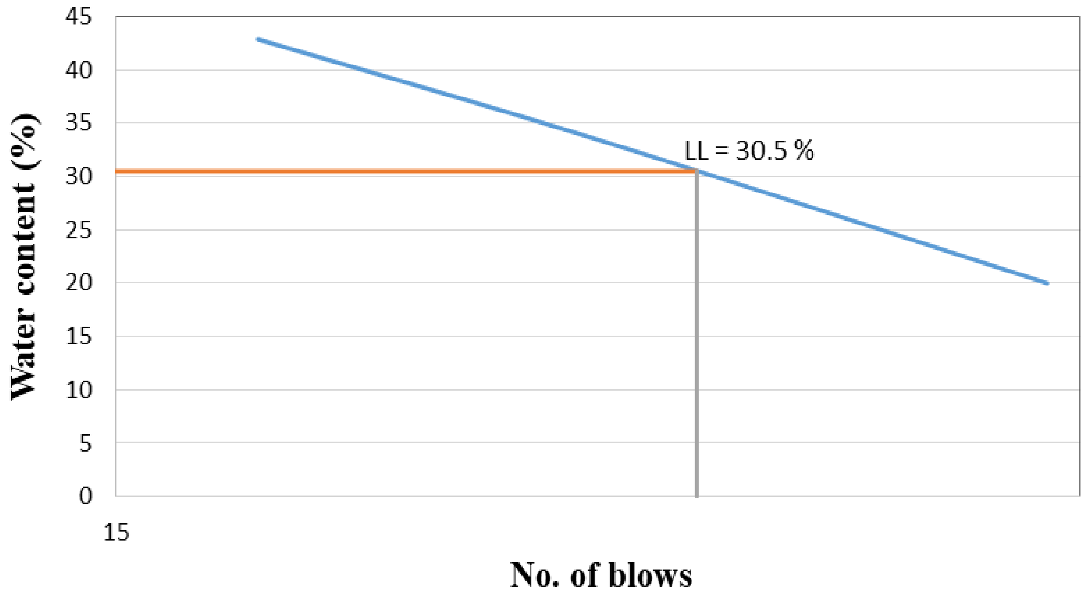


Figure 4.2: Consistency limits graph of soil

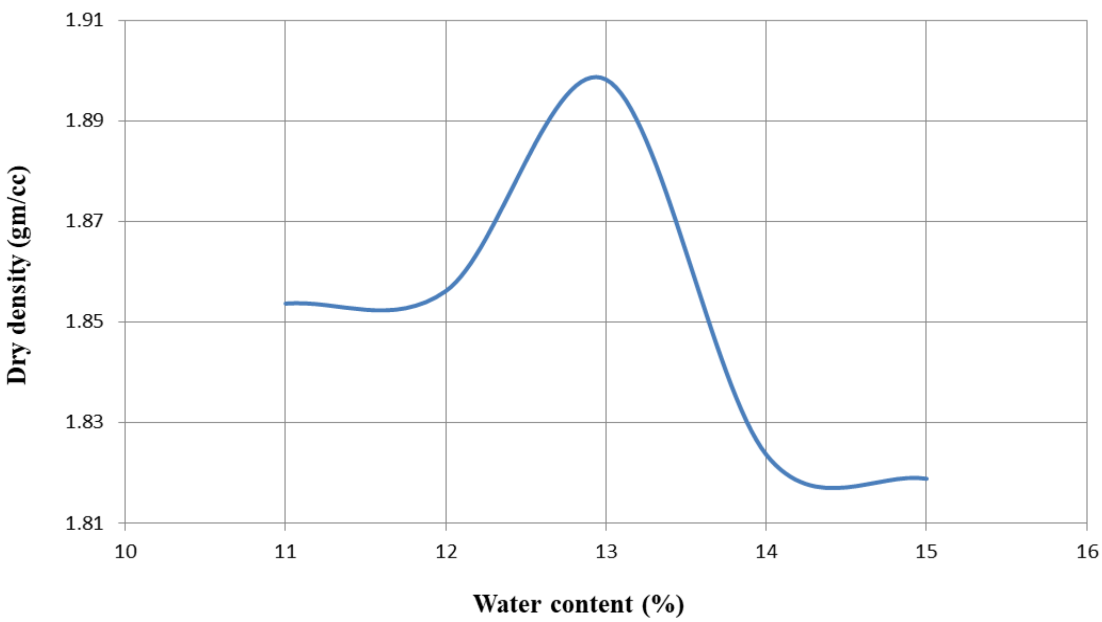


Figure 4.3 Standard proctor test compaction curve for soil

Table 4.1: Characteristics of soil

Serial No.	Property	Notations	Values	Units
1.	Gravel fraction	-	9.7	%
2.	Sand fraction	-	81.3	%
3.	Silt and Clay fraction	-	9	%
4.	Specific gravity	G	2.63	-
5.	Liquid limit	LL	30.5	%
6.	Plastic limit	PL	25	%
7.	Soil classification	SP-SM	-	-
8.	Maximum dry Density	$\gamma_{dmax.}$	18.63	KN/m^3
9.	Optimum moisture content	OMC	12.94	%

4.2.2 Jute geotextile

Jute geotextile is a type of geosynthetic material made from natural jute fiber. Geotextiles are permeable fabrics that are used in various geotechnical and civil engineering applications to improve soil stability, drainage, filtration, and erosion control. Jute, commonly referred to as "the golden fibre," is a long, silky, and glossy vegetable fibre that is largely grown in Bangladesh and India. Jute fibre possesses excellent tensile strength, biodegradability, and eco-friendliness, making them suitable for geotechnical applications. Jute geotextiles offer several advantages in geotechnical engineering. Firstly, they provide effective erosion control by stabilizing soil slopes, embankments, and riverbanks. The geotextiles prevent soil erosion caused by rainfall and water flow, protecting the underlying soil structure and preventing sedimentation in nearby water bodies. A woven jute fibre sheets are used in this research as shown in Fig. 4.4. The jute geotextile is a sustainable and cost-effective solution for a variety of geotechnical and environmental applications offering superior performance and durability compared to other natural fibre-based materials. Jute fibre is a versatile natural fibre with a number of notable physical and chemical properties which is shown in Table 4.2.

Figure 4.4 Woven Type Jute sheet

Table 4.2: Properties of jute fibre

Jute fibre	Values	Units
Physical properties		
Density	1.3	g/cm^3
Elongation at break	1.5-1.8	%
Tensile strength	393-773	MPa
Young's modulus	26.5	GPa
Color	Light brown to gray	-
Texture	Coarse, rough and stiff	-
Chemical properties		
Lignin	12-15	%
Cellulose	65-70	%
Hemicellulose	12-14	%
Pectin	0.5-1	%
Reaction with acids	Decomposes	-

4.2.3 Test procedure

Standard methods were applied to samples of reinforced and unreinforced soil to determine the California bearing ratio (CBR). The needed quantity of oven-dried soil was thoroughly mixed with water in the first phase to achieve its optimal moisture content (OMC). Then, according to IS: 2720 Part-16 (1987), this mixture was put into a CBR mould with dimensions of 15 cm in diameter and 17.5 cm in depth, together with a base plate that can be detached and contains perforations. To achieve the maximum dry density, laboratory standard proctor test (light compaction) was conducted and the soil was compacted accordingly. Filter paper and a perforated metallic disc were placed over the specimen to prepare the soil samples and a spacer disc was inserted into the mould reducing the effective height to 12.7 cm with a net capacity of 2250 cm^3. After the soil samples were prepared, the CBR mould containing the unsoaked soil sample was subjected to testing using a CBR testing machine shown in Fig. 4.5. On the basis of plunger penetrations of 2.5 mm and 5 mm, the CBR values of soil samples that were both unreinforced and reinforced were then assessed. A load was applied to the sample's top surface during testing at a consistent rate of penetration (1.25 mm/min) through the plunger. The CBR values were computed as the ratio of the load required to penetrate the soil sample by the plunger at a depth of 2.5 mm or 5 mm to the standard loads after the load and corresponding penetrations were recorded. The strength and stiffness of the soil may be ascertained through this testing technique, which is helpful for a variety of engineering applications.

Figure 4.5 CBR testing machine

CHAPTER 5

Results and discussion

I.S light compaction, direct shear test and CBR test are conducted according to IS: 2720 Part-13 (1986), IS: 2720 Part-16 (1987), respectively in the laboratory.

5.1 Direct shear test results

Unreinforced soil sample is mixed with single layer of jute as well as polypropylene to investigate how the addition of geotextiles impacts on cohesion (C), angle of friction (ϕ) and overall shear strength of an unreinforced soil specimen on varied normal stresses (50, 100 and 150 KPa). These parameters are crucial in determining the soil's stability as well as bearing capability in addition to how they are affected by the addition of geotextiles can help improve soil reinforcement techniques and reduce the risk of soil failure. By mixing jute textile, it is found that c and phi value increases which resulting into increase in shear strength whereas by reinforcing polypropylene geotextile, c and phi value decreases which resulting in decrease in shear strength with respect to unreinforced soil. Table 5.1 represents the increment and decrement in c and phi value in comparison to unreinforced soil sample and Table 5.2 compares soil with and without reinforcement to show the increment and decrement in shear strength under varied normal stresses. In Fig. 5.1, comparison between unreinforced and reinforced soil samples is shown on a graph that is plotted between normal stress and shear stress. The shear strength is calculated as:

$$S = C + \sigma_n \tan(\phi) \quad (1)$$

Table 5.1: Comparison table of shear strength parameters among unreinforced and reinforced soil

Parameters for shear strength	Unreinforced soil	Reinforced soil with jute fibre	Reinforced soil with polypropylene fibre
Cohesion (KPa)	19.7	23.25	13.96
Friction angle (°)	31.39	32.825	30.04

Table 5.2: Comparison of shear strength among the geotextiles

Normal stress (KPa)	Shear stress (KPa) (unreinforced soil)	Shear strength (KPa) (unreinforced soil)	Shear stress (jute) (KPa)	Shear strength (jute) (KPa)	Increment in shear strength by reinforcing jute (%)	Shear stress (PP) (KPa)	Shear strength (PP) (KPa)	Decrement in shear strength by reinforcing polypropylene (%)
50	48.85	50.22	54.739	55.499	10.51	42.50	42.874	14.63
100	83.478	80.73	89.272	87.753	8.7	72.511	71.784	11.1
150	109.88	111.25	119.24	120.00	7.8	100.33	106.69	4.1

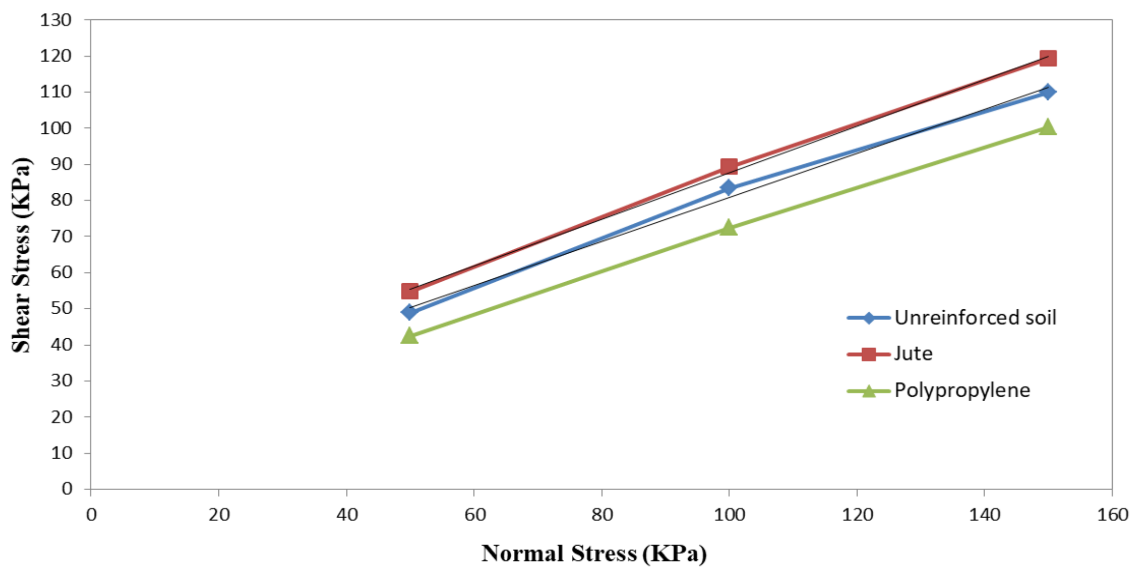


Figure 5.1: Shear stress versus normal stress curve in soil with and without reinforcement

5.2 CBR test results

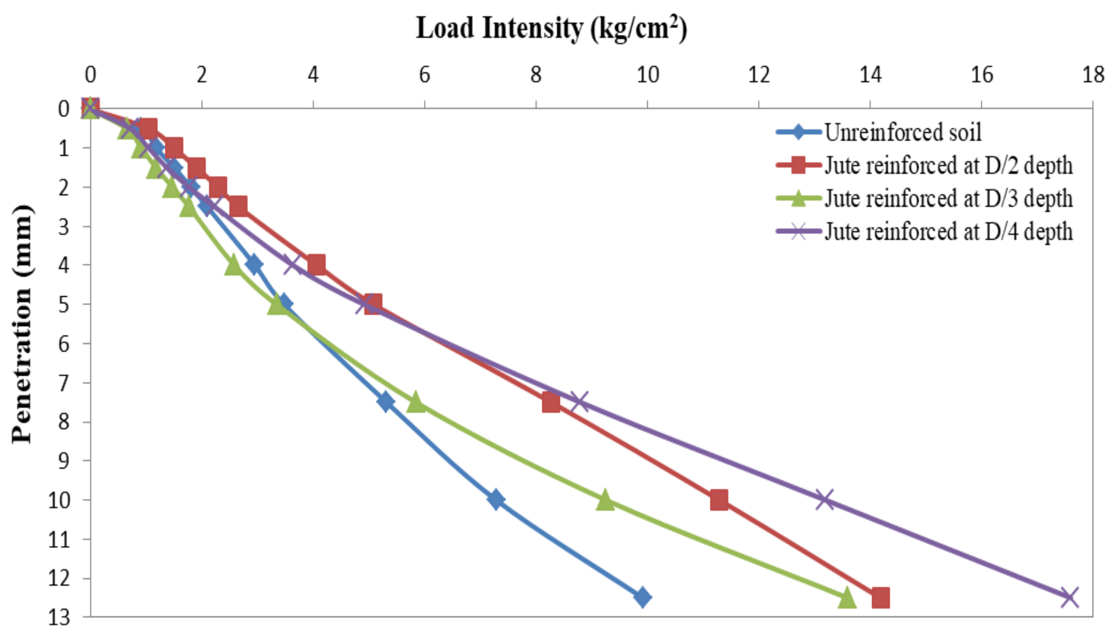
The CBR test involves mixing an unreinforced soil sample with single, double, and triple layers of geotextiles to determine the optimal depth of the layers that will yield a higher CBR value and increase the strength of the subgrade. The test also examines the impact of jute and polypropylene (PP) geotextiles on CBR values with the results compared between reinforced and unreinforced soil samples. Ultimately, this comparative analysis provides effectiveness of geotextiles reinforcement in enhancing soil strength and stability of soil.

5.3 CBR results for various layers of jute and polypropylene (PP) geotextiles

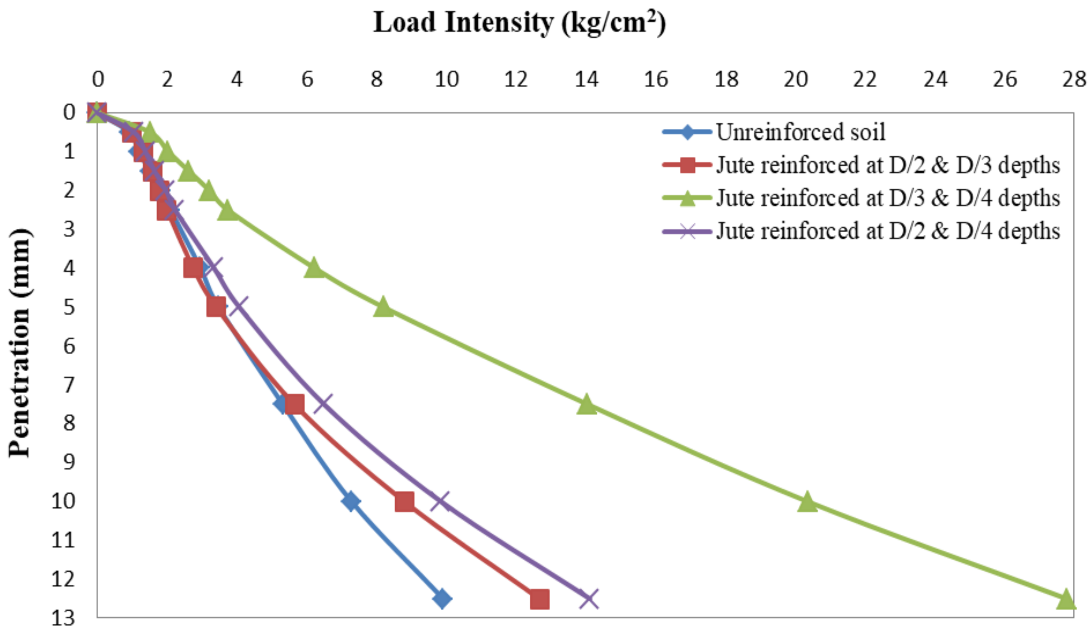
A comparative analysis of the outcomes obtained from jute textile reinforced soil samples and polypropylene geotextile reinforced soil samples provides valuable insights into the performance of each material in enhancing the stability and strength of the soil. These findings are visually presented in Figure 5.2 for jute textile reinforcement and Figure 5.3 for polypropylene geotextile reinforcement. To determine the most suitable reinforcing material for a specific application, it is crucial to examine the California bearing ratio (CBR) values at different penetration depths. In this case, Table 5.3 presents the CBR values for jute textile reinforcement, while Table 5.4 displays the CBR values for polypropylene geotextile reinforcement. An significant finding is that for both jute textile and polypropylene geotextile reinforcements, the CBR value at 5 mm penetration consistently exhibits a larger value compared to the CBR value at 2.5 mm penetration. Based on this consistent trend, it is recommended to prioritize and consider the CBR value at 5 mm penetration when evaluating the performance of the reinforcing materials. By focusing on the CBR value at 5 mm penetration, one can gain a more accurate assessment of the reinforcing material's ability to enhance the soil's stability and strength. This information is crucial in selecting the most appropriate reinforcing material for a specific application, ensuring optimal performance and long-term durability.

Table 5.3: Unsoaked CBR values of unreinforced and jute textile reinforced soil at 2.5 & 5 mm penetration (D = 12.7 cm)

Unsoaked CBR	Unreinforced soil (%)	Jute reinforced in single layer (%)			Jute reinforced in double layers (%)			Jute reinforced in triple layers (%)
		D/2 (6.35 cm)	D/3 (4.23 cm)	D/4 (3.175 cm)	D/2 (6.35 cm) & D/3 (4.23 cm)	D/3 (4.23 cm) & D/4 (3.175 cm)	D/2 (6.35 cm) & D/4 (3.175 cm)	D/2 (6.35 cm) & D/3 (4.23 cm) & D/4 (3.175 cm)
$(CBR)_{2.5mm}$	3.004	3.8	2.53	3.2	2.9	5.53	3.2	3.75
$(CBR)_{5mm}$	3.32	4.85	3.2	4.7	3.25	7.82	3.9	4.75

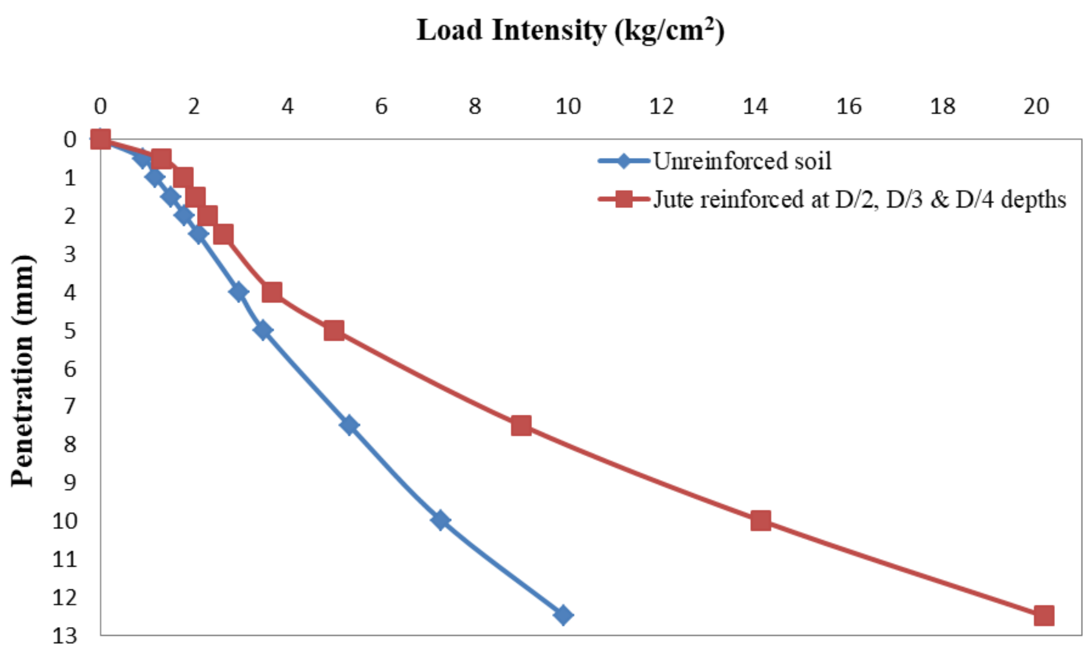


(a)



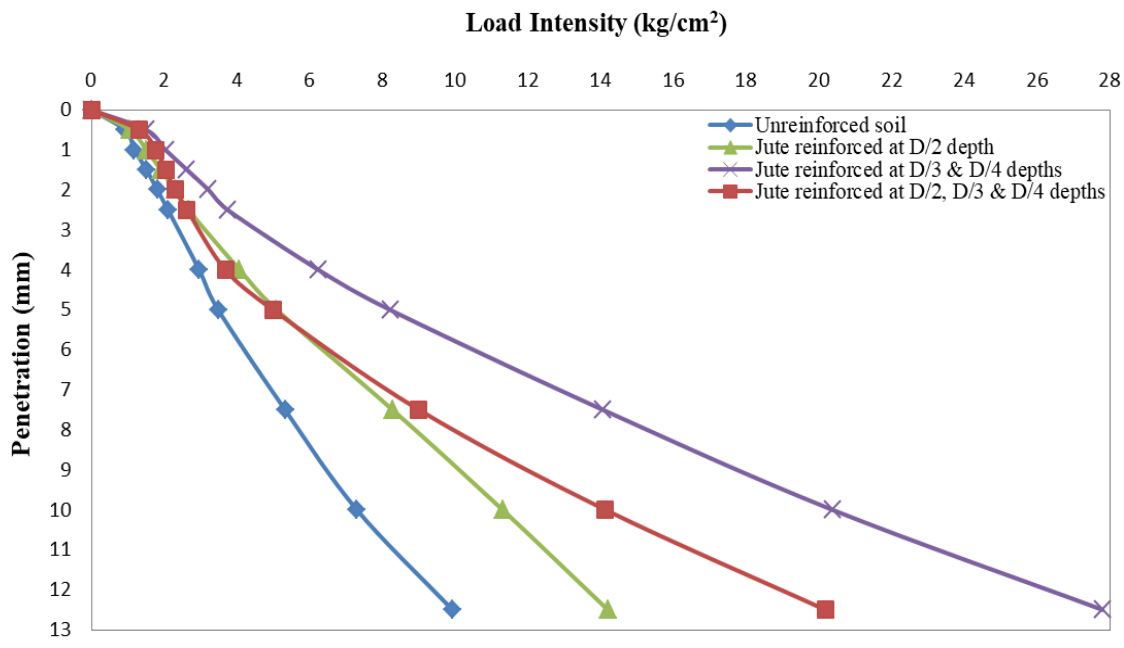
Load Intensity (kg/cm²)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Penetration (mm)
Unreinforced soil
Jute reinforced at D/2 & D/3 depths
Jute reinforced at D/3 & D/4 depths
Jute reinforced at D/2 & D/4 depths

(b)



Load Intensity (kg/cm²)
0 2 4 6 8 10 12 14 16 18 20
0 1 2 3 4 5 6 7 8 9 10 11 12 13
Penetration (mm)
Unreinforced soil
Jute reinforced at D/2, D/3 & D/4 depths

(c)

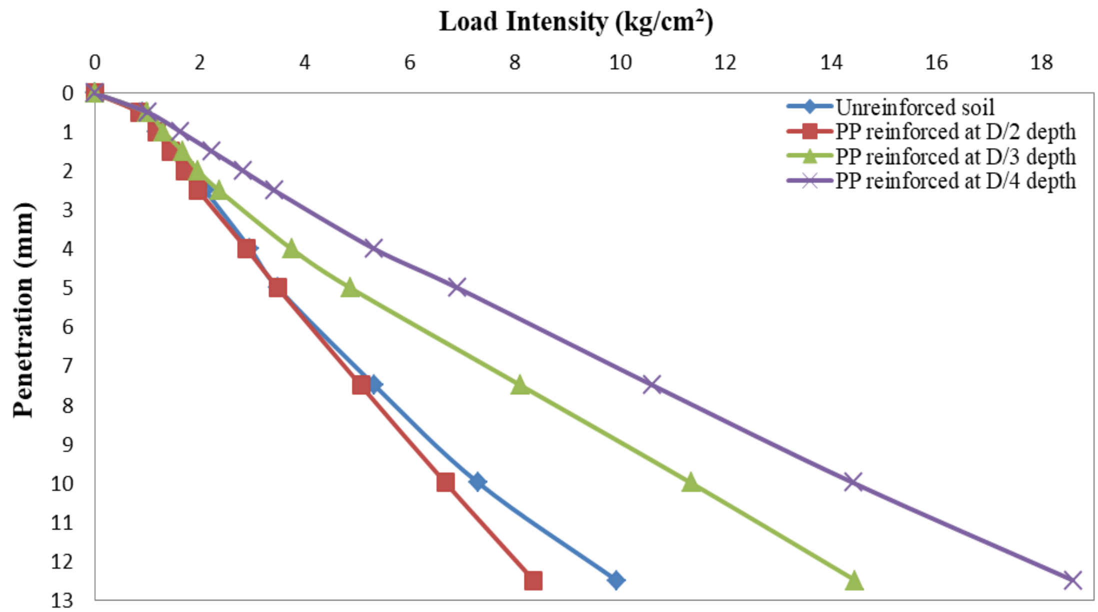


(d)

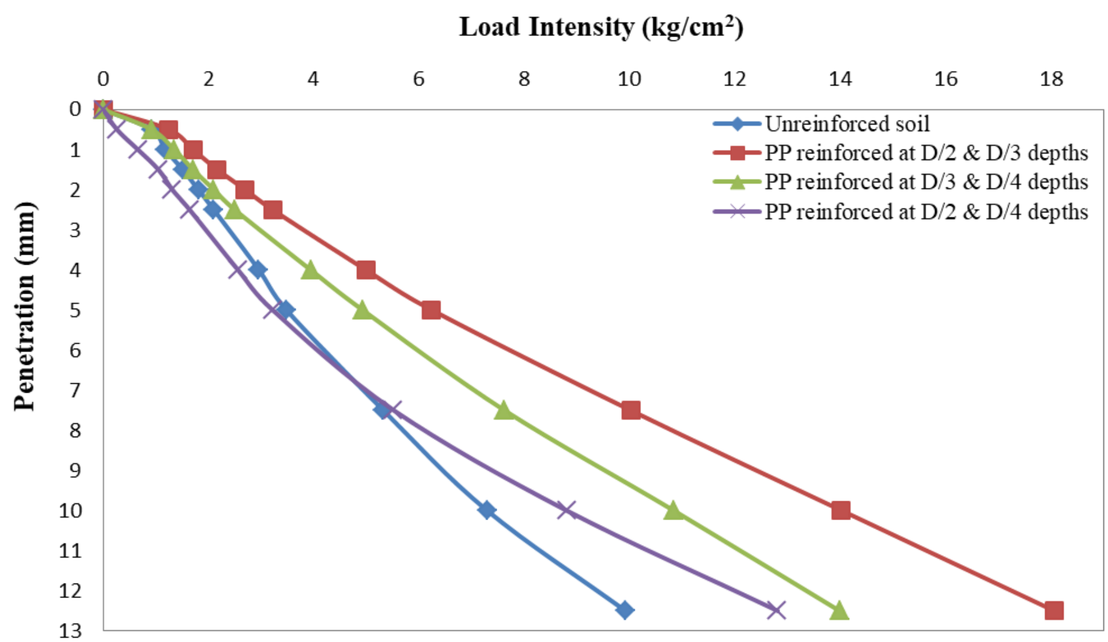
Fig. 5.2 Load intensity versus penetration plot for (a) soil reinforced with single, (b) double, (c) triple and (d) optimum depths of jute textile among all layers

Table 5.4: Unsoaked CBR values of unreinforced and polypropylene (PP) geotextile reinforced soil at 2.5 and 5 mm penetration (D = 12.7 cm)

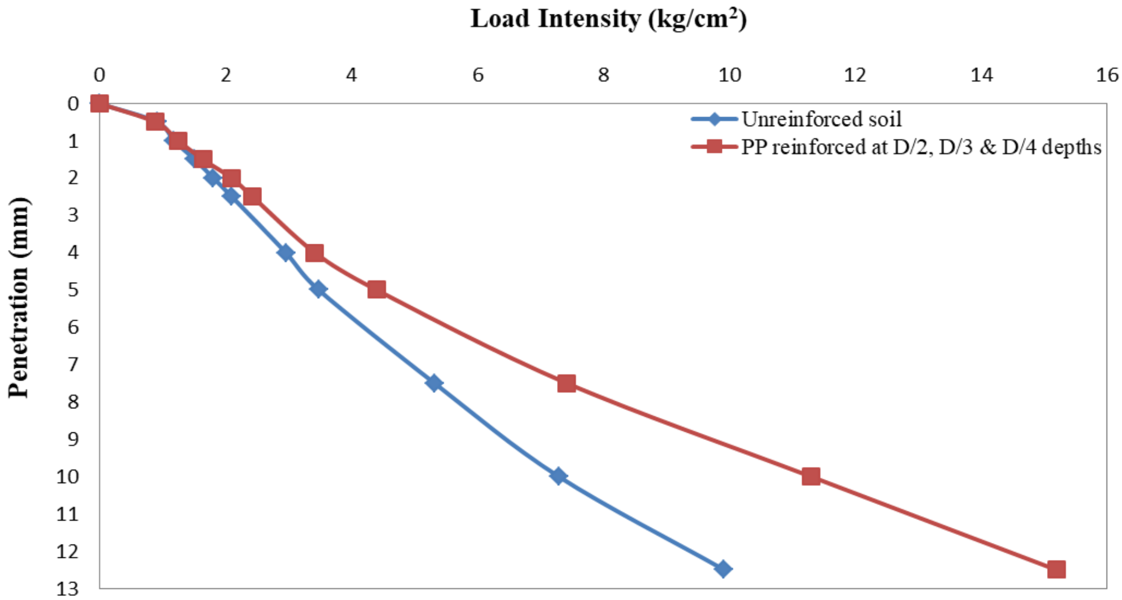
Unsoaked CBR	Unreinforced soil (%)	Polypropylene reinforced in single layer (%)			Polypropylene reinforced in double layers (%)			Polypropylene reinforced in triple layers (%)
		D/2 (6.35 cm)	D/3 (4.23 cm)	D/4 (3.175 cm)	D/2 (6.35 cm) & D/3 (4.23 cm)	D/3 (4.23 cm) & D/4 (3.175 cm)	D/2 (6.35 cm) & D/4 (3.175 cm)	D/2 (6.35 cm) & D/3 (4.23 cm) & D/4 (3.175 cm)
$(CBR)_{2.5mm}$	3.004	2.82	3.4	4.9	4.6	3.6	2.35	3.5
$(CBR)_{5mm}$	3.32	3.32	4.63	6.6	5.94	4.7	3.1	4.2


Load Intensity (kg/cm²)
Penetration (mm)
Unreinforced soil
PP reinforced at D/2 depth
PP reinforced at D/3 depth
PP reinforced at D/4 depth

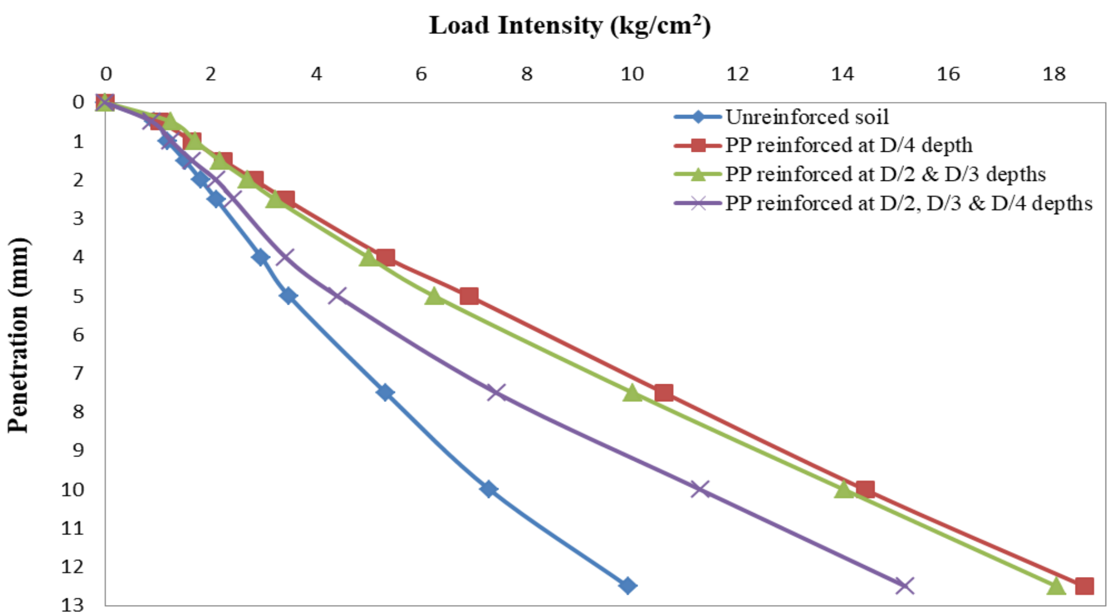
(a)


Load Intensity (kg/cm²)
Penetration (mm)
Unreinforced soil
PP reinforced at D/2 & D/3 depths
PP reinforced at D/3 & D/4 depths
PP reinforced at D/2 & D/4 depths

(b)



(c)



(d)

Figure 5.3 Load intensity versus penetration plot for (a) soil reinforced with single, (b) double, (c) triple and (d) optimum depths of PP geotextile among all layers

5.4 Determination of stiffness capacity

The California bearing ratio (CBR) test involves mixing an unreinforced soil sample with single, double and triple layers of jute fibre at various depths to determine the optimal depth of the layers. From the data of CBR results, evaluate the spring constant (K) values and stiffness capacity ($K/K_{max.}$) of soil which is shown in Table 5.5 as well as in the equation forms. By reinforcing the single, double and triple layers of jute fibre in unreinforced soil sample which signifies the optimum depth at D/4 (3.175 cm) which represents the higher stiffness capacity and increases the strength of the pavement in comparison to unreinforced soil specimen. Fig. 5.4 illustrates the stiffness capacity versus penetration factor plot curves for single, double and triple layers of jute fibre reinforced soil as well as a comparison between reinforced and unreinforced soil. The plot demonstrates the significant improvement in stiffness capacity of the reinforced soil compared to the unreinforced soil at the same penetration factor.

$$k = \frac{F}{\delta} \rightarrow \frac{Q(t, L_f, P_r)}{\delta(t, dgr)} \tag{1}$$

The Eq. 1 relates the spring constant (k) of soil to the applied force (F) divided by the amount of deflection (δ) that it experiences under the load.

$$Q = f(t, L_f, P_r) \tag{2}$$

The Eq. 2 represents the applied force (Q) on sample of soil as a function of time (t), load factor (L_f) and proving ring reading (P_r). The equation suggests that the applied force is influenced by several factors including the time over which the load is applied, the size of the soil and the output signals of measuring devices used to measure the load.

$$\delta = f\left(t, d_{gr}\right) \tag{3}$$

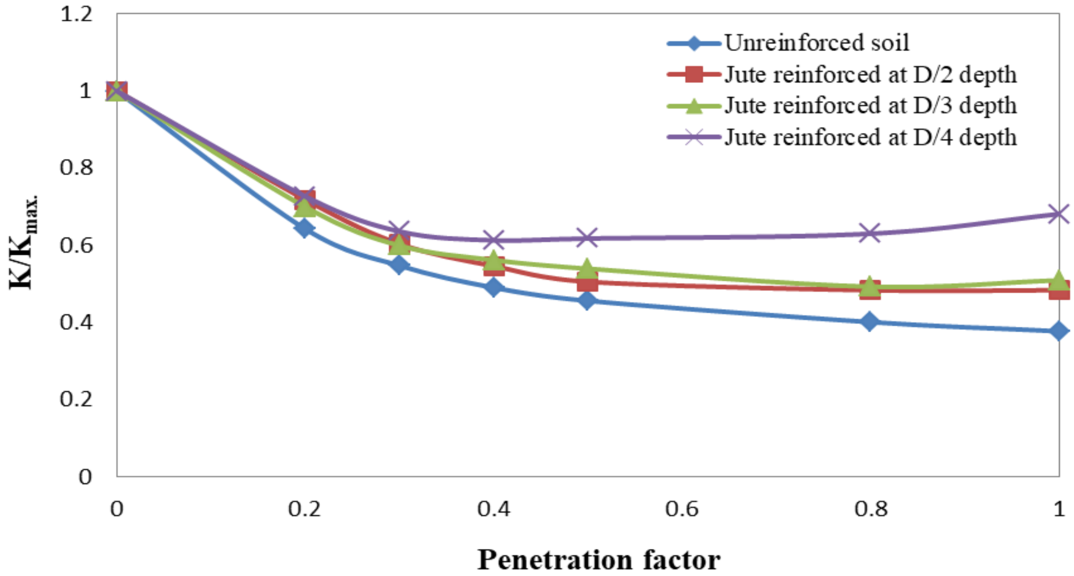
The Eq. 3 relates the deflection (δ) of soil to the variables time (t) and dial gauge reading (d_{gr}). The dial gauge reading refers to the displacement or deflection of the material under the applied load. The equation implies that a number of variables, such as the duration of the load application and the displacement of the soil specimen as measured by a dial gauge, affect the amount of deflection of a soil.

$$P_f = \frac{\delta}{\delta_{max.}} \tag{4}$$

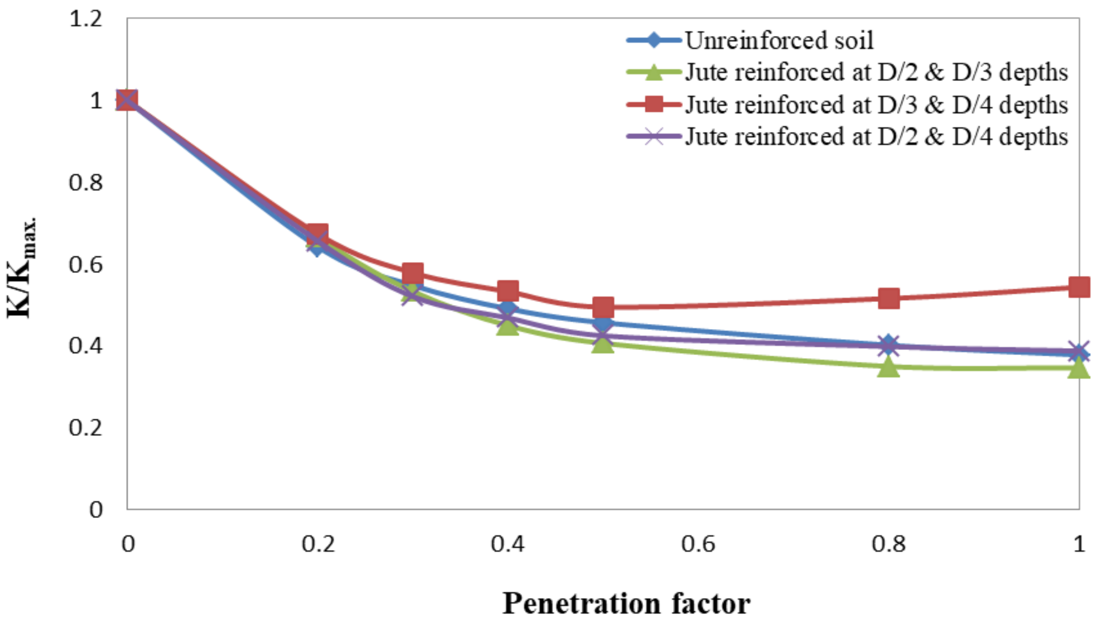
Where, P_f is the penetration factor, δ is the deflection of the specimen and $\delta_{max.}$ is the maximum deflection.

Table 5.5 Comparison of stiffness capacity values at different penetration factor between unreinforced and reinforced soil (D = 12.7 cm)

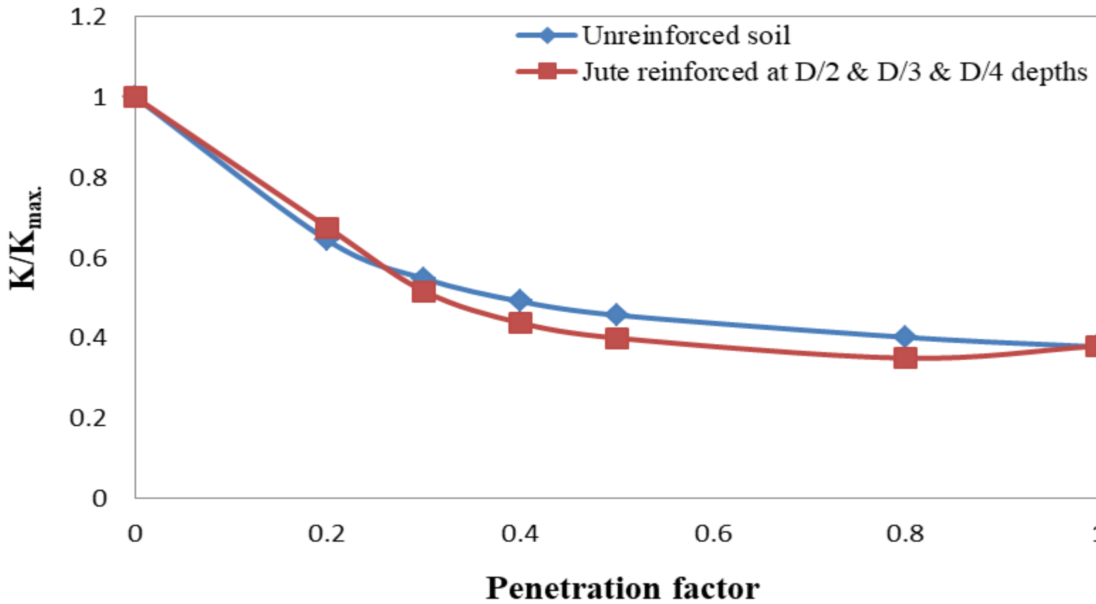
Penetration factor (P_f)	$K/K_{max.}$ (Unreinforced soil)	$K/K_{max.}$ (Jute fibre embedded in single layer)			$K/K_{max.}$ (Jute fibre embedded in double layers)			$K/K_{max.}$ (Jute fibre embedded in triple layers)
		D/2 (6.35 cm)	D/3 (4.23 cm)	D/4 (3.175 cm)	D/2 (6.35 cm) & D/3 (4.23 cm)	D/3 (4.23 cm) & D/4 (3.175 cm)	D/2 (6.35 cm) & D/4 (3.175 cm)	D/2 (6.35 cm) & D/3 (4.23 cm) & D/4 (3.175 cm)
0	1	1	1	1	1	1	1	1
0.2	0.643	0.718	0.7	0.727	0.667	0.674	0.656	0.675
0.3	0.548	0.604	0.6	0.636	0.533	0.579	0.521	0.516
0.4	0.4911	0.546	0.562	0.613	0.449	0.533	0.468	0.437
0.5	0.457	0.506	0.54	0.618	0.406	0.495	0.425	0.4
0.8	0.402	0.484	0.493	0.631	0.35	0.516	0.398	0.35
1	0.378	0.484	0.51	0.682	0.346	0.543	0.387	0.379


Unreinforced soil
Jute reinforced at D/2 depth
Jute reinforced at D/3 depth
Jute reinforced at D/4 depth
K/K$_{max.}$
Penetration factor
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1

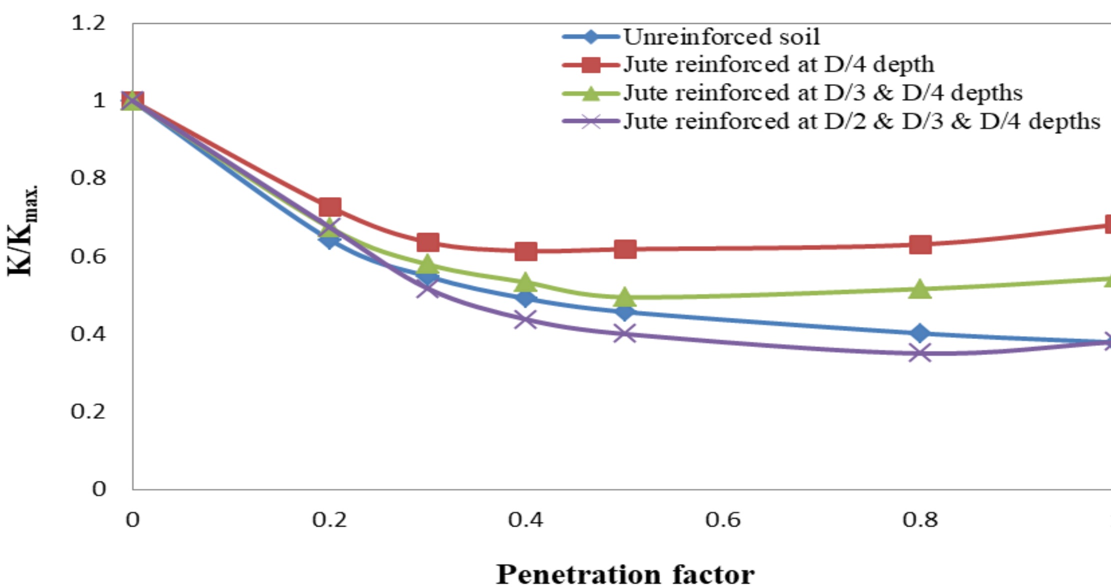
(a)


Unreinforced soil
Jute reinforced at D/2 & D/3 depths
Jute reinforced at D/3 & D/4 depths
Jute reinforced at D/2 & D/4 depths
K/K$_{max.}$
Penetration factor
1.2
1
0.8
0.6
0.4
0.2
0
0
0.2
0.4
0.6
0.8
1

(b)



(c)



(d)

Figure 5.4: Stiffness capacity versus penetration factor plot for (a) soil reinforced with single, (b) double, (c) triple and (d) optimum depths of jute fibre among all layers

CHAPTER 6

Conclusions

The main findings of this study can be summarized as follows:

1. The implementation of jute textile as a reinforcement material has shown remarkable increment in the shear strength of soil subgrade. In contrast, the inclusion of synthetic polypropylene geotextile as reinforcement resulted in reduced shear strength of the subgrade.
2. Enhanced California Bearing Ratio (CBR) values were obtained experimentally when natural jute textile was introduced as reinforcement. The combine effect of jute textile at depths D/3 (4.23 cm) and D/4 (3.175 cm) shows optimum result. The dual reinforcement improved the CBR value from 3.32% to 7.82%. In case polypropylene geotextile, when employed at the depth of D/4 (3.175 cm) from surface shows higher CBR value. The result represents an increase in CBR value from 3.32 % to 6.6 %. Nevertheless, it is essential to note that the utilization of jute textile as reinforcement exhibits a substantially higher CBR value compared to polypropylene.
3. As a result, the subgrade becomes stronger which can allow for a thinner pavement. This means that jute fibre reinforced soil can be a practical and effective ground improvement approach, especially for engineering projects involving weak soil. Jute textile shows better results as reinforcement compared to polypropylene geotextile.
4. Incorporating jute fibre in soil improves stiffness at different penetration depths, especially at D/4 (3.175 cm), enhancing pavement strength. Stiffness capacity increased from 0.378 to 0.682, a significant 80.42% improvement compared to unreinforced soil.
5. Stiffness capacity increases with the number of jute fibre layers, enhancing soil stiffness but single layered jute fibre reinforced soil exhibits the highest stiffness capacity.

Reinforced soil's stiffness capacity is significantly higher than unreinforced soil at the same penetration factor, indicating improved load carrying capacity. Jute fibre reinforcement effectively enhances soil strength, benefiting pavement strength.

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