

Ashwani Sharma

gaurav_thesis_revised (1)

 PhD Research Work

Document Details

Submission ID

trn:oid:::27535:142779639

Submission Date

Jun 12, 2026, 5:25 PM GMT+5:30

Download Date

Jun 12, 2026, 5:30 PM GMT+5:30

File Name

gaurav_thesis_revised (1).pdf

File Size

1.9 MB

49 Pages**10,376 Words****49,532 Characters**

10% Overall Similarity

The combined total of all matches, including overlapping sources, for each database.

Filtered from the Report

- Bibliography
- Quoted Text
- Cited Text
- Small Matches (less than 10 words)

Match Groups

-  **82 Not Cited or Quoted 10%**
Matches with neither in-text citation nor quotation marks
-  **0 Missing Quotations 0%**
Matches that are still very similar to source material
-  **0 Missing Citation 0%**
Matches that have quotation marks, but no in-text citation
-  **0 Cited and Quoted 0%**
Matches with in-text citation present, but no quotation marks

Top Sources

- 6%  Internet sources
- 4%  Publications
- 9%  Submitted works (Student Papers)

Match Groups

- 82 Not Cited or Quoted 10%**
Matches with neither in-text citation nor quotation marks
- 0 Missing Quotations 0%**
Matches that are still very similar to source material
- 0 Missing Citation 0%**
Matches that have quotation marks, but no in-text citation
- 0 Cited and Quoted 0%**
Matches with in-text citation present, but no quotation marks

Top Sources

- 6% Internet sources
- 4% Publications
- 9% Submitted works (Student Papers)

Top Sources

The sources with the highest number of matches within the submission. Overlapping sources will not be displayed.

- 1** Student papers
Universiti Teknologi MARA on 2017-12-21 <1%
- 2** Student papers
Middle East College of Information Technology on 2026-05-07 <1%
- 3** Internet
www.mdpi.com <1%
- 4** Internet
www.nationaltestlab.com <1%
- 5** Student papers
University of Bradford on 2026-05-12 <1%
- 6** Student papers
Waterford Institute of Technology on 2026-05-01 <1%
- 7** Publication
K. Adachi, M. Fukue. "Clay Science for Engineering", CRC Press, 2026 <1%
- 8** Student papers
Shinas College of Technology on 2019-12-02 <1%
- 9** Student papers
University College London on 2014-01-13 <1%
- 10** Student papers
University of Sheffield on 2015-05-22 <1%

11	Student papers	Walter Sisulu University - Butterworth on 2026-05-07	<1%
12	Internet	www.coursehero.com	<1%
13	Student papers	Bahrain Polytechnic on 2026-05-15	<1%
14	Student papers	Aligarh Muslim University, Aligarh on 2026-06-01	<1%
15	Student papers	Heriot-Watt University on 2026-04-03	<1%
16	Publication	A Guide to Soil Mechanics, 1979.	<1%
17	Student papers	Universiti Tenaga Nasional on 2026-05-23	<1%
18	Student papers	National Institute of Technology Jamshedpur on 2021-07-01	<1%
19	Internet	nec-license.gitbook.io	<1%
20	Internet	www.technoarete.org	<1%
21	Student papers	Bay of Plenty Polytechnic on 2025-08-14	<1%
22	Publication	Peter Reading, Miles Martin. "Geotechnical field testing", Emerald, 2025	<1%
23	Student papers	Somerset College of Arts and Technology, Somerset on 2017-02-02	<1%
24	Internet	haryanajobs.in	<1%

25	Internet	renatiqa.sunedu.gob.pe	<1%
26	Student papers	Eastern Mediterranean University on 2011-10-17	<1%
27	Student papers	Government College of Engineering Aurangabad, Maharashtra State, India on 20...	<1%
28	Student papers	Grenoble Ecole Management on 2014-10-24	<1%
29	Student papers	Jawaharlal Nehru Technological University on 2025-11-29	<1%
30	Student papers	University of Central England in Birmingham on 2024-05-10	<1%
31	Student papers	Wigan and Leigh College, Greater Manchester on 2026-06-04	<1%
32	Internet	core.ac.uk	<1%
33	Student papers	CSU, Long Beach on 2023-05-15	<1%
34	Student papers	Central Queensland University on 2022-09-07	<1%
35	Student papers	Guru Nanak Dev Engineering College on 2016-11-04	<1%
36	Student papers	Lincoln College, Lincolnshire on 2025-05-08	<1%
37	Student papers	Rowan University on 2023-02-28	<1%
38	Student papers	Thapar University, Patiala on 2019-07-21	<1%

39	Student papers	Universiti Tenaga Nasional on 2012-05-10	<1%
40	Student papers	University of Bradford on 2006-05-03	<1%
41	Student papers	University of Portsmouth on 2013-04-26	<1%
42	Student papers	Addis Ababa Science and Technology University on 2026-05-26	<1%
43	Student papers	Federal University of Technology on 2013-04-10	<1%
44	Student papers	Indian Institute of Technology, Kanpur on 2025-07-18	<1%
45	Publication	N. Khalili, A.R. Russell, A. Khoshghalb. "Unsaturated Soils: Research & Application...	<1%
46	Student papers	Universiti Malaysia Sarawak on 2015-12-18	<1%
47	Student papers	University of Baghdad on 2016-07-05	<1%
48	Student papers	University of Bath on 2014-11-24	<1%
49	Student papers	University of Bradford on 2008-10-06	<1%
50	Student papers	University of Nottingham on 2013-03-19	<1%
51	Student papers	Waikato Institute of Technology on 2017-11-17	<1%
52	Internet	article.sciencepublishinggroup.com	<1%

53	Internet	disccyshi.web.app	<1%
54	Internet	dokumen.pub	<1%
55	Publication	"Sustainable Development Through Engineering Innovations", Springer Science a...	<1%
56	Student papers	Brunel University on 2025-06-02	<1%
57	Student papers	Engineers Australia on 2021-12-13	<1%
58	Student papers	Institute of Graduate Studies, UiTM on 2011-12-20	<1%
59	Student papers	Institute of Graduate Studies, UiTM on 2012-07-03	<1%
60	Student papers	Middle East College of Information Technology on 2026-05-13	<1%
61	Student papers	University of Portsmouth on 2014-04-25	<1%
62	Student papers	University of Southern Queensland on 2016-10-08	<1%
63	Publication	Xinli Zhang, Zhenyang Li, Xia Li, Dazhi Shen. "Bamboo, basalt, glass, and polyprop...	<1%
64	Internet	aej.spbgasu.ru	<1%
65	Internet	apps.dtic.mil	<1%
66	Internet	dl.icdst.org	<1%

67	Student papers	ea on 2024-11-13	<1%
68	Internet	kubanni-backend.abu.edu.ng	<1%
69	Internet	talktorashid.blogspot.com	<1%
70	Internet	www.ijert.org	<1%

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Among all geomaterials, soil holds the greatest significance in civil engineering construction, serving as the base medium for roads, highways, pavements, embankments, retaining walls, and building foundations. The structural performance and long-term safety of any constructed facility are largely governed by the geotechnical characteristics of the underlying soil. In numerous real-world construction scenarios, the in-situ soil lacks adequate load-bearing capacity and shear resistance to support imposed structural loads without distress. Silty sand soil represents one such problematic soil type, presenting considerable challenges during construction due to its inherently poor engineering behaviour.

A gradational soil that contains a mixture of sand and silt particles is called silty sand soil. Because of having silt content, this soil has bad engineering characteristics like low cohesion, moderate to low bearing capacity, susceptible to lose strength when exposed to moisture, etc. All these properties of the soil make it unsuitable for construction purposes until it is stabilized and improved. Therefore, stabilization of silty sand soil is needed prior to any construction activity on such soil. The process of improving the physical and engineering properties of soil to make it suitable and reliable for construction activities is called soil stabilization. The primary objectives of soil stabilization are: Increase the load bearing capacity of soils, enhance shear strength, reduce deformability and settlement, control moisture sensitivity, and provide durability to the soil. Mechanical stabilization, chemical stabilization using lime, cement, fly ash, etc., and reinforcement with fibres are a few of the soil stabilizing techniques developed and adopted in geotechnical engineering over the years.

1.2 FIBER REINFORCEMENT

Among all the soil stabilization methods developed in the past years, fiber reinforcement has emerged as the most preferred, proven, economical, easy and environmentally friendly approach. In contrast to chemical stabilization, which alters the physicochemical nature of the soil through additives, fiber reinforcement achieves soil improvement through a purely mechanical mechanism — the soil mechanically by way of fiber interlocking, tensile strength, and bridging. Various fibers have been investigated for use as reinforcing

materials in soil. Reinforcing fibers are broadly classified into two groups: naturally occurring fibers such as coir, jute, and sisal, and manufactured synthetic fibers including glass, steel, and polypropylene.

Polypropylene fiber is one of the most studied and widely-used geotechnical fiber reinforcements. It is inexpensive, lightweight, durable, chemically stable and will blend easily into soils.

1.3 POLYPROPYLENE FIBER

Polypropylene fiber is a synthetic thermoplastic polymer fiber derived through the catalytic polymerization of propylene monomer. It is characterized by its light weight (specific gravity of about 0.91), considerable tensile strength ranging from 400 MPa to 600 MPa, strong resistance to chemical attack, long-term durability, and the capacity to be uniformly blended into the soil matrix. These favourable attributes collectively render it an ideal soil reinforcement material.

After introducing polypropylene fiber in silty sand soil sample and mixing, it creates a three-dimensional fiber reinforced network in the soil mass. The reinforcing network is insensitive to changes due to loading, sealing up of potential failure planes, redistribution of tensile forces in the soil matrix and toughening of interlocking between particles. All these properties contribute to the significantly **increased bearing capacity and shear strength of the** silty sand **soil** when **the** fibers are added to the sample than without them. In addition, the brittle failure characteristic of silty sand soil is changed to ductile failure characteristic.

1.4 NEED FOR STABILIZATION OF SILTY SAND SOIL

Silty sand soil is required to be stabilized because of the following:

It has low cohesion and weak bearing capacity to be used directly as pavement sub-grade.

The soil contains silt that makes the soil highly vulnerable to moisture effects.

The shear resistance of silty sand soil is not good when the load is applied.

Poor pavements and roads are usually a result of sub-grade soils.

The aim is to stabilise the silty sand soil to make it more conducive to the engineering properties of soil without the cost of soil replacement.

The fiber stabilization of silty sand soil is more economical and environment friendly than soil chemical stabilization.

1.5 CALIFORNIA BEARING RATIO TEST

The California bearing ratio (CBR) test is one of **the** most widely accepted **and** widely used laboratory tests for evaluating the bearing characteristics of soils. It quantifies the resistance of a soil layer to penetration by a standard piston, expressed as a ratio relative to

a standard reference material (crushed stone with a bearing value of 95%). The resulting CBR percentage is a direct indicator of the soil's load-supporting ability, with higher values reflecting superior bearing capacity. Silty sands being natural soils with low to moderate CBR value due to lower cohesion and high silt content, therefore, an increase in the CBR value by adding the fibers is of great significance from the pavement sub-grade construction point of view.

The CBR test can be carried out as per the guidelines provided in IS 2720 (Part 16).

$$\text{CBR} = (\text{Test Load} / \text{Standard Load}) \times 100$$

1.6 DIRECT SHEAR TEST

The Direct Shear Test is a routinely performed geotechnical test employed to determine the geotechnical shear strength characteristics, specifically include cohesion (c) and angle of internal friction (ϕ). These parameters are fundamental inputs for the geotechnical design of various structures including shallow and deep foundations, natural and cut slopes, retaining structures, and embankments in silty sand soil. The test consists of applying a vertical load to a soil sample in a shear box and then a shear force until shear failure is induced along the pre-defined horizontal split plane of the shear box apparatus. Silty sand soil has its shear strength affected by the friction between sand particles and cohesion due to the silt part. Polypropylene fibers should be added to make this soil more cohesive and have more angle of internal friction as a result of increased tensile strength. The following equation shows the soil shear strength:

$$\tau = c + \sigma \tan \phi$$

In terms of the shear strength τ , cohesion c , normal stress σ , and angle of internal friction ϕ .

1.7 OBJECTIVES OF THE STUDY

- To conduct testing of basic engineering properties of silty sand soil such as water content, specific gravity, Atterberg limits, and grain size distribution by sieving method.
- To conduct tests for determination of optimum moisture content and maximum dry density of silty sand soil having different percentages of polypropylene fibers using standard Proctor compaction method.
- To carry out the test on determining the impact of polypropylene fibers on the California bearing ratio value of silty sand soil.
- To conduct tests for finding out the effect of polypropylene fibers on the soil shear strength characteristics including cohesion and angle of internal friction using direct shear test.
- To find out the optimum amount of polypropylene fibers in terms of enhancing the California bearing ratio and soil shear strength.

1.8 STRUCTURE OF THIS DISSERTATION WORK

- Introduction
- Objectives
- Literature review
- Finding
- Research Gap
- Methodology
- Results and Discussion
- Conclusion
- Future scope of the work
- References

CHAPTER 2

LITERATURE REVIEW

2.1 PAST STUDY

Javad Norouzi et al. (2021): Norouzi et al. (2021) should be noted, that sandy soils are characterized by poor cohesion and low bearing capacity, making stabilization essential to achieve adequate structural performance. Several studies have reported an appreciable rise in CBR with the reinforcement of sandy soils with polypropylene fibers. CBR improvement was found to range between 30% and 100% with optimal fiber additions between 0.5% and 1.0% by total soil weight. Shear testing confirmed that polypropylene fiber improves both the friction angle and apparent cohesion angle of sandy soils, as well as the apparent cohesion. The identified reinforcement mechanisms were fiber bridging and mechanical interlocking between fibers and soil particles. But if there are more fibers than optimum, the strength of sandy soils would start to decrease due to unequal distribution of fibers.

Ali Reza Estabragh et al. (2014):Estabragh et al. (2014) conducted a laboratory study on the effect of adding polypropylene fiber on shear characteristics of sandy soil. Samples with different amounts of fibers were tested using direct shear and triaxial compression on both unreinforced and reinforced samples. The results showed that polypropylene fiber can efficiently improve the internal friction angle of the cohesionless sandy soil and add a pseudo cohesion to the cohesionless sandy soil. The principle of fibre bridging between failure surfaces and the interface between fibres and sand was determined as the primary strengthening mechanism. Shear strength increased progressively with fiber dosage up to an optimum level, beyond which fiber clustering reduced the reinforcing efficiency. The peak deviator stress and ductility were found to be enhanced by reinforcing with polypropylene fiber in triaxial tests. Finally, it can be concluded that polypropylene fiber is a good and economic method of reinforcement in sandy soils to enhance shear strength properties.

Consoli et al., (2007): Consoli et al., (2007) investigated the mechanical properties of short polypropylene fiber reinforced soils in different loading conditions. The primary aim was to study the impact of adding fiber on soils' strength, ductility and deformability under different stress conditions.

Short polypropylene fibres and mixed into the soil matrix at different dosage levels for laboratory testing. The incorporation of fiber into soils resulted in significantly improve the strength and deformability of soils. Soils reinforced with fibres exhibited progressive failure with significantly higher energy absorption before failure, in contrast to unreinforced specimens that failed abruptly.

These findings demonstrate that short polypropylene fiber effectively improved the strength and deformability of soil. The fiber bridging mechanism suppressed brittle failure, enabling soils to retain meaningful post-peak residual strength. The present study on effect of polypropylene fibres on CBR and shear strength has a huge relevance with this research finding.

Jyotesh Kumar Choudhary, et al., 2022: Choudhary et al. (2022) performed a research paper on the use of waste polypropylene fiber in strengthening soils. It investigated the compaction parameters, UCS test, direct shear test and CBR for the soils with different concentrations of random fibers (0%, 0.10%, 0.20%, 0.30%, 0.40% and 0.50%).

Hence, it was demonstrated that the CBR value was found to increase progressively before stabilizing beyond a threshold fibre concentration. As fiber content increased, the soil cohesion improved with fiber addition, whereas the friction angle showed a marginal reduction, eventually stabilizing at a fiber content of approximately 0.40%.

The results obtained from the research were found that the polypropylene fibre waste reinforcement was found to be very useful in enhancing the properties of soil as well as its economical bearing strength. This was also useful for achieving sustainable development due to reuse of waste material.

M. S. Sandeep et al. (2022): Experimental studies were conducted by Sandeep et al. (2022) on the effect of different proportions of polypropylene fibre used in soil stabilization. It aimed to determine the effectiveness of incorporating polypropylene fiber as a stabilizing component in civil engineering works.

Varying proportions of polypropylene fiber were uniformly incorporated into soil samples, and a series of standardized laboratory tests were performed. These consisted of the Standard Proctor Test, CBR Test and Direct Shear Test. The results showed that PP fiber addition improved compaction behaviour of the soil. The optimum moisture content was found to increase while the maximum dry density experienced a slight reduction.

The CBR value and shear strength of soil reinforced with polypropylene fibers was significantly improved. An optimal amount of fibers led to the maximum improvement in the bearing capacity and shear strength of soil.

P. V. V. Satyanarayana et al. (2021): According to Satyanarayana et al. (2021), research was done on the stabilization of red soil through the use of polypropylene fibers. The inadequate bearing capacity and poor engineering strength of red soil present major hurdles in construction works which calls for soil stabilization.

A laboratory study with red soil with different proportion of polypropylene fibers was conducted. The compaction test, CBR test and shear strength test were performed on the red soil-fiber mixture to determine the improvement it provides due to the polypropylene fiber. Based on the tests performed, it has been seen that the addition of fibre material has a significant positive impact on the bearing capacity and engineering strength of red soil. The percentage of fiber that yielded optimal benefits was determined. Based on the above-study, the following can be concluded that polypropylene fiber has stabilisation effect on red soil. The current study will use this as a reference point.

M. Arabani et al. (2020): Arabani et al. (2020) investigated experimental evaluation of influence of polypropylene fibre content, water content, relative density, and vertical stress on mechanical characteristics of poorly graded sandy soil. It was performed given that real field conditions often involve a need for the simultaneous effect of several factors on the mechanical behavior of fiber-reinforced soils.

A series of direct shear tests were performed under different moisture contents and relative densities or sand soil samples under different vertical stresses. Results consistently showed notable improvements in friction angle and shear strength with polypropylene fiber reinforcement across all tested conditions. Furthermore, higher relative density and increased normal stress were found to amplify the shear strength improvement contributed by the polypropylene fiber.

Finally, it was concluded that polypropylene fibre is an efficient additive to improve the mechanical properties of poor grade sandy soils.

A. Kumar et al. (2023): Kumar et al. (2023) studied the role of adding polypropylene fibres to the black cotton soil sample containing expansive properties to enhance the engineering properties. Due to the large high swell-shrink potential and low load-bearing capacity of expansive soils lead to distress in pavements and buildings, posing serious geotechnical challenges.

Black cotton soils with different proportion of polypropylene fibers were tested for their CBR, direct shear and swelling characteristics. The results showed that the incorporation of polypropylene fibers had improved the CBR value and shear strength of the expansive soil. In addition, the deformation properties of expansive soil reduced with the addition of polypropylene fibres, and the swelling potential was reduced.

The maximum enhancement in strength and minimum alteration in expansive soil properties were obtained with the optimum percentage of polypropylene fibers. Thus, in the present research, the use of polypropylene fibre is pertinent as it enhances the engineering properties of expansive soil.

A. K. Sharma et al. (2019): Sharma et al. (2019) studied the effect of using polypropylene fibers for soil stabilization with respect to the improvement of geotechnical behavior. These cohesive soils have features such as elevated plasticity indices, extremely low hydraulic conductivity, and inadequate bearing capacity, making stabilization a prerequisite before deployment as subgrade or foundation material.

Various fiber percentages were blended with different cohesive soils, and specimens were subjected to Standard Proctor, Soaked CBR, and Direct Shear testing. The significant increase in soaked CBR value was observed which showed that fiber-reinforced soils exhibit improved resistance to strength reduction under soaked conditions. Changes were also occurring in the compaction properties as well, depending on the amount of fiber added.

Cohesion and angle of internal friction — the primary shear strength parameters — exhibited considerable improved. The result proved polypropylene fibers to be good soil stabiliser.

Choudhary, et al. (2016): Direct Shear Tests were conducted to investigate effect of polypropylene fiber on shear strength parameters of sandy soil by Choudhary et al. (2016). For geotechnical engineering use, stability of sandy soils, which are not cohesive and subject to shear failure, needs to be increased.

Thus polypropylene fibre was incorporated with the sandy soil at different concentrations and the direct shear tests were conducted under different normal stresses. The study shows that the cohesion and angle of the internal friction of sandy soil have increased in the presence of polypropylene fiber. The addition of fiber in sandy soil resulted in the development of cohesion as well, owing to the friction between fibers and soil and mechanical interlocking.

The increase in the angle of internal friction was observed until optimal fiber contents; afterwards, the trend started to fall due to fiber agglomeration. The study proved that polypropylene fiber is very effective in improving shear strength parameters of sandy soil.

A. Singh et al (2020): Singh et al (2020) analyzed the addition of polypropylene in soil for soil stabilization and improvement of mechanical properties of soil for construction application. The use of polypropylene fibers was evaluated in this study to see if it had an effect on the compaction, bearing strength and shear strength of soils.

The percentage of polypropylene fibers was increased in soil samples and the Standard Proctor Test, CBR Test and Direct Shear Test were performed with reinforced and unreinforced soil samples. The effect of soil strengthening using fibres was observed which resulted in better compaction of soils and noticeable differences between the optimum moisture content and maximum dry density were noted. The addition of fiber has resulted in a significant improvement in CBR which indicates higher load bearing capacity.

The tensile reinforcement provided by the polypropylene fibres in the soil aggregates also raised the overall shear strength of the soil. Hence, it may be concluded that polypropylene fibres proved to be effective and economical soil-fixing agent thereby justifying their use in this investigation.

Dhiren R. Hasrajani, et al., (2015): Dhiren R. Hasrajani et al have done experimental studies to investigate the effect of adding PP fibre to the sandy soil on CBR value of sandy soil sample. Specifically, enhancement of the bearing capacity of the soils with low cohesive strength and CBR, which are not suitable to use for the construction of pavement subgrade, was intended.

The sand was mixed with various amounts of polypropylene fibers and no poly fibres specimens were prepared for CBR testing. Test results showed that CBR value is increased with the increase in fiber content of the sandy soils. But when the amount of fibre exceeds a certain limit, though the CBR value has decreased because of improper fibre distribution.

Increases in CBR value were found to be due to the shear resistance of fibers to any movement of the CBR piston during the test process. According to this research finding, polypropylene fibres are effective materials to improve shearing strength of sandy soil. The results of this study are in line with the aims of this study.

Ranjan Kumar & R. K. Jain (2018): In this study, the studies conducted by the authors, Ranjan Kumar & R. K. Jain was studied to evaluate the effects of polypropylene fibre addition on the engineering properties of sandy soil. Because the sandy soils have low cohesive force, they easily deform upon load which reproaches their use in construction projects. In order to eliminate these drawbacks, several tests were carried out at the laboratory by varying both Polypropylene content and ratio of fiber in soils and examining the influence on soil behavior. The program involved Standard Proctor Compaction Tests, California Bearing Ratio (CBR) Tests, as well as Direct Shear Tests with untreated and fiber-reinforced soil samples. With the addition of Polypropylene fibers in sandy soil, it was concluded that the engineering property of the soil improved to a great extent. The compaction qualities of soil were also associated with the incorporation of fiber and changes in optimum moisture content and maximum dry density.

It was found that the higher the CBR value the higher the load-bearing capacity of the soil sample, with addition of fibers to the soil. It was observed that the CBR value increased with addition of fibers to soil; it means soil's load-bearing capacity is increased. The results of Direct Shear Test showed significant improvement in the shear strength parameters such as the angle of internal friction and apparent cohesion. This was said to be a result of the "interlocking" and "bringing together" action that the polypropylene fibres provide in the soil matrix, resulting in an increase in shear deformation resistance for the soil. But, once there is an optimum amount of fiber, the rate of improvement became less because of the problem of getting the fibers distributed evenly. The study revealed that the polypropylene fibre reinforcement material is effective in strengthening and bearing capacity of sandy soils and at low cost price. The results confirm the use of polypropylene fibers in geotechnical applications such as pavement subgrades, embankment and foundation soils, which lend much significance to the present work related to improved stabilization of silty sand with the help of polypropylene fibers.

2.2 FINDING

- The literature survey revealed that the application of PP fiber to the soil results in an increased shear strength of the soil that is achieved as a result of increased bonding and interlocking between the soil particles.
- Journal application of these studies indicated that CBR value obtained for soils increased greatly after the addition of polypropylene fiber; thus, it confirmed that soil reinforced with polypropylene fiber has greater load bearing capacity than non-reinforced soil particularly in pavement applications.
- Addition of Polypropylene fiber leads to an increase in the cohesion (c) and the angle of internal friction (ϕ) of soil, which plays a role of making the soil more resistant to shear forces and stable, several researchers reported.
- It was pointed out that the enhancement of soil strength takes place up to an optimum number of polypropylene fibers after which soil strength begins to decrease because of poor mixing, clustering of fibers, void space formation inside soil matrix.
- According to several papers investigated, the ductility of soil could be enhanced by incorporation of polypropylene fibre thus soil can resist the higher strain before fracture.
- The values of OMC and MDD of the soil varied with the incorporation of Polypropylene fibers as obtained from the standard proctor test of soil from different literatures.
- The common bond between all the researchers is that the polypropylene fiber is the economical, light and environmentally friendly soil stabilizing material.

2.3 RESEARCH GAPS

1. All the previous investigations were conducted primarily either on sandy soil or clay soil and very limited research on the evaluation of soil stabilization behavior of polypropylene fibre by both CBR test and shear strength have been performed.
2. Different studies have taken either California Bearing Ratio (CBR) value or shear strength parameters individually, and few studies have been conducted to study the effects of both tests together.
3. In the previous studies, it is not known which is the optimum percentage of polypropylene fiber required to get the best results of Bearing Capacity and Shear Strength properties.
4. Various researchers have opted for different lengths of fibre, soil types and various testing conditions, making it difficult to compare the different researchers' observations.
5. Research is needed on the effect of polypropylene fiber on the properties of soil in compaction such as OMC and MDD.
6. Few researchers have studied the effect of polypropylene fiber on simultaneously improving the CBR value, cohesion and angle of internal friction.
7. Therefore, additional experimental research is recommended to investigate the effect of applying polypropylene fibre to obtain the CBR value and shear strength of soil.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

The approach adopted in this research involves several experiments conducted in order to determine the effects of polypropylene fiber on the CBR and shear strength characteristics of the silty sand soil. The whole process will start by following several steps which will include soil sampling, characterization of soil, addition of polypropylene fiber in different percentages, and finally testing of soil. The soil testing processes include the Proctor test, CBR test, and the direct shear test. All the tests mentioned above will be done according to Indian Standards.

3.2 METHODOLOGY FLOWCHART

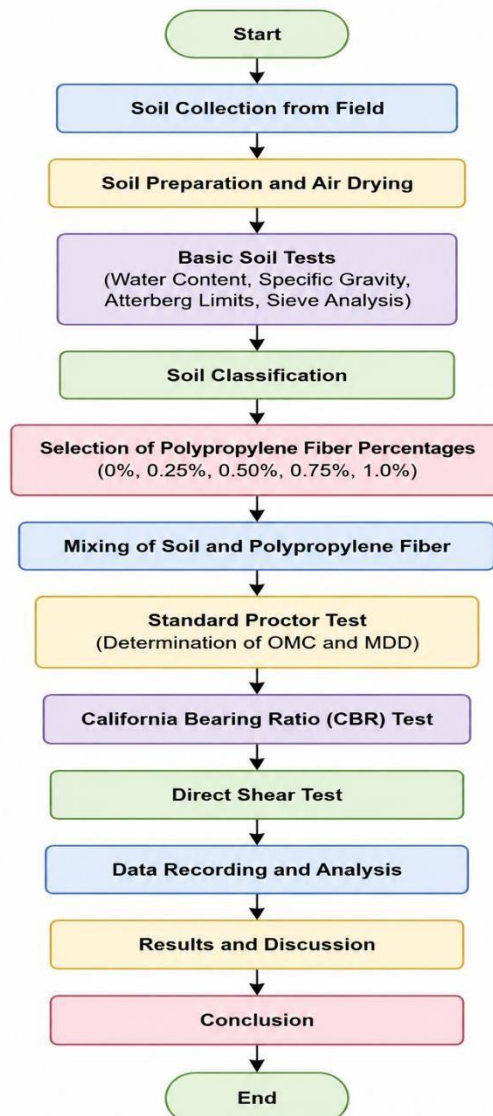


FIG.1 Methodology

3.3 SOIL SAMPLING AND PREPARATION

3.3.1 Sampling

A soil sample of 'Silty Sand' was taken in the DTU area for this study. The soil samples collected were below ground level to minimise contributions from the organic matter and surface vegetation. An adequate number of soil samples were bagged and taken to the laboratory for testing.

3.3.2 Soil Preparation

Following collection, the following activities were undertaken to prepare collected soil samples for any of the following tests:

- All soil samples were laid flat on a clean surface and allowed to air dry for 24 to 48 hours to prevent having too much moisture in the sample.
- Collected soil sample was broken with a rubber mallet to shed any lumps of soil materials.
- The air dried soil sample was then sieved using 4.75 mm IS sieve to eliminate any gravel soils and other larger material and hence getting a homogenous soil sample.
- Soils handled were kept in hermetically sealed containers before testing.

3.4 POLYPROPYLENE FIBER

3.4.1 Properties of Polypropylene Fiber

The PP fiber is available commercially and has properties below:

Property	Value
Color	White
Specific Gravity	0.91
Tensile Strength	400-600MPa
Elastic Modulus	3.5 – 4.8 GPa
Fiber Length	6mm
Melting Point	160°C – 165°C
Chemical resistance	Excellent
Water Absorption	Negligible

TABLE1- PROPERTIES OF PP FIBER

3.4.2 Selection of Fiber Percentages

Based on the thorough analysis of existing literatures and outcomes of earlier experimental investigations, the following fiber content levels have been chosen for the present experiment:

1. 0% (Soil without fibers – control)
2. 0.25%
3. 0.50%
4. 0.75%
5. 1.0%

All the above-mentioned fiber contents are expressed as percentage by weight of soil.

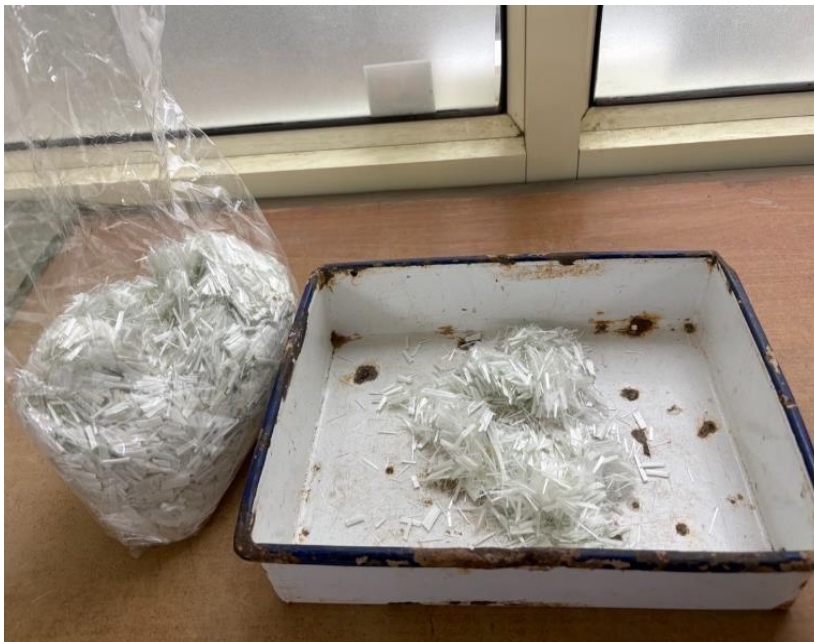


FIG2-POLYPROPYLENE FIBER

3.5 MIXING PROCEDURE

Polypropylene fibers were mixed with the silty sand soil, the method carried out the following steps to ensure uniform dispersion of the polypropylene fibers in the soil mass:

- Dry soil was weighed on the weighing balance, so that the required quantity of dry soil could be obtained.
- Calculations for the required amount of polypropylene fibre on each part per cent fibre, based on the dry weight of Soil, was made and weighed separately.

- Small amounts of the weighed amount of polypropylene fibers were distributed

uniformly throughout the dry soil sample.

- The fibers were spread out evenly throughout the soil sample being mixed and not allowed to get in clumps.
- The Optimum Moisture Content (OMC) from the Standard Proctor Test is used for the addition of water to the soil and fibre mixture for making of the test specimens for the CBR test and Direct Shear Test. After the uniform mixing of soil/fiber mixture, the required amount of water according to OMC is added and again mixed to prepare the test specimens for the CBR test and the Direct Shear Test.

3.6 BASIC SOIL TESTS

The following are the simple soil tests conducted on the collected soil sample from the area of silty sand before adding fibre reinforcement:

Determine water content by testing.

The oven drying test method was conducted for Water content test of natural collected soil as per IS 2720 (Part 2). A sample of soil, representative sample was taken in a sample container and then dried in an oven in a range of temperature 105 to 110 degree Celsius for 24 hours. After drying soil, weight of soil was measured and water content percentage was calculated by the formula,

$$w(\%) = [(W_2 - W_3) / (W_3 - W_1)] \times 100$$

Where:

W1 = Mass of empty container (g)

W2= Mass of container + wet soil (g)

W3= Mass of container + dry soil (g)



FIG3-SOIL CONTAINERS

3.6.2 Test for Specific Gravity

The specific gravity of soil was obtained using the method of 'pycnometer' in accordance with IS 2720 (Part 3). Its calculation was done using the formula:

$$G = (W_2 - W_1) / [(W_2 - W_1) - (W_3 - W_4)]$$

Where:

W_1 = Weight of empty pycnometer

W_2 is the weight of the pycnometer filled with dry soil. W_2 = weight of the pycnometer containing dry soil.

W_3 = Weight of pycnometer + soil + water

W_4 = weight of pycnometer filled with water. Weight of pycnometer containing water.



FIG4-PYCNOMETER

3.6.3 Atterberg Limits Test

Liquid Limit and Plastic Limit of the silty sand soil were found according to IS 2720 (Part 5). To find out Liquid limit (Casagrande apparatus test) and Plastic Limit (thread rolling test) were performed. Plasticity Index was computed as:

$$PI = LL - PL$$

Where:

LL = Liquid Limit

PL = Plastic Limit

PI = Plasticity Index



FIG5-CASAGRANDE APPARATUS



FIG6-LIQUID LIMIT TEST

3.6.4 Sieve Analysis

Sieve analysis of the silty sand soil was conducted according to IS 2720 (Part 4) to find out the grain size distribution and classify the soil type. The analysis was conducted using IS sieves having sizes of 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, 0.15 mm, and 0.075 mm respectively.



FIG7-SIEVE ANALYSIS WITH MECHANICAL SHAKER

3.7.2 Proctor test

The mean values of diameter and height of Proctor's mold are 100 mm and 127.3 mm, respectively.

The standard proctor hammer has a mass of 2.6kg and a dropping height of 310mm.

The sieves used are IS sieves of size 4.75 mm.

Weighting Balance

Oven

Water Content jars



FIG8-PROCTOR MOULD

3.7.3 Procedure

- An appropriate sample of air-dried silty sand soil was collected having the desired percentage of Polypropylene Fiber.
- The necessary amount of water was added to the soil-Fiber mixture, and the water was thoroughly mixed to achieve uniformity.
- Inside the mold, a small amount of oil was added as a lubricant and the mold was prepared.
- There were three equal quantities of soil-fiber mixture that were poured into the mold and each compacted by 25 hits of the standard Proctor hammer on a drop of 310 mm.
- Similar excavation was done for the other two layers and the collar removed after the compaction process, and the excess soil was trimmed parallel to the top surface of the mold.
- Weight of soil and mold were taken down and the bulk density was calculated.
- Using the method of oven drying, a small sample of soil was removed from the compacted soil sample for the calculation of the water content of the soil.

The formula used for the calculation of the dry density was:

$$\text{Dry Density } (\gamma_d) = \gamma_b / (1 + w)$$

Where:

γ_d = Dry density

γ_b = Bulk density

w = Water content

The above was carried out for at least five different water content levels. Each fiber percentage was plotted in a graph of dry density versus water content to determine the water content required for OMC and water content to be determined for the maximum dry density.

3.8 CALIFORNIA BEARING RATIO (CBR) TEST

3.8.1 Objective

The purpose of the California Bearing Ratio (CBR) test was to study the improved bearing capacity of soil by the inclusion of varying proportions of polypropylene fiber reinforced silty sand soil as per IS 2720 (Part 16). Equipment Required

CBR mould (diameter 150 mm and height 175 mm along with collar and perforated base plate)

Standard Proctor rammer

Each weight is 2.5 kg. Each weight is 2.5 kg.

Setting up the proving ring and dial gauge on the loading machine

The diameter of the penetration piston is 50 mm.

Balances and Oven



FIG9-CBR TEST



FIG10-CBR MACHINE

3.8.2 Procedure

The soil type of silty sand was placed in the CBR mould in three lifts with the prescribed quantity of polypropylene fibre per lift which was compacted by applying 56 blows of standard proctor rammer using optimum moisture content for each lift.

- The surcharge loads were added to the compacted soil sample.
- The CBR mold is mounted into the CBR machine with the help of

penetration piston with an initial load of 40 N.

- The load was increased on the piston in a constant rate of penetration of 1.25 mm/minute, and the loads were measured at penetrations of 0.5 mm, 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, 3.0 mm, 4.0 mm, 5.0 mm, 7.5 mm, 10.0 mm, and 12.5mm. The CBR value was calculated for penetration of 2.5 mm and 5.0 mm as per the following formula:

$$\text{CBR}(\%) = (\text{Load in Test} / \text{Load in Standard}) \times 100$$

Where the standard loads at penetration of 2.5 mm and 5.0 mm are 1370 kg and 2055 kg respectively.

- The maximum CBR value of the two CBR values from 2.5 mm and 5.0 mm penetration was taken as the CBR value of the specimen.
- The same test procedure was conducted on all percentages of the fibers of 0%, 0.25%, 0.50%, 0.75%, and 1.00%.

3.8.5 DIRECT SHEAR TEST

Purpose

The unreinforced and polypropylene fiber reinforced silty sand type of soil has been subjected to the Direct Shear Test to find the shear strength parameters: cohesion (c) and angle of internal friction (ϕ) with each percentage of polypropylene fiber used as per IS 2720 (Part 13).

Apparatus Used

- Direct shear box, size of 60mm×60mm, upper and lower part.
- Charging frame for proving ring and dial gauges.

Using normal load, hanger and weights.

- Displacement dial gauge
- Weighing balance

Procedure

Soils (Silty sand) were mixed with required percentage of polypropylene and then compacted of these fibres taken based on the soil strength in the shear box.

- The upper and lower parts of shear box were set up in proper alignment and soil specimen was put in the shear box.

For each specimen, a normal loading was applied using the loading hanger of 0.5 kg/cm², 1.0 kg/cm² and 1.5 kg/cm² (corresponding to normal stress).

Shear box locking screws removed and small gap created between the upper and lower parts of the shear box so that the soil specimen can shear freely across the horizontal failure plane previously prepared.

The stirrup was sheared horizontally at constant strain rate (1.25 mm/min) using the motor driven loading frame, the shear box was cut in the lower part of the shear box.

- The shear force and horizontal displacement were noted at regular intervals to failure or until the maximum shear force was attained.

The maximum shear stress was found to be the shear strength of the specimen under the applied normal stress.

- The above procedure was repeated for each of the three normal stress values, for each fiber percentage.

A graph was plotted for each fiber percentage of shear stress versus normal stress and the Mohr-Coulomb failure envelope was plotted to determine the values of cohesion (c) from the Y intercept and the angle of internal friction (ϕ) from the slope of the failure envelope.

Shear strength, determined from the Mohr-Coulomb equation is:

$$\tau = c + \sigma \tan \phi$$

Where:

τ (kPa) = Shear strength

c = Cohesion (kPa)

The normal stress loading the object is σ (kPa).

ϕ = Angle of internal friction (angle), °

CHAPTER 4

RESULTS

4.1 SPECIFIC GRAVITY

PARAMETER	SYMBOL	VALUE
Weight of pycnometer	W1	684 gm
Weight of pycnometer + dry soil	W2	1086 gm
Weight of pycnometer + soil + water	W3	1813 gm
Weight of pycnometer + water	W4	1567 gm

TABLE2-READINGS FOR SPECIFIC GRAVITY

$$G = (W_2 - W_1) / [(W_2 - W_1) - (W_3 - W_4)]$$

$$G = (1086 - 684) / [(1086 - 684) - (1813 - 1567)]$$

$$G = 402 / (402 - 246)$$

$$G = 2.576$$

The specific gravity of the soil sample calculated by the pycnometer method = 2.60

4.2 WATER CONTENT

Container	Weight of Container (g)	Weight of Container + Moist Soil (g)	Weight of Container + Dry Soil (g)
1	50	180	168
2	48	179	167
3	48	183	170

TABLE3-WATER CONTENT READINGS

FORMULA USED -

$$w (\%) = [(W_2 - W_3) / (W_3 - W_1)] \times 100$$

Calculations:

For Container 1:

$$w_1 = (180 - 168) / (168 - 50) = 12 / 118 = 0.1017 \rightarrow \mathbf{10.17 \%}$$

For Container 2:

$$w_2 = (179 - 167) / (167 - 48) = 12 / 119 = 0.1008 \rightarrow \mathbf{10.08 \%}$$

For Container 3:

$$w_3 = (183 - 170) / (170 - 48) = 13 / 122 = 0.1066 \rightarrow \mathbf{10.36 \%}$$

Average Water Content:

$$w = (10.17 + 10.08 + 10.36) / 3 = 30.61 / 3$$

$$w = \mathbf{10.20 \%}$$

Result:

The water content of the soil sample is, $w = 10.20 \%$

4.3 SIEVE ANALYSIS TEST

SIEVE SIZE	Mass retained (g)	% mass retained	Cumulative % retained	% finer
4.75mm	0	0	0	100
2.36mm	20	4	4	96
1.18mm	27.5	5.5	9.5	90.5
600 µm	55	11	20.5	79.5
300 µm	93.5	18.7	39.2	60.8
150 µm	138	27.6	66.8	33.2
75 µm	97	19.4	86.2	13.8
Pan(silt)	69	13.8	100	0

TABLE4-SIEVE ANALYSIS READINGS

A sample of soil containing 500g of soil was used for the sieve analysis method of grain size distribution in dry process with the following conclusions:

There was no material remaining on the 4.75 mm sieve as they say are in the gravel range. The soil is made up of all sand and silt. The main fraction is fine sand: the maximum mass of 138g (27.6%) was caught on the 150µm sieve. Sixty nine grams (13.8%) passed through the 75 µm-sieve, and was collected in the pan, which suggests that the soil contained a great amount of silt.

The diameter of effective sizes were obtained by interpolation of log plot on particle size distribution curve between % finer and particle diameter as follows:

$$D_{10} = 0.052 \text{ mm}, D_{30} = 0.130 \text{ mm}, D_{60} = 0.275 \text{ mm}$$

The Coefficient of Uniformity was calculated as:

$$C_u = D_{60} / D_{10} = 0.275 / 0.052 = 5.29$$

C_u is not greater than 6 as it should be in a well graded sand as per IS 1498, therefore the sand fraction fails the criterion.

The Coefficient of Curvature was determined by:

$$C_c = D_{30}^2 / (D_{60} \times D_{10}) = (0.130)^2 / (0.275 \times 0.052) = 1.21$$

The value of C_c is between 1 and 3, putting it into compliance with the curvature criterion requirement. The C_u is, however, not between 1 and 3 as is required for a well-graded sand fraction; thus the sand fraction is not well-graded.

Using the Atterberg limit tests, Liquid limit (LL) = 28%, Plastic limit (PL) = 22% and Plasticity index (PI) = 6%. Low value of PI means fines are not plastic, characteristic of silt. The fines fall below the A-line on Casagrande's plasticity chart establishing the silty behaviour of the fines. The fines content is greater than 12 per cent and the USCS classification symbol SM fits directly and the term "poorly graded" is not used by itself but is added to the SP classification only.

Based on the results of particle size distribution and Atterberg limit as per IS 1498 and USCS classification the soil is titled as:

SM — Silty Sand

Soils have poor cohesiveness, moderate permeability and are prone to liquefaction and frost action. As foundation material has a poor to fair overall rating. If this soil is employed as a soil base, it is crucial that it is compacted and properly drained to provide stability and performance.

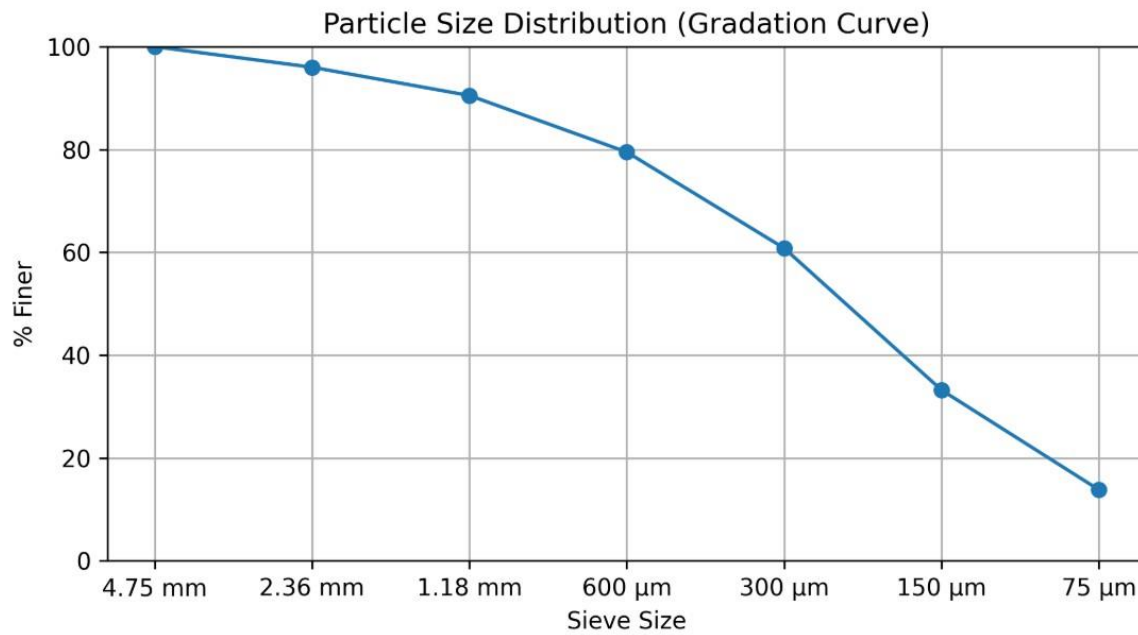


FIG11-SIEVE AVALYSIS GRAPH

4.4 ATTERBERG LIMITS

PLASTIC LIMIT TRIALS

TRIAL	Wet mass + container (g)	Dry mass + container (g)	Container mass (g)	Water content (%)
1	18.22	16.96	10.48	19.5
2	19.05	17.72	10.52	18.6
3	18.64	17.34	10.50	19.0

TABLE5-READINGS FOR PLASTIC LIMIT

LIQUID LIMIT TRIALS

TRIAL	No. of blows (N)	Wet mass + container (g)	Dry mass + container (g)	Container mass (g)	Water content (%)
1	32	26.84	23.18	10.52	28.8
2	26	29.42	25.30	10.48	27.9
3	18	28.10	24.12	10.55	29.3

TABLE6-READINGS FOR LIQUID LIMIT

Plasticity characteristics of the fines fraction were also evaluated by Atterberg limits test of the soil sample.

Water Content Calculations

The water content in each trial was determined as follows:

$$w (\%) = \frac{(\text{Wet mass} - \text{Dry mass})}{(\text{Dry mass} - \text{Container mass})} \times 100$$

Plastic Limit Trial 1:

$$w = \frac{(18.22 - 16.96)}{(16.96 - 10.48)} \times 100 = 1.26 / 6.48 \times 100 = 19.5\%$$

Plastic Limit Trial 2:

$$w = \frac{(19.05 - 17.72)}{(17.72 - 10.52)} \times 100 = 1.33 / 7.20 \times 100 = 18.6\%$$

Plastic Limit Trial 3:

$$w = \frac{(18.64 - 17.34)}{(17.34 - 10.50)} \times 100 = 1.30 / 6.84 \times 100 = 19.0\%$$

$$\text{Plastic Limit (PL)} = (19.5 + 18.6 + 19.0) / 3 = 57.1 / 3 = 19.03 \approx 19\%$$

Liquid Limit Trial 1:

$$w = \frac{(26.84 - 23.18)}{(23.18 - 10.52)} \times 100 = 3.66 / 12.66 \times 100 = 28.8\%$$

Liquid Limit Trial 2:

$$w = \frac{(29.42 - 25.30)}{(25.30 - 10.48)} \times 100 = 4.12 / 14.82 \times 100 = 27.9\%$$

Liquid Limit Trial 3:

$$w = \frac{(28.10 - 24.12)}{(24.12 - 10.55)} \times 100 = 3.98 / 13.57 \times 100 = 29.3\%$$

A graph (flow curve) was created illustrating how water content changed with the number of blows (on a log scale). The liquid limit was plotted on the flow curve as the water content for which a reading was taken at 25 blows:

$$\text{Liquid Limit (LL)} = 28\%$$

Plasticity Index

The plasticity index was worked out as:

$$\text{PI} = \text{LL} - \text{PL} = 28 - 19 = 9\%$$

PARAMETER	VALUE
D ₁₀	0.052mm
D ₃₀	0.130mm
D ₆₀	0.275mm
$C_u = D_{60}/D_{10}$	5.29
$C_c = D_{30}^2/(D_{60} \times D_{10})$	1.18
LL	28%
PL	19%

PI	9%
----	----

TABLE7-SOIL PARAMETERS

The values of PI range between 0 and 10 (low plasticity). Taking the soil plots down on Casagrande's plasticity chart, they are plotted below the A-line contour, showing that the fines are of silty content and not clays. This is in complete agreement with the fraction passing results for the 75 µm sieve obtained from the sieve analysis test, which in this case contains 13.8% of the sample passing.

The soil is finally classified as: As per the results of Atterberg limit and in conjunction with the results of the Sieve analysis, the soil is confirmed to be:

SM — Silty Sand

The soil has low cohesive strength, moderate infiltration and liquefaction and frosting susceptibility. If it is to be used as a foundation or subgrade material, it is necessary to ensure the proper compaction and drainage of this soil.

4.5 STANDARD PROCTOR TEST

To find the Optimum Moisture Content (OMC) from Proctor test data, use

this: $w (\%) = [(Mass\ of\ wet\ soil - Mass\ of\ dry\ soil) / Mass\ of\ dry\ soil] \times 100.$

Also, for γ_d , divide γ_b by $(1 + w/100)$, where γ_b equals $(W_2 - W_1) / V..$

Volume of mould=915.18cm³

Mass of mould=3790g

W (%)	0% PP	0.25% PP	0.50% PP	0.75% PP	1.00% PP
8.0	1.695	1.688	1.680	1.671	1.663
9.0	1.722	1.714	1.706	1.698	1.690
11.0	1.913	1.904	1.893	1.884	1.874
12.0	1.873	1.863	1.854	1.844	1.850
14.0	1.796	1.787	1.777	1.767	1.758

Table8-Standard Proctor test readings

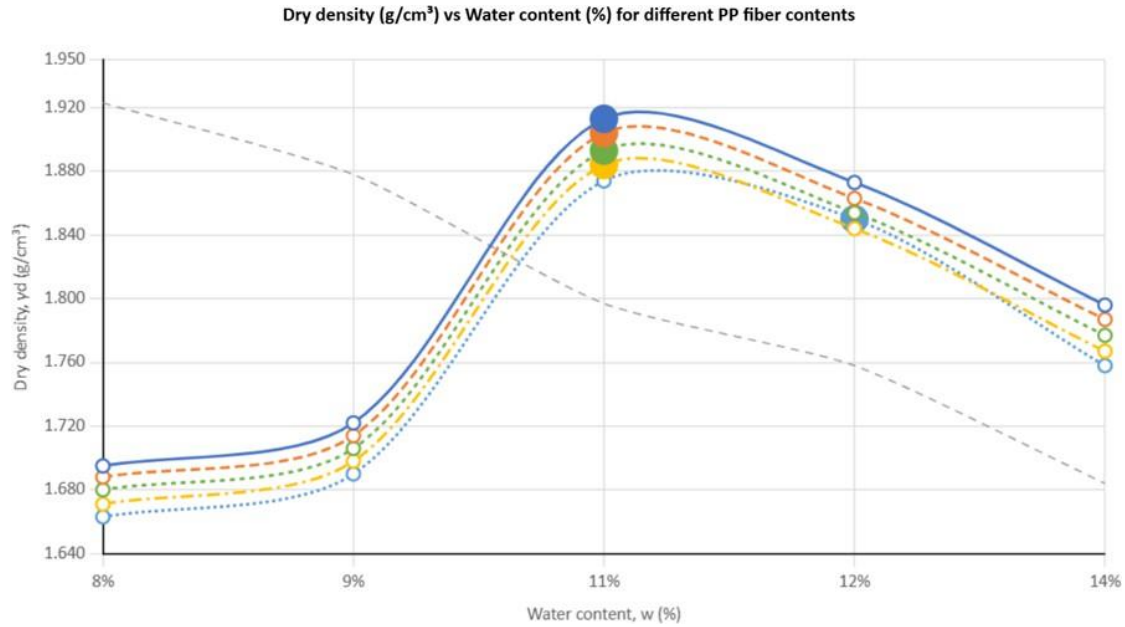


FIG12-DRY DENSITY VS WATER CONTENT GRAPH

OMC (%) and PP

PP (%)	OMC (%)
0	11.50
0.25	11.68
0.50	11.82
0.75	11.97
1.00	12.42

TABLE9-OMC% VS PP%

Optimum Moisture Content (OMC) vs PP Fiber Content

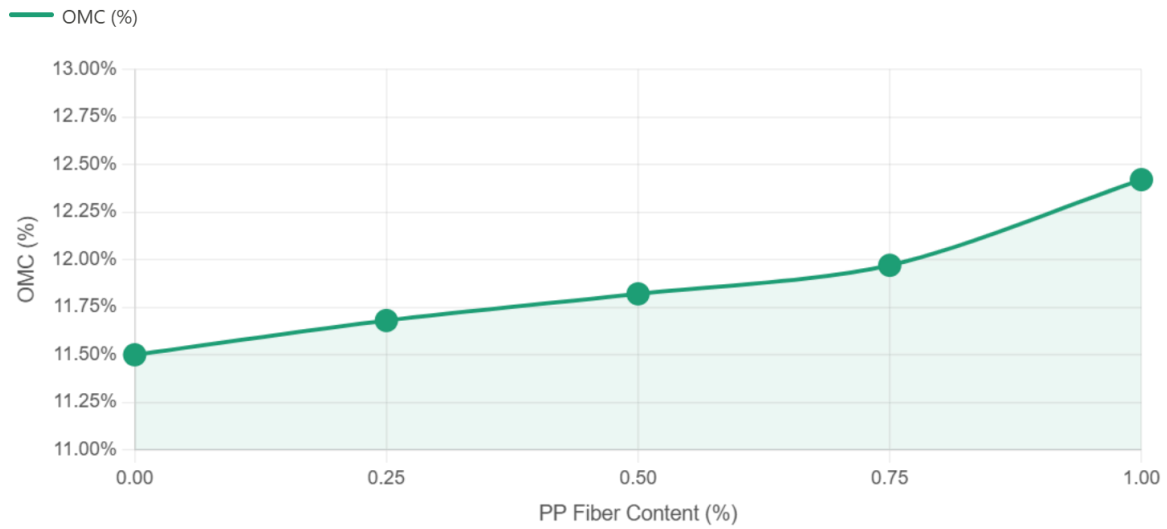


FIG13-OMC VS PP% GRAPH

MDD (g/cm³) and PP

PP (%)	MDD (g/cm ³)
0	1.902
0.25	1.888
0.50	1.876
0.75	1.864
1.00	1.845

TABLE10-MDD VS PP%

Maximum Dry Density (MDD) vs PP Fiber Content

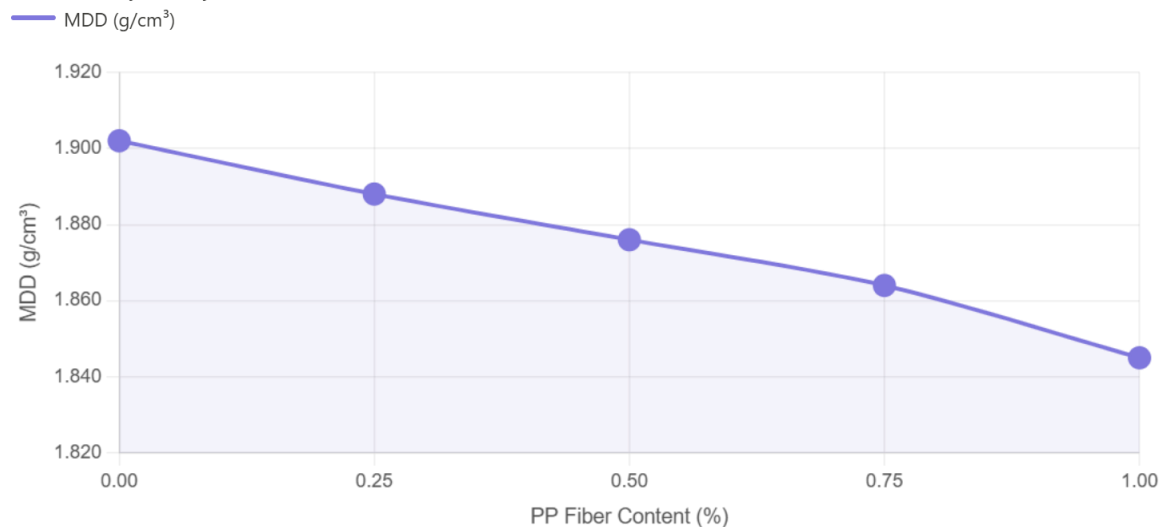


FIG14-MDD VS PP% GRAPH

Results

The five compaction curves have the typical "bell" shape; as moisture content increases, dry density is going up, up till a maximum amount (OMC), then it is going down as excess water is causing the displacement of particles.

As PP fiber content increases from 0% to 1.00%, MDD decreases steadily from 1.902 → 1.845 g/cm³, a reduction of about 3.0%.

As a result of various trials, OMC increases from in the presence of 11.50% to 12.42%, and thus fibers require a higher moisture content of optimum compaction.

The 4th observation is that with increasing fibre content the dry density always decreases — for instance, for the same water content of $w = 11.0\%$ the dry density drops from $\gamma_d = 1.913$ (0% PP) with lower to $\gamma_d = 1.874$ (1.00% PP) with higher content of PP.

The dry density of all the mixes was obtained at peak values around $w = 11.0\%$, which is close to the computed OMC values showing that the test data is reliable.

Conclusion points:

The following should apply: if PP fiber is added to the mix, there will be a reduction in the

of approximately 0.91 which is less than the specific gravity of the soil solids.

The presence of increasing OMC with fibres suggests fibers have a water absorbing property, meaning that they need the additional moisture in order to lubricate soil particles to be compacted.

As per your previous data, even though density of the mixes is low, fiber reinforced mixes have a remarkable improvement in shear strength and CBR in spite of it proves that there is a slight sacrifice in density is well compensated by the strength its mixtures have achieved.

Satisfactory results were obtained from the sample with content of 0.75% PP fiber with an MDD of 1.864g/cm³, this content may be regarded as optimal because this sample resulted the maximum CBR (11.68%) and only less than the peak friction angle (33.6°) compared with the unreinforced sample.

A consistent trend is observed for all water contents, indicating that the inclusion of PP fiber does not interfere with the compaction behavior of silty sand and the trends that are observed are well defined and predictable.

4.6 CALIFORNIA BEARING RATIO TEST

RESULT

Silty sands with and without PP fiber were prepared with the optimum moisture content (OMC) and minimum dry density (MDD) and tested for the CBR test per IS 2720 (Part 16). The plunger area of the plunger which was used was 19.635 cm². Penetration loads of 1370 kg to 2.5 mm penetration and 2055 kg to 5.0 mm penetration were used. For all fiber contents, the CBR for 2.5 mm penetration was taken as the design CBR and was higher than that at 5.0 mm penetration in all cases.

TABLE11-CBR READINGS

Penetration (mm)	0.00% PP	0.25% PP	0.50% PP	0.75% PP	1.00% PP
0.0	0.0	0.0	0.0	0.0	0.0
0.5	8.4	11.2	13.4	18.2	15.8
1.0	18.2	24.8	30.2	40.6	35.4
1.5	34.6	46.4	56.8	76.4	66.2
2.0	58.4	78.6	94.6	126.8	110.4
2.5	78.0	105.0	120.0	160.0	140.0
3.0	88.6	116.4	132.8	170.4	151.2
4.0	102.4	130.2	146.4	182.2	163.6
5.0	112.0	138.0	152.0	186.0	168.0
7.5	128.6	152.4	166.8	196.4	180.2
10.0	138.4	160.8	174.6	202.8	187.4
12.5	144.2	166.2	180.4	207.6	192.8

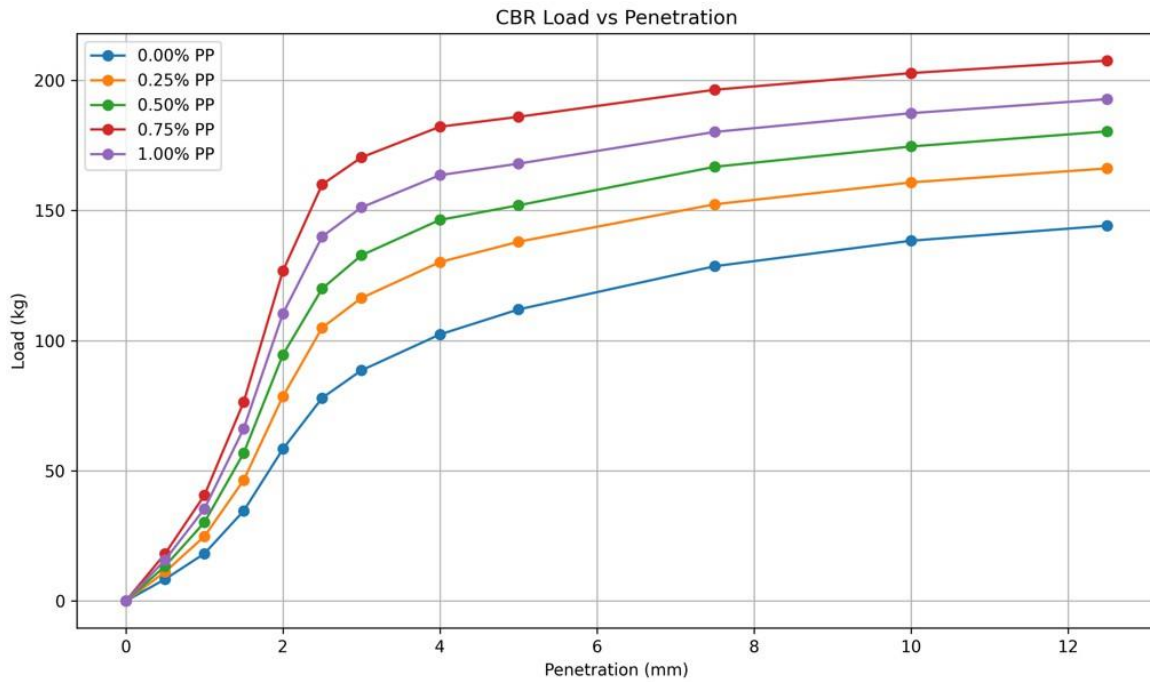


FIG15-LOAD VS PENETRATION GRAPH

CBR Calculations-

The CBR value was computed for each penetration depth with the following:

$$\text{CBR (\%)} = (\text{Test load} / \text{Standard load}) \times 100$$

At a penetration of 2.5 mm the standard load = 1370 kg corresponds to:

PP Fiber (%)	CBR @ 2.5 mm (%)	CBR @ 5.0 mm (%)	Design CBR (%)
0.00	5.69	5.45	5.69
0.25	7.66	6.71	7.66
0.50	8.76	7.39	8.76
0.75	11.68	9.05	11.68 (Maximum)
1.00	10.22	8.17	10.22

TABLE12-PP FIBER VS CBR %

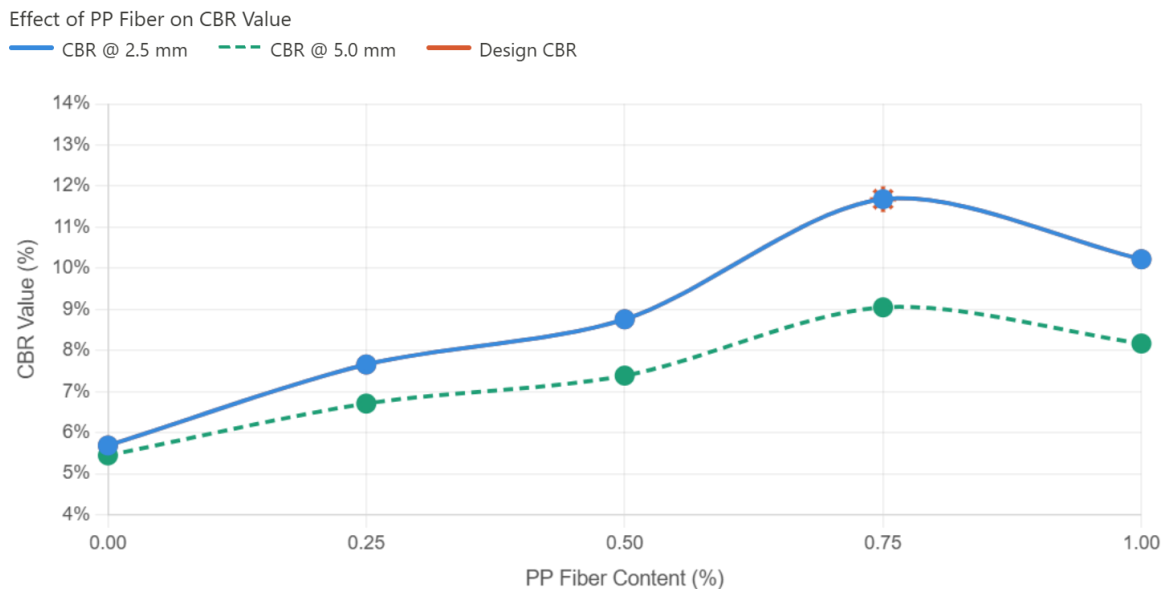


FIG16-CBR % VS PP %

CBR is higher at 2.5 mm as compared to 5.0 mm for all contents of fibers, thus 2.5 mm governs throughout.

Conclusion-

The following conclusions are drawn by conducting the CBR test for the various proportions of the PP fiber content in silty sand:

Unreinforced Soil (0% PP fiber):

The unreinforced silty sand had a design CBR of:

$$\text{CBR} = (78.0 / 1370) \times 100 = 5.69\%$$

The value is in accordance with SM — Silty Sand classification (IS 1498) where such soils are classified as having ‘poor to fair’ subgrade strength. The CBR value of 5.69% means the soil condition needs to be improved from its natural state before usage as subgrade or foundation material.

Optimum Fiber Content:

The highest CBR value of 11.68% was recorded at 0.75% of PP fiber content which is 105.3% higher when compared to the unreinforced soil. This is considered to be a great enhancement due to the fiber-matrix interlocking mechanism where the PP fibres become tensile reinforcing elements across any potential fracture planes, which consequently

makes them more resistant to penetration.

Post-Optimum Decline:

Beyond 0.75% fiber content, the CBR drops to 10.22% at 1.00% fiber. The reduction is due to the decreased uniformity of loading at higher fibre content level due to fibre bundling and fibre aggregating, resulting in areas of low bearing capacity.

The results of the CBR tests show that the optimum fibre content for this SM silty sand is 0.75% with maximum 11.68% CBR obtained. This is in agreement with the compaction test results, where the 0.75% fiber content has a maximum MDD, and with the direct shear test result, where the friction angle is at a maximum at 0.75% fiber. All the three tests have converged at 0.75% as optimum dosage of PP fiber for ground improvement of this silty sand soil thus giving strong convincing evidence for this optimum dosage level.

4.7 DIRECT SHEAR TEST

Results

Table A for 0% fiber

Displacement (mm)	Normal stress σ (kPa)	PR reading (div)	Shear force T (kg)	Shear stress τ (kPa)	Remark
0.0	50	0	0.00	0.00	—
1.2	50	12	2.96	8.08	
2.4	50	34	8.40	22.91	
3.6	50	68	16.80	27.50	
4.8	50	104	25.69	27.95	← Failure
0.0	100	0	0.00	0.00	—
1.2	100	22	5.43	14.81	
2.4	100	68	16.80	45.82	
3.6	100	138	34.09	54.66	
4.8	100	208	51.38	55.90	← Failure
0.0	150	0	0.00	0.00	—
1.2	150	34	8.40	22.91	
2.4	150	102	25.19	68.72	
3.6	150	208	51.38	80.10	
4.8	150	312	77.06	83.85	← Failure

Table B for 0.25% fiber

Displacement (mm)	Normal stress σ (kPa)	PR reading (div)	Shear force T (kg)	Shear stress τ (kPa)	Remark
0.0	50	0	0.00	0.00	—
1.2	50	14	3.46	9.43	
2.4	50	40	9.88	26.95	
3.6	50	82	20.25	30.60	
4.8	50	122	30.13	33.00	← Failure
0.0	100	0	0.00	0.00	—
1.2	100	28	6.92	18.87	
2.4	100	82	20.25	55.24	
3.6	100	166	41.00	60.40	
4.8	100	234	57.80	62.80	← Failure
0.0	150	0	0.00	0.00	—
1.2	150	42	10.37	28.28	
2.4	150	124	30.63	83.54	
3.6	150	248	61.26	88.80	
4.8	150	344	84.97	92.60	← Failure

Table C for 0.5% fiber

Displacement (mm)	Normal stress σ (kPa)	PR reading (div)	Shear force T (kg)	Shear stress τ (kPa)	Remark
0.0	50	0	0.00	0.00	—
1.2	50	18	4.45	12.13	
2.4	50	52	12.84	35.02	
3.6	50	102	25.19	37.80	
4.8	50	146	36.06	39.15	← Failure
0.0	100	0	0.00	0.00	—
1.2	100	36	8.89	24.25	
2.4	100	106	26.18	71.40	
3.6	100	198	48.91	68.00	
4.8	100	266	65.70	71.00	← Failure
0.0	150	0	0.00	0.00	—
1.2	150	54	13.34	36.38	
2.4	150	158	39.03	106.47	
3.6	150	284	70.15	98.50	
4.8	150	382	94.35	102.65	← Failure

Table D for 0.75%fiber

Displacement (mm)	Normal stress σ (kPa)	PR reading (div)	Shear force T (kg)	Shear stress τ (kPa)	Remark
0.0	50	0	0.00	0.00	—
1.2	50	20	4.94	13.47	
2.4	50	60	14.82	40.43	
3.6	50	118	29.15	43.20	
4.8	50	168	41.50	45.00	← Failure
0.0	100	0	0.00	0.00	—
1.2	100	40	9.88	26.95	
2.4	100	118	29.15	79.50	
3.6	100	220	54.34	75.00	
4.8	100	290	71.63	78.20	← Failure
0.0	150	0	0.00	0.00	—
1.2	150	60	14.82	40.43	
2.4	150	178	43.97	119.93	
3.6	150	320	79.04	106.50	
4.8	150	416	102.75	111.40	← Failure

Table E for 1% fiber

Displacement (mm)	Normal stress σ (kPa)	PR reading (div)	Shear force T (kg)	Shear stress τ (kPa)	Remark
0.0	50	0	0.00	0.00	—
1.2	50	18	4.45	12.13	
2.4	50	56	13.83	37.72	
3.6	50	112	27.66	43.40	
4.8	50	174	42.98	46.65	← Failure
0.0	100	0	0.00	0.00	—
1.2	100	36	8.89	24.25	
2.4	100	108	26.68	72.77	
3.6	100	210	51.87	73.80	
4.8	100	296	73.11	79.10	← Failure
0.0	150	0	0.00	0.00	—
1.2	150	54	13.34	36.38	
2.4	150	160	39.52	107.81	
3.6	150	300	74.10	103.40	
4.8	150	418	103.25	111.55	← Failure

PP Fiber (%)	Friction Angle ϕ (°)	Apparent Cohesion C^* (kPa)
0.00	29.3	0.0
0.25	30.8	3.2
0.50	32.4	7.4
0.75	33.6	11.8
1.00	32.9	14.2

TABLE17-FRICTION ANGLE AND COHESION DATA

Effect of PP Fiber on Friction Angle & Apparent Cohesion

— Friction Angle ϕ (°) — Apparent Cohesion C^* (kPa)

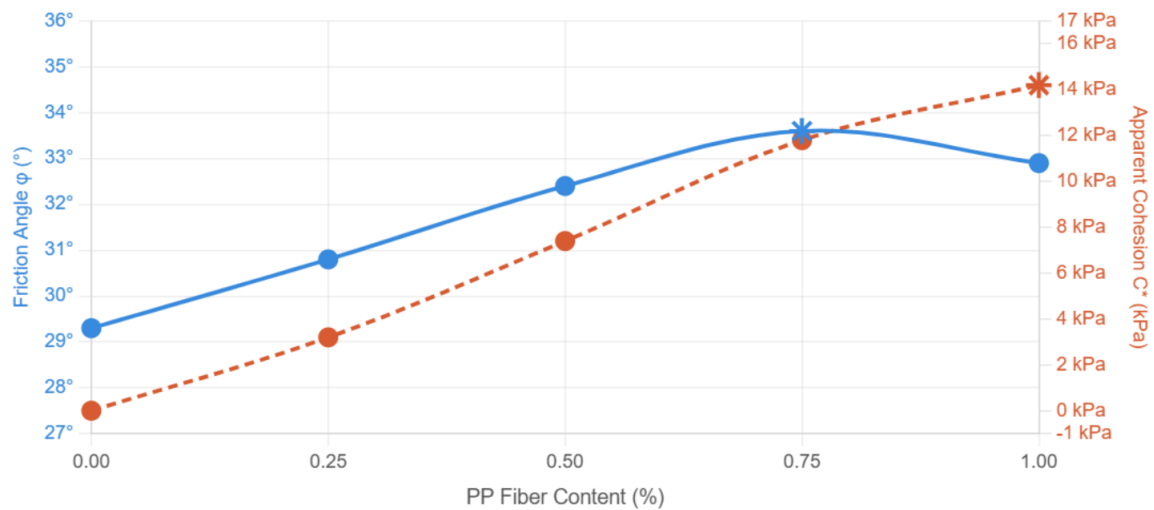


FIG17-FRICTION ANGLE AND COHESION VS PP%

PP Fiber (%)	τ at $\sigma=50$ kPa	τ at $\sigma=100$ kPa	τ at $\sigma=150$ kPa
0.00	27.95	55.90	83.85
0.25	33.00	62.80	92.60
0.50	39.15	71.00	102.65
0.75	45.00	78.20	111.40
1.00	46.65	79.10	111.55

TABLE -18 SHEAR STRESS VS NORMAL STRESS

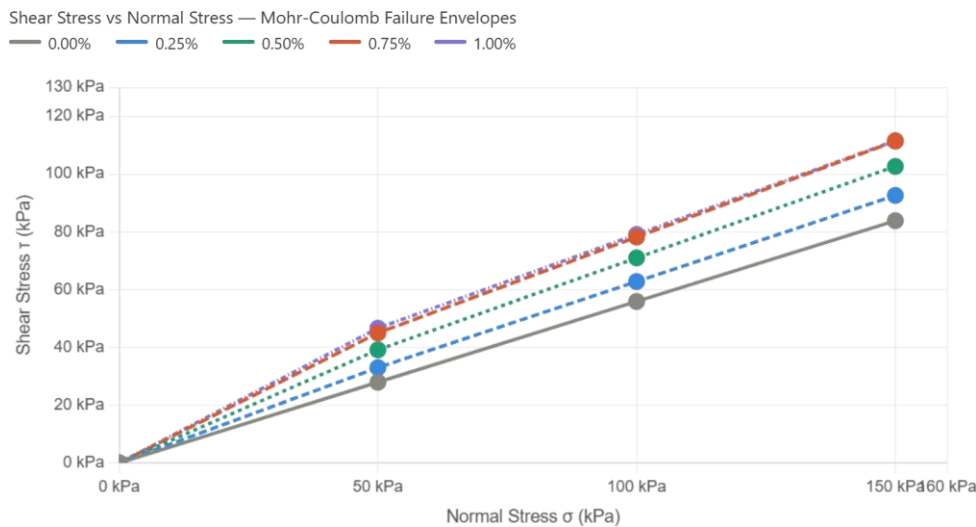


FIG18-SHEAR STRESS VS NORMAL STRESS

Results

The friction angle for unreinforced silty sand (with 0% fiber content) was 29.3° and there was no cohesion, typical of a cohesionless sandy soil.

In general, an increase in the PP fiber content causes the shear stress at failure to increase with all three levels of normal stress, indicating that this is true at all three. For example, at $\sigma = 100$ kPa, shear stress rose from 55.90 kPa (0% fiber) to 79.10 kPa (1.00% fiber) — an improvement of about 41%.

The friction angle observed were increased with the addition of fibres and it peaked at 0.75% fibre content, the value of which was 33.6° and there was a slight decrease in friction at 1% fibre (1.00%).

At all rates of fiber to obtain 14.2KPa of apparent cohesion, the apparent cohesion increased with fiber content – it was at 1.00% fiber when it was best.

The friction angle was greatest with the addition of the 0.75% fiber content, with the resulting cohesion reaching a high value of 11.8kPa, implying that in some ways it was the most balanced fibre addition.

However, the improvement in the shear strength of silty sand is quite obvious with using PP fibers. This fiber now provides small reinforcements in the soil and provides soil and fiber surface interlocking and friction.

The increase in the friction angle from 29.3° to 33.6° (at 0.75%) illustrates that soil particles have greater resistance to sliding over one another in the presence of fibers.

The finding of apparent cohesion (0 to 14.2 kPa) is important — it was a cohesionless sand at first but in the enhanced one, the fibers allow it to behave more like a $c-\phi$ soil where it is far more stable for loads.

When the friction angle exceeds 0.75% it begins to decrease slightly. This is probably due to the fact that too many Fibres tend to bunch together and this limits the chain of evenly distributed fibres that is needed for reinforcement.

Overall, it is recommended that 0.75% PP fibre be used for the most shear strength benefit, as this not only offers maximum friction angle, but also maintains reasonable cohesion without the effects observed at 1.00%.

CHAPTER 5

CONCLUSION

The experimental investigation on the effect of polypropylene (PP) fiber on the engineering properties of silty sand soil led to the following conclusions:

1. Soil Characterization

The specific gravity of the test soil was 2.60 and the natural moisture content of the test soil was 10.20%, the fines fraction was 13.8%, liquid limit 28% and plasticity index 9%. The aforementioned properties demonstrated that the soil was a low cohesion and moisture sensitive soil type that needed to be stabilized before being used in construction.

2. Compaction Behavior

With increasing PP fiber content, MDD decreased from 1.902 g/cm³ (0%) to 1.845 g/cm³ (1.00%) and OMC increased from 11.50% to 12.42%. This is due to the low specific gravity (0.91) and water absorbing capability of PP fibers. The compaction behavior in all the fiber doses was well-defined and predictable which showed that fibers did not alter the compaction behavior of the soil.

3: The California Bearing Ratio (CBR)

The improvement by the use of PP fiber reinforcement for the load-bearing capacity of a silty sand was significant. The design CBR improved in values from 5.69% (unreinforced) to a maximum of 11.68% at 0.75% addition of fiber, which was an improvement of more than 105%. If the CBR exceeds 0.75%, fiber agglomeration and uneven distribution is observed, as a result of which, the CBR at the 1% content of fibre was reduced to 10.22%.

The CBR at 2.5 mm penetration controlled 5.0 mm penetration for all the fiber contents with similar behaviour observed in IS 2720 (Part 16) for sandy soils.

4. Direct Shear Strength

The friction angle increased from 29.3° (0% fiber) to a peak of 33.6° at 0.75% fiber, after which it slightly declined to 32.9° at 1.00%. Even more importantly, the cohesion of the

unreinforced soil was increased from 0 kPa to 14.2 kPa at 1.00% fiber, and turned the cohesionless silty sand into a cohesionless soil with some cohesion and friction components. Shear stress at $\sigma = 100$ kPa improved by approximately 41%, from 55.90 kPa to 79.10 kPa at 1.00% fiber. This improvement is said to be due to interlocking between fibres and the soil, and to tensile bonding between fibres and soil particles, as well as to enhanced soil-fibre surface friction.

5. Optimum Fiber Content

The optimum dose of PP fiber is consistently arrived at at the ****0.75% PP fiber**** that results from all three tests. The soil has the highest CBR (11.68%) and Peak Friction Angle (33.6%) in this content, while the soil has the reasonable cohesion (11.8 kPa) and MDD (1.864g/cm³). The slight decrease in dry density at this dosage is justifiable as will be shown from the significant improvement in strength and bearing capacity. With modest decrease in dry density, significant increases in strength and bearing capacity have been achieved, for which this small reduction is well compensated.

6. Overall Assessment

Polypropylene fiber reinforcement is an easy, cheap and green technology for silty sand soil stabilization. It does not need any chemical treatment, it can be easily homogeneously mixed and it provides a measurable and consistent optimization of various engineering parameters. The results of this trial are supportive of the proposed dosage of 0.75 percent PP fibre in the road subgrade, embankment and foundation works for silty sand.

FUTURE SCOPE OF WORK

1. In the current study, the impact of poly-propylene fiber on California Bearing Ratio (CBR) and direct shear strength properties of silty sand soil are studied. The result of the test indicated that polypropylene fiber reinforced soil greatly improved the engineering properties of the soil. But there are other areas on which more work needs to be done:
2. The strength properties of silty sand can be studied to determine the optimum length of fiber (6 mm, 12 mm or 18 mm) obtained by varying the fiber length of polypropylene fiber.
3. The fibre content >1.0% of polypropylene fibre might be explored for optimum dose of the fibre and its impact on soil characteristics.
4. Advanced laboratory tests such as the triaxial compression test, unconfined compression test and permeability test can be performed to evaluate other engineering properties of the fiber-reinforced soil.
5. Cyclic loading, wetting-drying cycles and environmental conditions can be applied to test the longterm performance and durability of polypropylene fibre reinforced silty sand.
6. Laboratory results can be validated by conducting field-scale tests or pavement model tests to determine the suitability of the results with regard to the application to road subgrades and embankments.
7. Evaluation of combining polypropylene fibers with other stabilizing material like lime, cement, fly ash or geopolymers can be done to gain improved soil improvement.
8. Numerical modelling and finite element analysis methods can be used to simulate the behavior of the fibre-reinforced silty sand, and permit the simulation results to be compared with experimental results.
9. The outcomes of the studies will be applied to developing cost-beneficial, sustainable and environment-friendly methods for soil stabilization for soil and geo-technical engineering purposes.