Threads of Stability: Harnessing Polypropylene's Grip on Red Soil

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Abstract - *This study investigates the soil stabilization of red soil using polypropylene fibers. The specific gravity, Atterberg limits, and particle size distribution of the soil were determined. The Proctor compaction test was conducted to establish the maximum dry density and optimum moisture content. Reinforced soil samples were prepared with varying fiber contents. Shear strength tests, including direct shear and unconfined compression, were performed to assess soil stability. The study was conducted using soil samples from the Garchuk area of Guwahati city. The results provide valuable insights into the behavior of red soil stabilized with polypropylene fibers, contributing to practical engineering applications. This research addresses a knowledge gap and offers guidance for sustainable and effective soil stabilization techniques.*

Key Words: Soil stabilization, Red soil, Polypropylene fibers, Shear strength, Compaction test.

1.INTRODUCTION

Red soil, characterized by its distinct reddish color and high clay content, poses significant challenges for construction and engineering projects due to its inherent instability and poor load-bearing capacity. The instability of red soil can result in uneven settlements, excessive soil erosion, and compromised structural integrity, leading to significant economic losses and safety concerns. To mitigate these challenges, various soil stabilization techniques have been employed, among which the incorporation of polypropylene fibers has emerged as a promising solution.

Polypropylene, a versatile thermoplastic polymer, exhibits exceptional mechanical properties, including high tensile strength, low density, and resistance to chemical degradation. These properties make it an attractive material for enhancing the engineering characteristics of red soil. By introducing polypropylene fibers into red soil, it is possible to improve its stability, increase its load-bearing capacity, and reduce the potential for settlement and erosion.

In a research conducted by *Yi et al. (2006)* a series of tests were performed on clayey soil specimens treated with varying percentages of polypropylene fiber (0.05%, 0.15%, 0.25% by weight of the parent soil) and lime (2%, 5%, 8% by weight of the parent soil). Unconfined compression, direct shear, and swelling and shrinkage tests were carried out to assess the engineering properties of the treated soil. The results indicated that the addition of polypropylene fiber increased the strength, toughness, and shrinkage potential of the soil. However, it led to a reduction in the swelling potential. Based on the scanning electron microscopy (SEM) analysis, it was found that the presence of fiber contributed to physical interaction between fiber and soil, highlighting the fiber's contribution to the soil's properties.

Another study conducted by *Nangia et al. (2015)* investigated the behavior of polypropylene fiber-reinforced soil samples collected from five locations along the Yamuna river bank in Delhi. Various percentages of polypropylene fiber (ranging from 0% to 2.5% of the dry weight of soil samples) were added to the soil. Unconfined compressive strength and direct shear tests were performed to evaluate the strength characteristics and stress-strain behavior of the reinforced soil samples. The study revealed that the addition of fibers enhanced the shear strength of the soil, particularly in well-graded samples. Moreover, the shear strength increased with higher percentages of fibers. Additionally, it was observed that fine soils exhibited increased optimum moisture content due to the increased surface area resulting from fiber addition.

Sandy soils, characterized by their low cohesion and poor load-bearing capacity, often require stabilization techniques to improve their engineering properties. *Attom et al. (2010)* conducted a study on sandy soil stabilization using polypropylene fibers. They examined two types of fibers, one flexible with a flat profile and the other relatively stiffer with a crimped profile, at varying aspect ratios. The results indicated that increasing the content of flexible flat profile fibers improved shear strength, angle of internal friction, and ductility of the sandy soil. Higher aspect ratios of these fibers further enhanced shear strength. The crimped profile fibers primarily increased shear strength under high normal load conditions. Moreover, increasing the percentages of both fiber types increased the angle of internal friction. These findings contribute to understanding the role of polypropylene fiber types and aspect ratios in enhancing shear strength parameters of sandy soil.

Studies consistently demonstrate that the inclusion of polypropylene fibers improves the UCS of soil. The fibers contribute to enhanced interlocking and cohesion within the soil matrix, resulting in increased strength. A study conducted by Soğancı et al. (2015) in the Konya region investigated the swelling characteristics of expansive soil and the effects of polypropylene fiber inclusion on these properties. It was determined that the soil in the area had a propensity for swelling, requiring proper granular equipment to be inserted by excavating the ground to a depth of 50-60 cm. Laboratory tests were conducted to examine the impact of polypropylene fiber on the swelling behavior of the soil. The test results revealed that the inclusion of fiber reduced the swell percentage of the expansive soil. Additionally, as the fiber content increased, the unconfined compressive strength of the soil increased. However, the optimum moisture content did not exhibit significant changes with the addition of polypropylene fiber, while the maximum dry density decreased in compaction tests. The incorporation of fiber in both unreinforced and reinforced soil led to an increase in the unconfined compressive strength of the expansive soil.

In an experimental study conducted by Malekzadeh et al. (2012) the effect of polypropylene fiber on the mechanical behavior of expansive soils was investigated. The study consisted of two phases: the first phase examined the impact of fiber inclusion on maximum dry density and optimum moisture content through dynamic compaction tests. The second phase focused on the unconfined compression, tensile strength, and swell behavior of unreinforced and reinforced soil samples. The findings showed that the addition of polypropylene fiber effectively reduced one-dimensional swell and increased unconfined compressive strength and tensile strength. A 1% fiber content yielded the highest cohesion and tensile strength values. Another review by Ayyappan,et al. (2010) highlighted the positive influence of randomly distributed polypropylene fibers on soil-fly ash mixtures. Fiber inclusion significantly improved the unconfined compressive strength, with an optimal dosage of 1% by dry weight of soil-fly ash. Longer fibers contributed more to strain energy absorption capacity, with a fiber length of 12mm producing the best results. Overall, both studies emphasized the effectiveness of polypropylene fiber reinforcement in enhancing the physical and mechanical properties of soils, particularly in mitigating the swelling behavior and increasing strength parameters.

This study aims to contribute to the advancement of soil stabilization techniques by investigating the efficacy of polypropylene fibers in improving the engineering properties of red soil. The results of this research will not only enhance our understanding of the behavior of stabilized red soil but also provide practical guidance for engineers and construction professionals seeking sustainable and effective solutions for projects involving red soil.

2. MATERIALS AND METHODS

The experimental work consisted of several steps to investigate the soil stabilization of red soil using polypropylene fibers. The first step involved determining the specific gravity of the representative soil sample collected from the Garchuk hillside area of Guwahati city using the pycnometer method. This method involved filling a pycnometer with distilled water and recording its weight. Then, a known weight of the soil sample was added to the pycnometer, and the weight was recorded again. Next, the soil's index properties, specifically the Atterberg limits, were determined. The liquid limit of the soil was measured using Casagrande's apparatus. Soil samples with moisture contents close to their liquid limit were taken and placed in the apparatus. The soil was gradually divided into two halves by a grooving tool, and the number of blows required for the soil to close the groove was recorded. This provided the moisture content representing the liquid limit of the soil.

The plastic limit of the soil was determined by rolling the soil sample on a flat glass plate until its diameter reached approximately 3 mm. The moisture content at this stage represented the plastic limit of the soil.

To assess the particle size distribution, a sieve analysis was conducted. The soil sample was dried and passed through a series of standard sieves with different mesh sizes. The retained soil mass on each sieve was measured, and the percentage of soil passing through each sieve was calculated. This data was then used to plot the particle size distribution curve.

The maximum dry density and corresponding optimum moisture content (OMC) of the soil were determined using the Proctor compaction test. Various moisture contents were selected, and soil samples were compacted in a standard Proctor mold with a specified number of blows. The dry density of each compacted sample was determined, and the moisture content associated with the maximum dry density was considered the OMC.

To prepare the reinforced soil samples, polypropylene (PP) fibers were mixed with the soil. Different fiber contents of 0%, 0.1%, 0.2%, and 0.3% were adopted for the study. For samples without fiber reinforcement, the air-dried soil was mixed with water based on the OMC of the soil. For samples with fiber reinforcement, the required amount of fibers was added incrementally to the air-dried soil and mixed thoroughly. Once a homogenous mixture was achieved, the required amount of water was added to obtain the desired moisture content.

Shear strength tests were conducted to evaluate the effectiveness of the soil stabilization. The direct shear test (DST) was performed to determine the cohesion and angle of internal friction of the soil. The soil samples prepared with different fiber contents were subjected to shearing under known normal stresses and shear displacements. The shear stress and shear displacements were recorded during the test, and the shear strength parameters were calculated.

Additionally, the unconfined compression test (UCS) was carried out to determine the unconfined compressive strength of the soil samples. Cylindrical soil samples prepared with different fiber contents were loaded axially until failure. The load and deformation data were recorded, allowing for the calculation of the unconfined compressive strength.

3. RESULTS AND DISCUSSIONS

3.1 Index Properties

3.1.1 Specific Gravity

Table 3.1: Observations for Specific Gravity

Sample Number	1	2
Weight of pycnometer (W1) in gm.	50	48
Weight of pycnometer + dry soil (W2) in gm.	100	98
Weight of pycnometer + dry soil +water (W3) in gm.	178	174
Weight of pycnometer + water (W4) in gm.	148	146
Specific Gravity	2.5	2.27
Avg. Specific Gravity	2.38	

3.1.2 Liquid Limit

Table 3.2: Observations for Liquid Limit

Sample Number	1	2	3	4
Mass of empty container	11	10	10	10
Mass of container + wet soil in gm.	20	14	15.5	13.5
Mass of container + dry soil in gm.	18.5	13	14	12.5
Mass of oven dried soil	7.5	3	4	2.5
Mass of water	1.5	1	1.5	1
Number of blows	60	35	29	21
Water content (%)	20	33.33	37.5	40

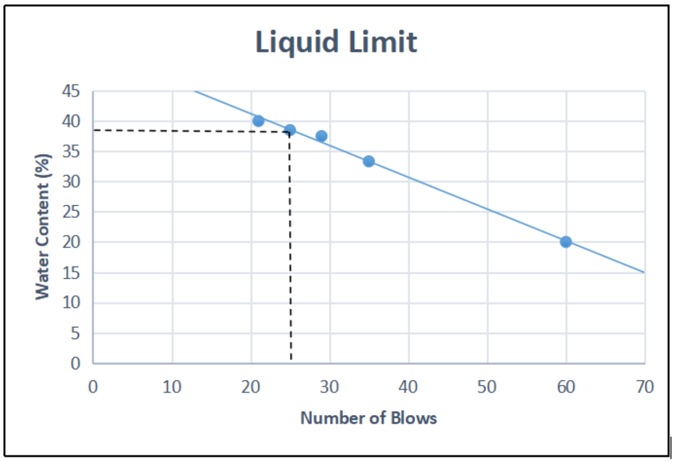


Chart 3.1: Liquid Limit Chart

Liquid limit as obtained from curve = 38.5 (Corresponding to 25 blows)

3.1.3 Plastic Limit

Table 3.3: Observations for Plastic Limit

Sample Number	1	2	3
Mass of empty container	10	10	10
Mass of (container + wet soil) in gm.	12	13	12
Mass of (container + oven dried soil) in gm.	11.5	12	11.5
Mass of oven dried soil	1.5	3	1.5
Mass of water	0.5	1	0.5
Water content (%)	33.33	33.33	33.33
Average Plastic Index	33.33		

3.2 Particle Size Distribution

Table 3.4: Observations for Particle size distribution

Sl no.	IS Sieve	Particle Size D(mm)	Mass retained (gm)	% Weight Retained	Cummulative % retained	Cummulative % finer (N)
1	4.75mm	4.75	0	0	0	100
2	2mm	2	12	2.44	2.44	97.56
3	1mm	1	44	8.97	11.514	88.486
4	600µ	0.600	166	33.87	45.384	54.616
5	425µ	0.425	82	16.73	62.114	37.886
6	300µ	0.300	56	11.42	73.534	26.466
7	150µ	0.150	96	19.59	93.124	6.876
8	75µ	0.075	26	5.3	98.424	1.576
9	Pan		8			

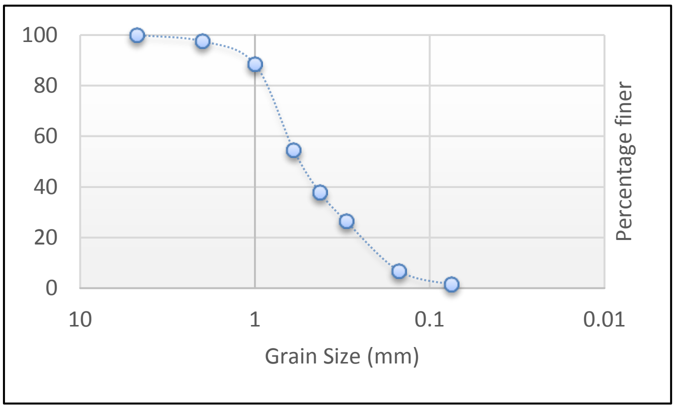


Chart 3.2: Particle size distribution curve

Uniformity Coefficient, $C_u = \frac{D_{60}}{D_{10}} = \frac{0.72}{0.08} = 9$

Curvature Coefficient, $C_c = \frac{D_{30}^2}{D_{10} \times D_{60}} = \frac{0.34^2}{0.08 \times 0.72} = 2$

3.3 Standard Proctor Test

Table 3.5: Observations for Standard Proctor Test

Test Number	I	II	III	IV	V
Weight of empty mould (Wm), gm	4812	4812	4812	4812	4812
Internal diameter of mould (d), cm	105	105	105	105	105
Height of mould (h), cm	117	117	117	117	117
Volume of mould (V)=(π/4)d2h, cc	1013	1013	1013	1013	1013
Water added (%)	7	10	13	16	20
Weight of water added (ml)	175	250	325	400	500
Weight of mould + soil, gm	6426	6633	6668	6653	6640
Weight of soil, gm	1614	1821	1856	1841	1828
Mass of container, (M1) gm	10	10	10	12	10
Mass of container+ wet soil, (M2) gm	35	22	24	25	30
Mass of container+ dry soil, (M3) gm	32.5	20.2	21	22.1	25.5
Water content W%= (M2-M3)/ (M3-M1)*100	11.62	17.5	19	24	30
Bulk density,γt, (KN/m3)	15.85	17.86	18.21	18.06	17.94
Dry density,γd =γt/1+(W/100), KN/m3	14.2	15.2	15.3	14.58	13.8

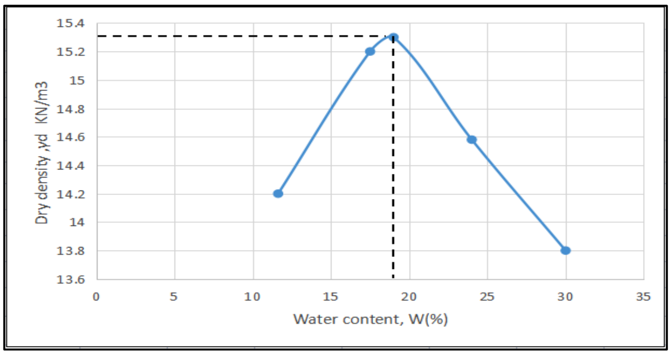


Chart 3.3: Proctor compaction test curve

From the curve it is evident that,
Optimum Moisture Content (OMC) = 19%
Maximum Dry Density (MDD) = 15.3 KN/m^3

3.4 Direct Shear Test

Table 3.6: Observations for Direct Shear Test

Volume of shear box	90 cm^3
Maximum dry density of soil	15.3 KN/m^3=1.56 gm/cc
Optimum moisture content of soil	19%
Weight of the soil to be filled in the shear box	1.56 x 90 =140.4 gm
Weight of water to be added	(19/100) x 140.4 = 26.676 gm

i) Unreinforced Soil:

Table 3.7: Observations for Unreinforced Soil

Sample no.	Normal stress (kg/cm^2)	Proving ring reading	Shear load (KN)	Shear stress (KN/m^2)
1	1	108	0.2886	80.167
2	1.5	139	0.3692	102.56
3	2	175	0.4628	128.56

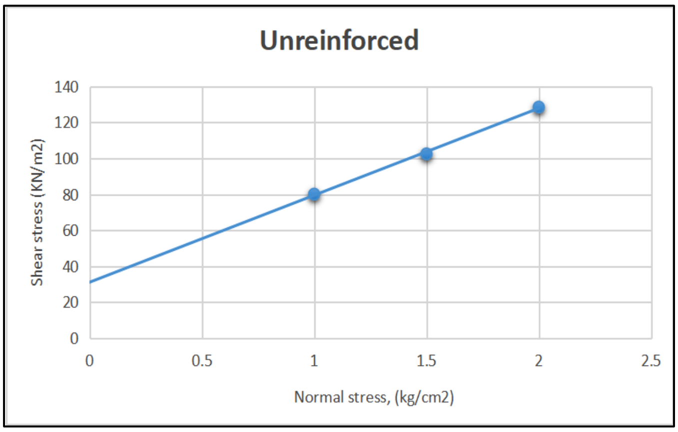


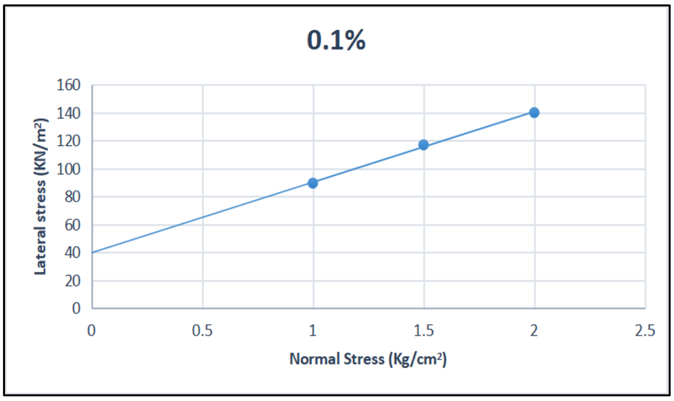
Chart 3.4: Normal stress vs Shear stress

Computation from curve:
Cohesion(C) = 0.325 kg/cm²
Angle of internal friction(Ø) = 26°33'

ii) Reinforcement = 0.1%

Table 3.8: Observations for 0.1% reinforcement

Sample no.	Normal stress (kg/cm²)	Proving ring reading	Shear load (KN)	Shear stress (KN/m²)
1	1	121	0.3224	89.56
2	1.5	159	0.4212	117
3	2	191	0.5044	140.11



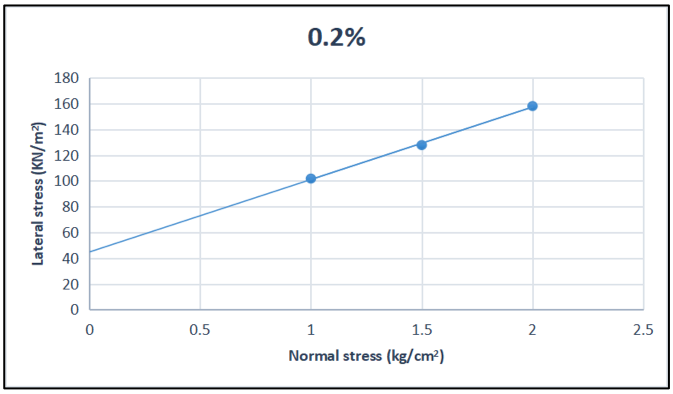
Curve 3.5: Normal stress vs Shear stress for soil with 0.1% fiber content

Computation from curve:
Cohesion (C) = 0.375 kg/cm² = 37.5 KN/m²
Angle of internal friction (Ø) = 30°57'

iii) Reinforcement = 0.2%

Table 3.9: Observations for 0.2% reinforcement

Sample no.	Normal stress (kg/cm²)	Proving ring reading	Shear load (KN)	Shear stress (KN/m²)
1	1	138	0.3666	101.83
2	1.5	174	0.4602	127.83
3	2	216	0.5694	158.167



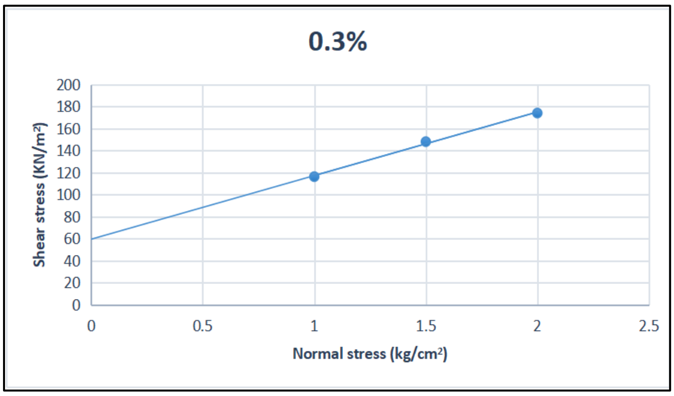
Curve 3.6: Normal stress vs Shear stress for soil with 0.2% fiber content

Computation from curve:
Cohesion (C) = 0.44 kg/m² = 44KN/m²
Angle of internal friction (Ø) = 33°1'

iv) Reinforcement = 0.3%

Table 3.10: Observations for 0.2% reinforcement

Sample no.	Normal stress (kg/cm²)	Proving ring reading	Shear load (KN)	Shear stress (KN/m²)
1	1	158	0.4186	116.27
2	1.5	202	0.533	148.056
3	2	238	0.6266	174.056



Curve 3.7: Normal stress vs Shear stress for soil with 0.3% fiber content

Computation from curve:
Cohesion (C) = 0.575 kg/m² = 57.5 KN/m²
Angle of internal friction(Ø) = 34°59'

3.5 Unconfined Compression Strength Test

i) Unreinforced

Table 3.11: Observations for unreinforced soil

Dial gauge reading	Strain (ϵ)	Proving ring reading	Corrected area $A_c = A_0/(1-\epsilon)$	Load P (KN)	Axial Stress P/A_c (MPa)
0.2	0.0023	0.4	11.36	0.005	0.0044
0.4	0.0045	0.4	11.39	0.005	0.0043
6.0	0.0682	5.8	12.169	0.072	0.0595
6.6	0.075	4.4	12.259	0.055	0.0448

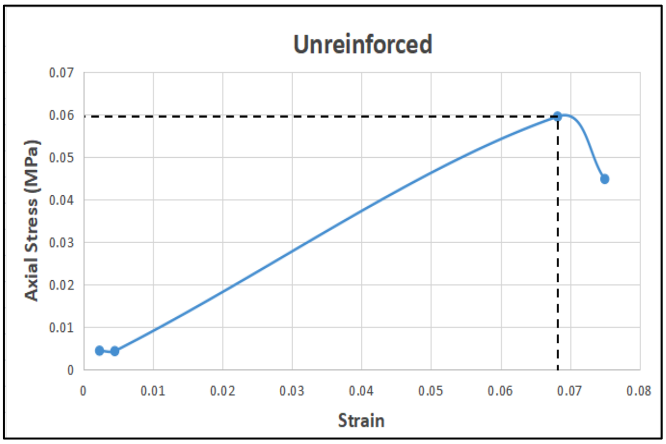


Chart 3.8: Stress vs Strain curve for Unreinforced soil

As obtained from curve:
UCS = 0.05957 MPa

ii) Reinforcement = 0.1%

Table 3.12: Observations for 0.1% reinforced soil

Dial gauge reading	Strain (ϵ)	Proving ring reading	Corrected area $A_c = A_0/(1-\epsilon)$	Load P (KN)	Axial Stress P/A_c (MPa)
0.2	0.0023	0.6	11.36	0.075	0.0066
0.4	0.0045	1	11.39	0.125	0.0109
11.4	0.1295	10	13.027	1.25	0.0959
13	0.1478	8.8	13.269	1.1	0.0828

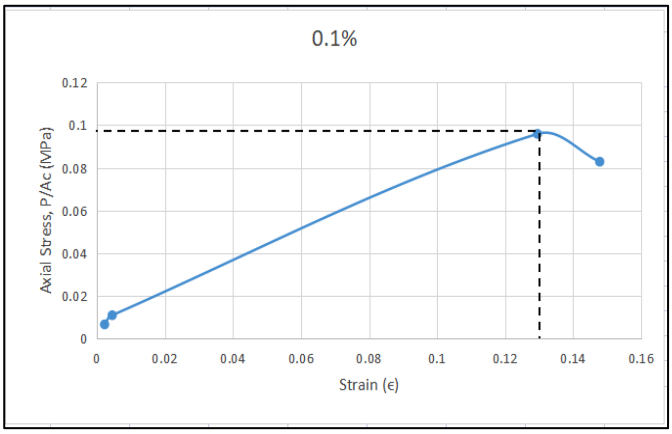


Chart 3.9: Stress vs Strain curve for soil with 0.1% fiber content

As obtained from curve:
UCS = 0.09595 MPa

iii) Reinforcement = 0.2%

Table 3.13: Observations for 0.2% reinforced soil

Dial gauge reading	Strain (ϵ)	Proving ring reading	Corrected area $Ac = A0/(1-\epsilon)$	Load P (KN)	Axial Stress P/Ac (MPa)
0.2	0.0023	0.6	11.36	0.075	0.0066
0.4	0.0045	0.8	11.39	0.010	0.0088
13.4	0.1523	12.2	13.37	1.525	0.1140
14.8	0.1659	12.2	13.59	1.525	0.1122

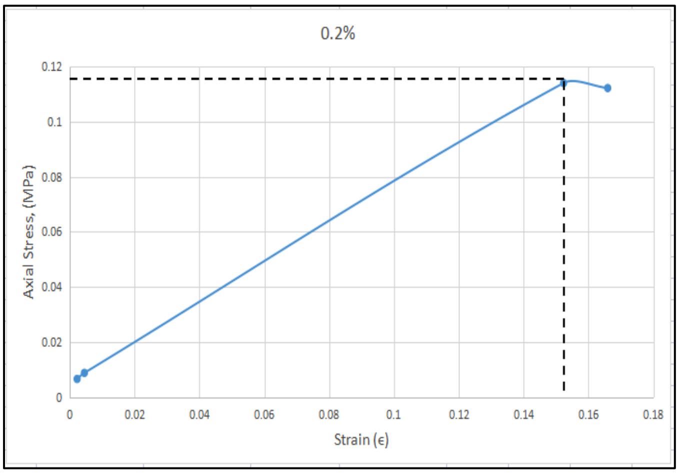


Chart 3.10: Stress vs Strain curve for soil with 0.2% fiber content

As obtained from curve:
UCS = 0.1140 MPa

iv) Reinforcement = 0.3%

Table 3.14: Observations for 0.3% reinforced soil

Dial gauge reading	Strain (ϵ)	Proving ring reading	Corrected area Ac= A0/(1-ϵ)	Load P (KN)	Axial Stress P/Ac (MPa)
0.2	0.0023	2.4	11.36	0.3	0.0264
0.4	0.0045	2.6	11.39	0.33	0.0285
11.2	0.1273	18.4	12.99	2.3	0.177
12.6	0.1432	18.4	13.24	2.3	0.1738

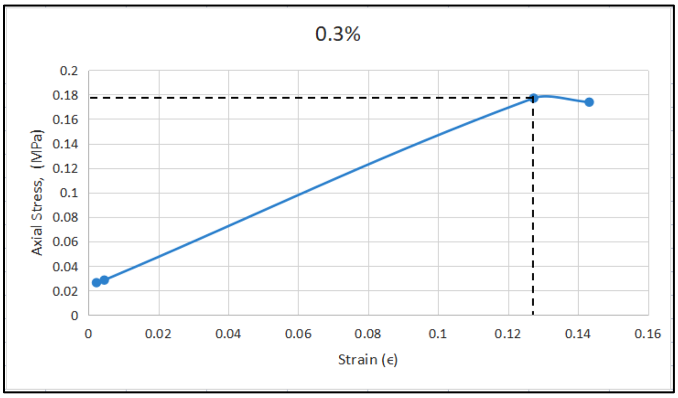


Chart 3.11: Stress vs Strain curve for soil with 0.3% fiber content

As obtained from curve:
UCS = 0.177 MPa

3.6 Discussions

The relationship between shear strength parameters and fiber content :

(a) Cohesion and fiber content

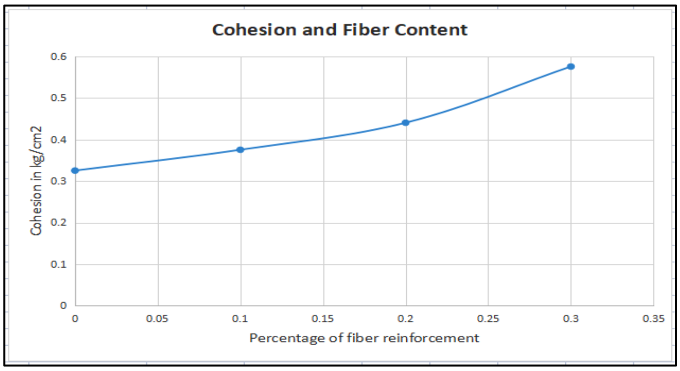


Chart 3.12: Relationship between cohesion and fiber content

(b) Angle of internal friction and fiber content

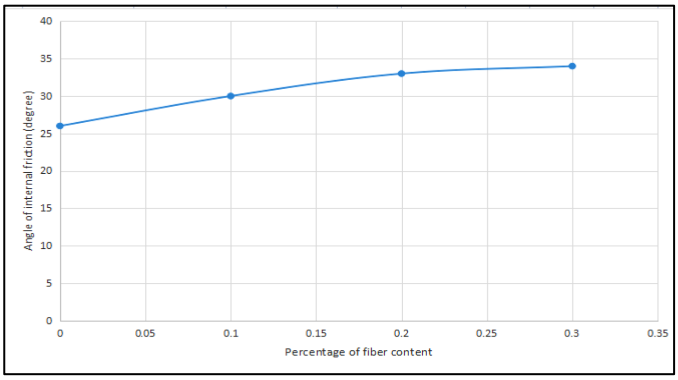


Chart 3.13: Relationship between angle of internal friction and fiber content

(c) UCS and fiber content

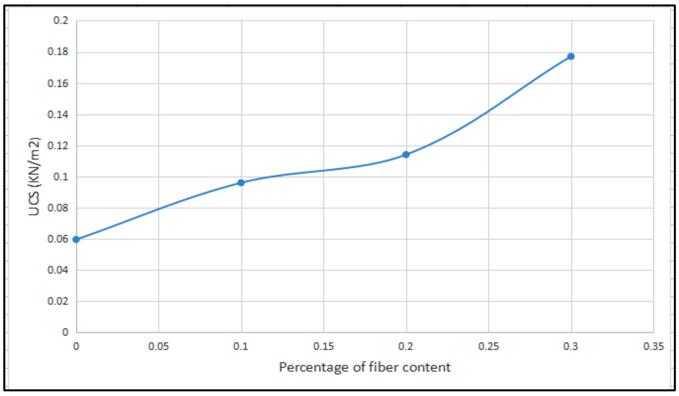


Chart 3.14: Relationship between UCS and fiber content

3.6.1 Interference from direct shear Test

- Cohesion value increases from 0.325 kg/cm^2 to 0.575 kg/cm^2 by a factor of 1.76 times.

- The angle of internal friction increases from 26°33' to 34°59' by a factor of 1.32 times.

3.6.2 Interference from Unconfined Compression Test

- UCS value increases from 0.05957 MPa to 0.177MPa by a factor of 2.97 times.

4. CONCLUSIONS

In conclusion, based on the experimental study conducted, several key findings have emerged. Firstly, the direct shear test results revealed that the inclusion of polypropylene fibers at 0.1%, 0.2%, and 0.3% concentrations led to an increase in cohesion by 1.15 times, 1.17 times, and 1.3 times, respectively. The internal angle of friction (Ø) also increased by factors of 1.16, 1.067, and 1.059 for the corresponding fiber concentrations. Notably, the values of cohesion and angle of internal friction increased significantly, suggesting the effectiveness of polypropylene fiber reinforcement for this type of soil.

Secondly, the unconfined compression strength (UCS) test demonstrated a substantial enhancement in the values of unconfined compressive strength. The results indicated a net increase by a factor of 2.97, ranging from 0.05957 MPa to 0.177 MPa. This further supports the recommendation of using polypropylene fibers for reinforcing this type of soil.

Overall, the study concludes that fiber-reinforced soil can serve as a beneficial ground improvement technique, particularly in engineering projects involving weak soils. It can serve as a viable alternative to deep or raft foundations, effectively reducing costs and energy requirements. The findings of this research contribute to the understanding of soil stabilization methods and provide practical insights for engineers and construction professionals involved in projects dealing with similar soil conditions.

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