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RESEARCH ARTICLE

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SOIL STABILIZATION USING WASTE FIBER MATERIALS

Y.SHASHIDHAR REDDY, M.S.RAHUL, N.RAJ KUMAR
Osmania University, Hyderabad, Telangana, India.

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Y.SHASHIDHAR REDDY

ABSTRACT

The main objective of this study is to investigate the use of waste fiber materials in geotechnical applications and to evaluate the effects of waste polypropylene fibers on shear strength of unsaturated soil by carrying out direct shear tests and unconfined compression tests on two different soil samples. The results obtained are compared for the two samples and inferences are drawn towards the usability and effectiveness of fiber reinforcement as a replacement for deep foundation or raft foundation, as a cost effective approach

Keyword: Plastic Fibers, Specific Gravity, Index properties, Particle Size Distribution, SPC, Direct Shear, Unconfined Compression Tests.

INTRODUCTION

For any land-based structure, the foundation is very important and has to be strong to support the entire structure. In order for the foundation to be strong, the soil around it plays a very critical role. So, to work with soils, we need to have proper knowledge about their properties and factors, which affect their behavior. The process of soil stabilization helps to achieve the required properties in a soil needed for the construction work. From the beginning of construction work, the necessity of enhancing soil properties has come to the light. Ancient civilizations of the Chinese, Romans and Incas utilized various methods to improve soil strength etc., some of these methods were so effective that their buildings and roads still exist.In India, the modern era of soil stabilization began in early 1970's, with a general Shortage of petroleum and aggregates, it became necessary for the engineers to look at means to improve soil other than replacing the poor soil at the building site. Soil stabilization was used but due to the use of obsolete methods and also due to the absence of proper technique, soil stabilization lost favor. In recent times, with the increase in the demand for infrastructure, raw materials and fuel, soil stabilization has started to take a new shape. With the availability of better research, materials and equipment, it is emerging as a popular and cost-effective method for soil improvement. Here, in this project, soil stabilization has been done with the help of randomly distributed polypropylene fibers obtained from waste materials. The improvement in the shear strength parameters has been stressed upon and comparative studies have been carried out using different methods of shear resistance measurement.

2.0 **Experimental Investigation**

2.1Scope of work

The experimental work consists of the following steps:

1. Specific gravity of soil
2. Determination of soil index properties (Atterberg Limits)
   i. Liquid limit by Casagrande's apparatus
   ii. Plastic limit
3. Particle size distribution by sieve analysis
4. Determination of the maximum dry density (MDD) and the corresponding optimum moisture content (OMC) of the soil by Proctor compaction test
5. Preparation of reinforced soil samples.
6. Determination of the shear strength by:
   i) Direct shear test (DST)
   ii) Unconfined compression test (UCS).

1.2 Materials

I. Soil sample-1

II. Reinforcement: Short PP (polypropylene) fiber.

Index and strength parameters of PP-fiber

Behavior parameters	Values
Fiber type	Single fiber
Unit weight	0.91 g/cm^3
Average diameter	0.034 mm
Average length	12 mm
Breaking tensile strength	350 MPa
Modulus of elasticity	3500 MPa
Fusion point	165 °C
Burning point	590 °C
Acid and alkali resistance	Very good
Dispersibility	Excellent

$$\text{Specific gravity } G = \frac{W_2-W_1}{W_4-W_3-W_2-W_1}$$

2.3 Preparation of samples

Following steps are carried out while mixing the fiber to the soil-

i) All the soil samples are compacted at their respective Maximum Dry Density (MDD) and optimum moisture content (OMC),corresponding to the standard proctor compaction tests

ii) Content of fiber in the soils are herein decided by the following equations

Where, ρf= ratio of fiber content $\rho_f = \frac{W_f}{W}$

Wf = weight of the fiber

W = Weight of the air-dried soil

iii) The different values adopted in the present study for the percentage of fiber reinforcement are 0, 0.05, 0.15, and 0.25

iv) In the preparation of samples, if fiber is not used then, the air-dried soil was mixed with an amount of water that depends on the OMC of the soil

If fiber reinforcement was used, the adopted content of fibers was first mixed into the air-dried soil in small increments by hand, making sure that all the fibers were mixed thoroughly, so that a fairly homogenous mixture is obtained, and then the required water was added.

2.4 Brief steps involved in the experiments

2.4.1 Specific gravity of the soil

The specific gravity of soil is the ratio between the weight of the soil solids and weight of equal volume of water. It is measured by the help of a volumetric flask in a very simple experimental setup where the volume of the soil is found out and its weight is divided by the weight of equal volume of water

W_1- Weight of bottle in gms

W_2 –weight of bottle + Dry Soil in gms.

W_3-weight of bottle + Soil + Water.

W_4 - Weight of bottle + Water

Specific gravity is always measured in room temperature and reported to the nearest 0.1

2.4.2 Liquid limit

The Casagrande's tool cuts a groove of size 2mm wide at the bottom and 11 mm wide at the top and 8 mm high. The number of blows used for the two soil samples to come in contact is noted down. Graph is plotted taking number of blows on a logarithmic scale on the abscissa and water content on the ordinate. Liquid limit corresponds to 25 blows from

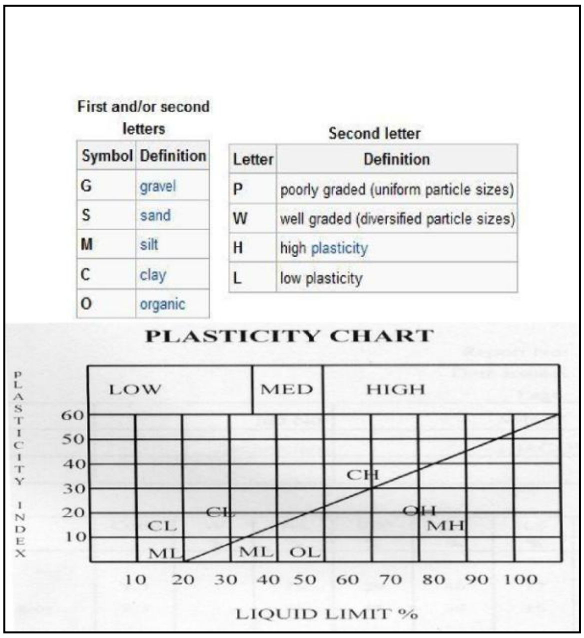
2.4.3 Plastic limit

This is determined by rolling out soil till its diameter reaches approximately 3 mm and measuring water content for the soil, which crumbles on reaching this diameter.

Plasticity index (Ip) was also calculated with the help of liquid limit and plastic limit;

$Ip = w_L - w_P$

W_L-Liquid limit W_P- Plastic limit



First and/or second letters

Symbol	Definition
G	gravel
S	sand
M	silt
C	clay
O	organic

Second letter

Letter	Definition
P	poorly graded (uniform particle sizes)
W	well graded (diversified particle sizes)
H	high plasticity
L	low plasticity

2.4.4 Particle size distribution

The results from sieve analysis of the soil when plotted on a semi-log graph with particle diameter or the sieve size as the abscissa with logarithmic axis and the percentage passing as the ordinate gives a clear idea about the particle size distribution. From the help of this curve, D10 and D60 are determined. This D10 is the diameter of the soil below which 10% of the soil particles lie. The ratio of, D10 and D60 gives the uniformity coefficient (Cu), which in turn is a measure of the particle size, range.

2.4.5 Proctor compaction test

This experiment gives a clear relationship between the dry density of the soil and the moisture content of the soil. The experimental setup consists of (i) cylindrical metal mold (internal diameter- 10.15 cm and internal height-11.7 cm), (ii) detachable base plate, (iii) collar (5 cm effective height), (iv) rammer (2.5 kg). Compaction process helps in increasing the bulk density by driving out the air from the voids. The theory used in the experiment is that for any compactive effort, the dry density depends upon the moisture content in the soil. The maximum dry density (MDD) is achieved when the soil is compacted at relatively high moisture content and almost all the air is driven out, this moisture content is called optimum moisture content (OMC). After plotting the data from the experiment with water content as the abscissa and dry density as the ordinate, we can obtain the OMC and MDD. The equations used in this

Experiment is as follows

Wet density = $\frac{\text{weight of wet soil in mold Gms volume of mold}}{\text{cc}}$

Moisture content % = $\frac{\text{Weight of water Gms}}{\text{Weight of dry soil}} \times 100$

Dry density γd (gm./cc) = $\frac{1+\text{moisture content}}{100}$

2.4.6 Direct shear test

This test is used to find out the cohesion (c) and the angle of internal friction (ϕ) of the soil, these are the soil shear strength parameters. The shear strength is one of the most important soil properties and it is required whenever any structure depends on the soil shearing resistance. The test is conducted by putting the soil at OMC and MDD inside the shear box, which is made up of two independent parts. A constant normal load (ς) is applied to obtain one value of c and ϕ. Horizontal load (shearing load) is increased at a constant rate and is applied till the failure point is reached. This load when divided with the area gives the shear strength 'τ' for that particular normal load. The equation goes as follows:

$\tau = c + \sigma * \tan(\phi)$

After repeating the experiment for different normal loads (ς) we obtain a plot which is a straight line with slope equal to angle of internal friction (ϕ) and intercept equal to the cohesion (c). Direct shear test is the easiest and the quickest way to determine the shear strength parameters of a soil sample. The preparation of the sample is also very easy in this experiment

3 RESULTS AND DISCUSSION

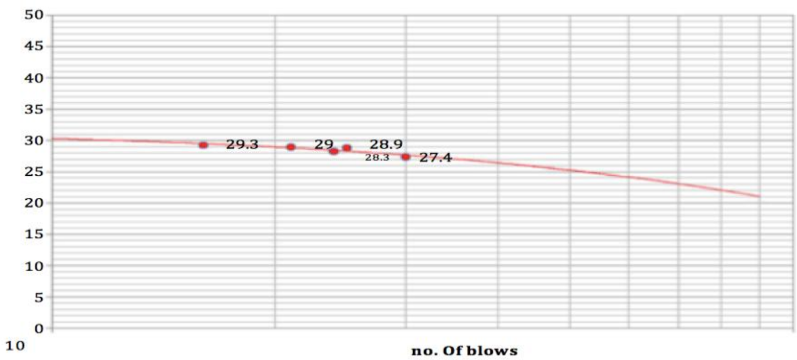
3.1 Specific Gravity

Table .3

Samplenumber	1	2	3
Mass of empty bottle (M1) in gms.	128.41	118.67	122.16
Mass of bottle+ dry soil (M2) in gms.	178.41	168.67	172.16
Mass of bottle + dry soil + water (M3) in gms.	401.86	396.29	399.03
Mass of bottle + water (M4) in gms.	369.67	365.378	367.355
Specific gravity	2.81	2.62	2.73
Avg. specific gravity	**2.72**		

3.2Index Properties

3.2.1 Liquid Limit



Sample No.	1	2	3	4	5
Mass of empty can	13.00	12.38	13.58	12.56	13.4
Mass of can + wet soil in gms.	50.70	47.60	48.00	36.60	50.00
Mass of can + dry soil in gms.	42.60	39.70	40.40	31.20	41.70
Mass of soil solids	29.60	27.32	26.82	18.64	28.30
Mass of pore water	8.10	7.90	7.60	5.40	8.30
Water content (%)	27.40	28.90	28.30	29.00	29.30
No. of blows	30	25	24	21	16

Liquid limit as obtained from graph = **28.90** (corresponding to 25 blows)

3.2.2 Plastic Limit

Sample No.	1	2	3
Mass of empty can	5.54	5.86	5.47
Mass of (can+wet soil) in gms.	9.4	10.6	9.9
Mass of (can + dry soil) in gms.	8.7	9.7	9.1
Mass of soil solids	3.1	3.8	3.6
Mass of pore water	0.7	0.9	0.8
Water content (%)	22.38	23.43	21.94
Average Plastic Index	22.58		

3.2.3 Plasticity Index

Ip = WL – WP = 28.90 – 22.58 = 6.32

According to USUC Classification of soils, ML: silt, low plasticity

3.3 Particle Size Distribution

Sieve Size	Retained (g)	Retained (%)	Cumulative Retained(%)	Cumulative Finer (%)
20	0	0	0	100
10	83.98	9.94	9.94	90.06
6.25	126.41	14.96	24.90	74.40
4.75	64.15	7.59	32.49	60.39
2	447.58	52.97	85.46	22.00
1	18.94	2.24	87.70	12.3
0.425	29.91	2.83	90.53	9.471
0.15	9.76	1.16	91.69	8.32
0.075	5.96	0.7	92.39	7.61
<0.075	64	7.57	99.96	0.04

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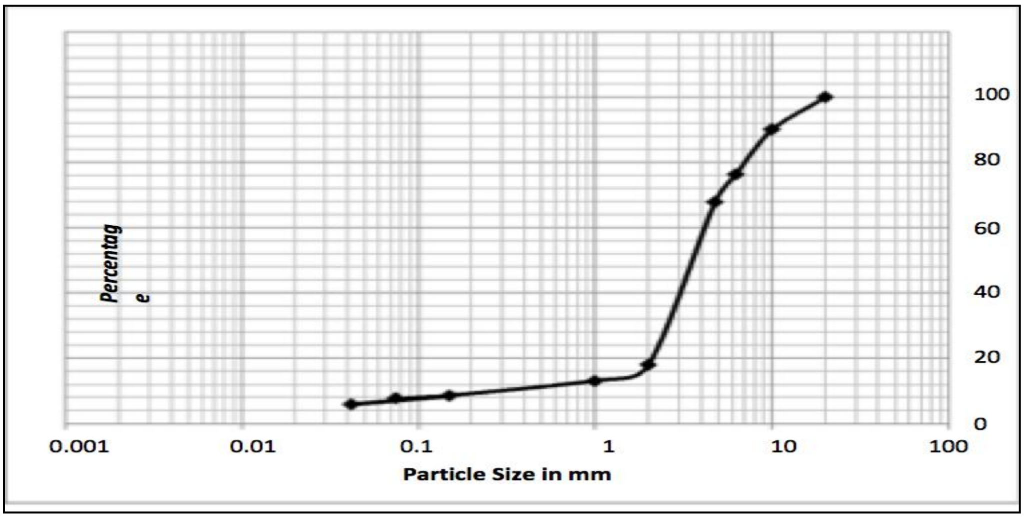
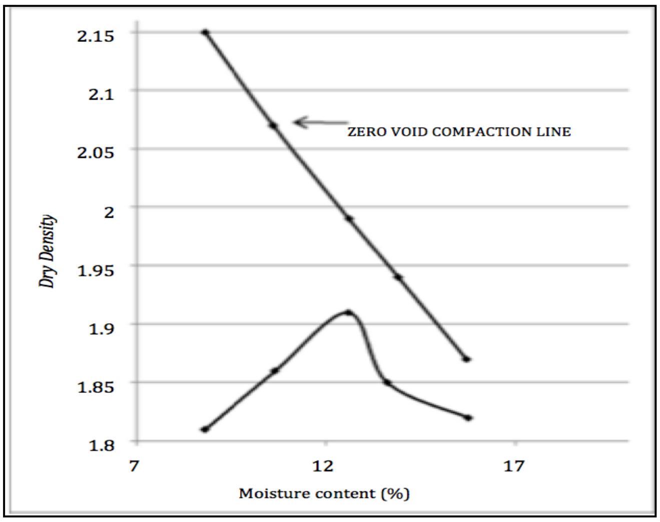


3.4 Standard Proctor Compaction Test

Test No.	1	2	3	4	5
Weight of empty mold (Wm) gms	2059	2059	2059	2059	2059
Internal diameter of mold (d) cm	10	10	10	10	10
Height of mold (h) cm	13	13	13	13	13
Volume of mold (V)=(π/4) d^2h cc	1000	1000	1000	1000	1000
Weight of Base plate (Wb) gms	2065	2065	2065	2065	2065
Weight of empty mold + base plate (W') gms	4124	4124	4124	4124	4124
Weight of mold + compacted soil + Base plate (W1) gms	6089	6179	6271	6086	6080
Weight of Compacted Soil (W1-W') gms	1965	2055	2147	2108	2102
Container no.	20.15	21.15	19.47	21.49	21.12
Weigh t of Container (X1) gms	20.19	21.14	19.48	21.55	21.14
Weight of Container + Wet Soil (X2) gms	84.81	124.16	89.93	154	113
Weight of Container + dry soil (X3) gms	79.59	114.24	82.05	138.13	100.5
Weight of dry soil (X3-X1) gms	59.4	93.1	62.57	116.58	79.36
Weight of water (X2-X3) gms	5.22	9.92	7.88	15.87	12.5

Water content W%= X2-X3/X3-1	8.79	10.65	12.59	13.61	15.75
Dry density ϒ d= Vt/1 + (W/100) gm./cc	1.81	1.86	1.91	1.85	1.82



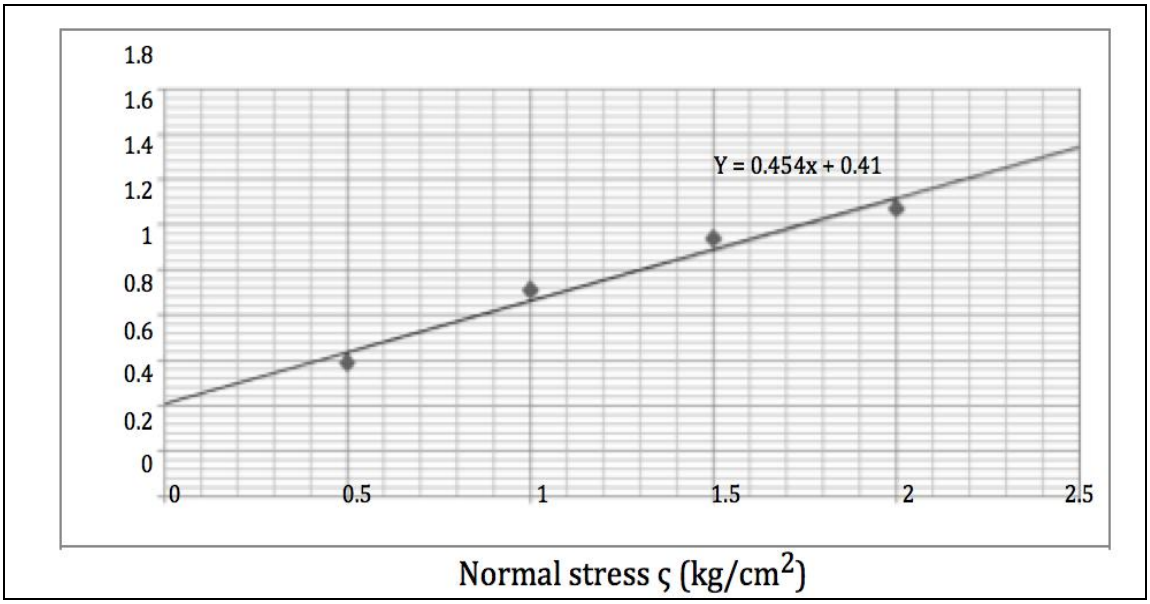
From the figure it is evident that, Optimum Moisture content (OMC)=12.6% Maximum dry density (MDD)=1.91g/cc

3.5 Direct Shear Test

Volume of shear Box	90 cm^3
Maximum dry density of soil	1.91 gm./cc
Optimum moisture content of soil	12.6 %
Weight of the soil to be filled in the shear box	1.91x90 = 171.9 gm.
Weight of water to be added	(12.6/100) x171.9= 21.66 gm.

i. Reinforcement = 0.05%

Sample no.	Normal load(ς)	Proving Constant	Shear load (N)	Shear load(kg)	Shear stress (kg/cm^2)
1	0.5	76	290.27	29.62	0.83
2	1.0	120	458.19	46.75	1.31
3	1.5	160	612.08	62.45	1.75
4	2.0	206	786.96	80.30	2.25



Computing from graph,Cohesion (C) = 0.325 kg/cm^2; Angle of internal friction (ϕ) = 47.72°

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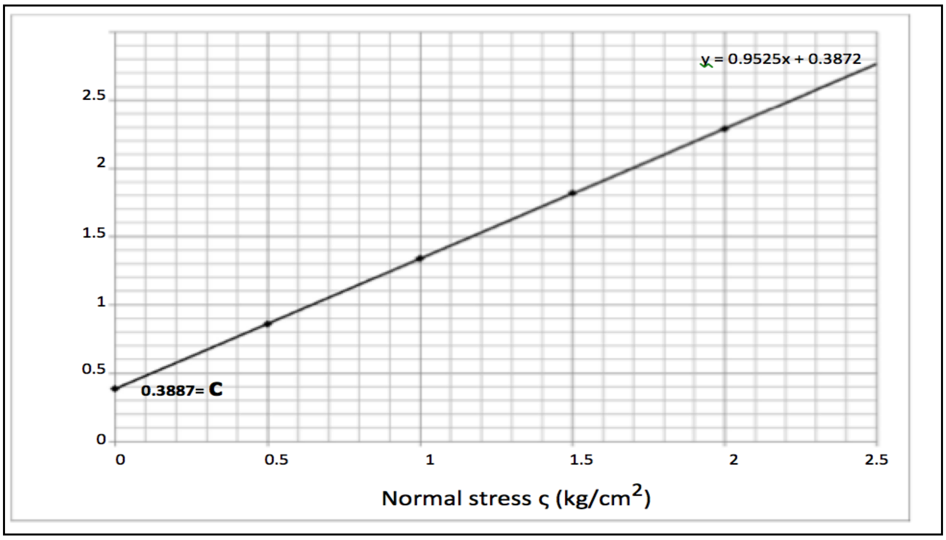
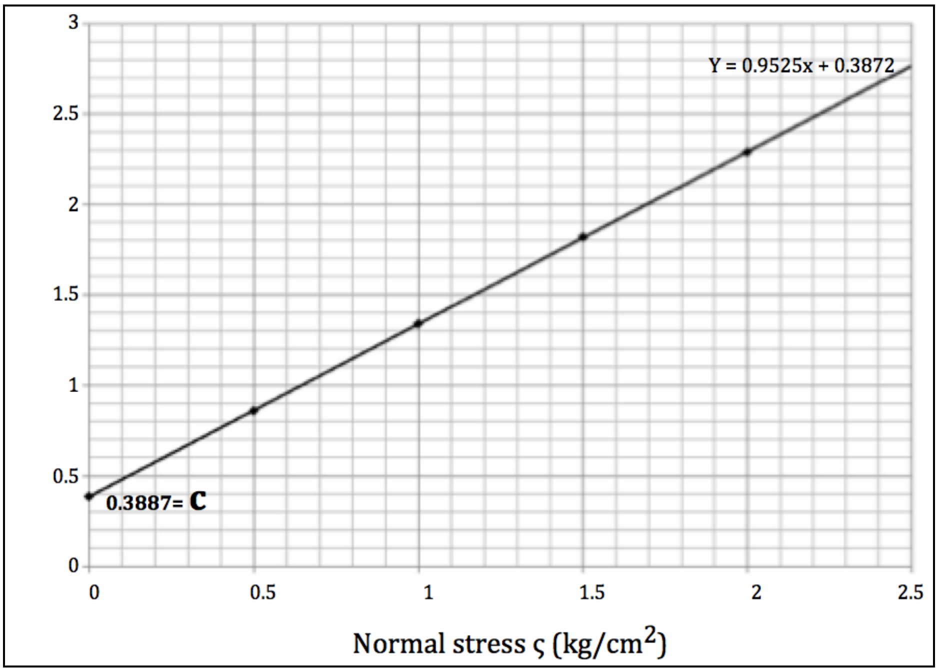


Cohesion (C) = 0.3575 kg/cm^2 Angle of internal friction (ϕ) = 48.101°

ii. Reinforcement=0.15%

Sample no.	Normal load (ς)	Proving Constant	Shear load (N)	Shear load (Kg)	Shear stress (Kg/cm^2)
1	0.5	78	297.23	30.33	0.85
2	1.0	121	461.68	47.11	1.32
3	1.5	164	626.07	63.88	1.79
4	2.0	207	793.99	81.02	2.27



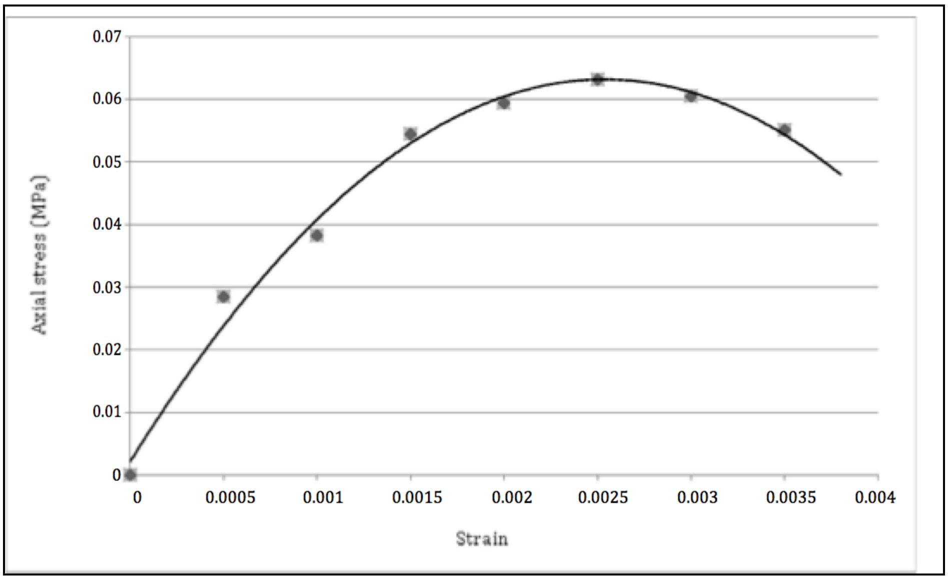
Computing from graph,

Cohesion (C) = 0.3747 kg/cm^2

Angle of internal friction (ϕ) = 48.254

iii. Reinforcement = 0.25%

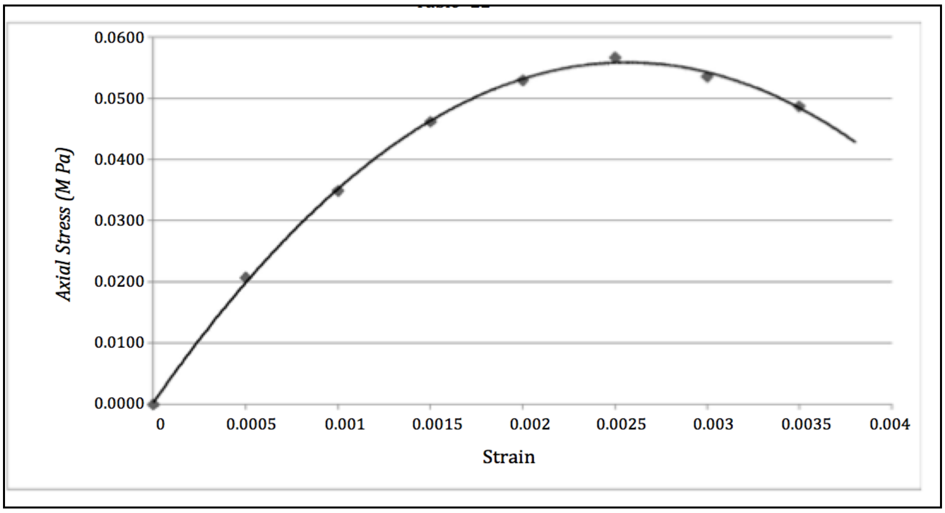
Sample no.	Normal load (ς)	Proving Constant	Shear load (N)	Shear load (Kg)	Shear stress (Kg/cm2)
1	0.5	79	300.79	30.69	0.86
2	1	122	468.64	47.82	1.34
3	1.5	166	636.61	64.96	1.82
4	2	209	800.95	81.73	2.29



Computing from graph; Cohesion (C) = 0.3887 kg/cm^2, Angle of internal friction (ϕ) = 48.483

i. Unreinforced

Dial gauge Reading	Strain (ϵ)	Proving ring Reading	Corrected area	Load (N)	Axial Stress (M pa)
50	0.0033	35	19.72	40.81	0.0207
100	0.0067	62	19.82	69.19	0.0349
150	0.0100	79	19.92	92.11	0.0462
200	0.0133	91	20.03	106.12	0.0530
250	0.0167	98	20.13	114.27	0.0567
300	0.0200	93	20.24	108.44	0.0536
350	0.0233	85	20.34	99.11	0.0487

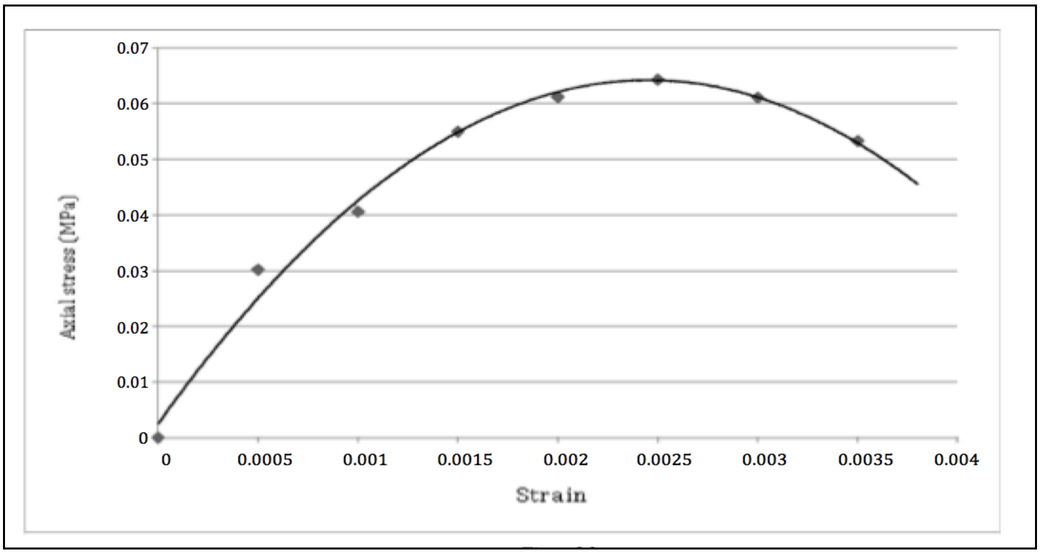


As obtained from graph,

UCS = 0.0562 M Pa

ii. Reinforcement = 0.05%

Dial gauge Reading	Strain (ϵ)	Proving ring Reading	Corrected area	Load (N)	Axial Stress (Mpa)
50	0.0033	48	19.72	55.97	0.0284
100	0.0067	65	19.82	75.79	0.0382
150	0.0100	93	19.92	108.44	0.0544
200	0.0133	102	20.03	118.93	0.0594
250	0.0167	109	20.13	127.09	0.0631
300	0.0200	105	20.24	122.43	0.0605
350	0.0233	96	20.34	111.94	0.0551

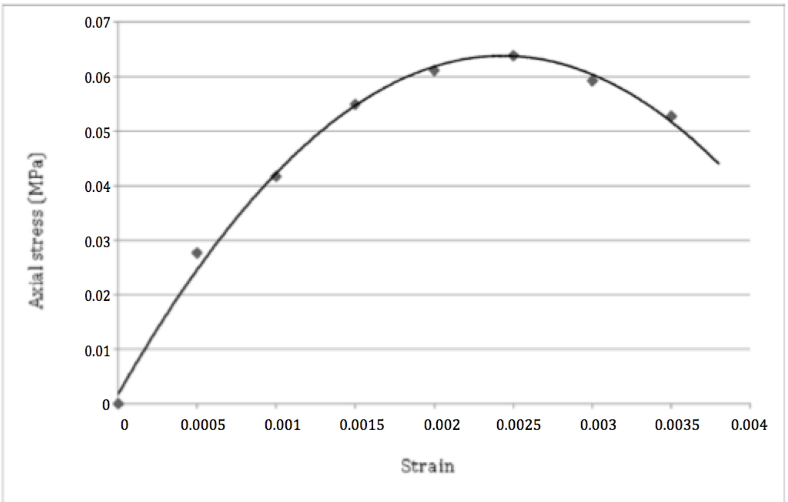


As obtained from graph, UCS = 0.0631 M Pa

iii. Reinforcement = 0.15%

Dial gauge Reading	Strain (ϵ)	Proving ring Reading	Corrected area	load (N)	Axial Stress (Mpa)
50	0.0033	47	19.72	54.8	0.0277
100	0.0067	71	19.82	82.79	0.0417

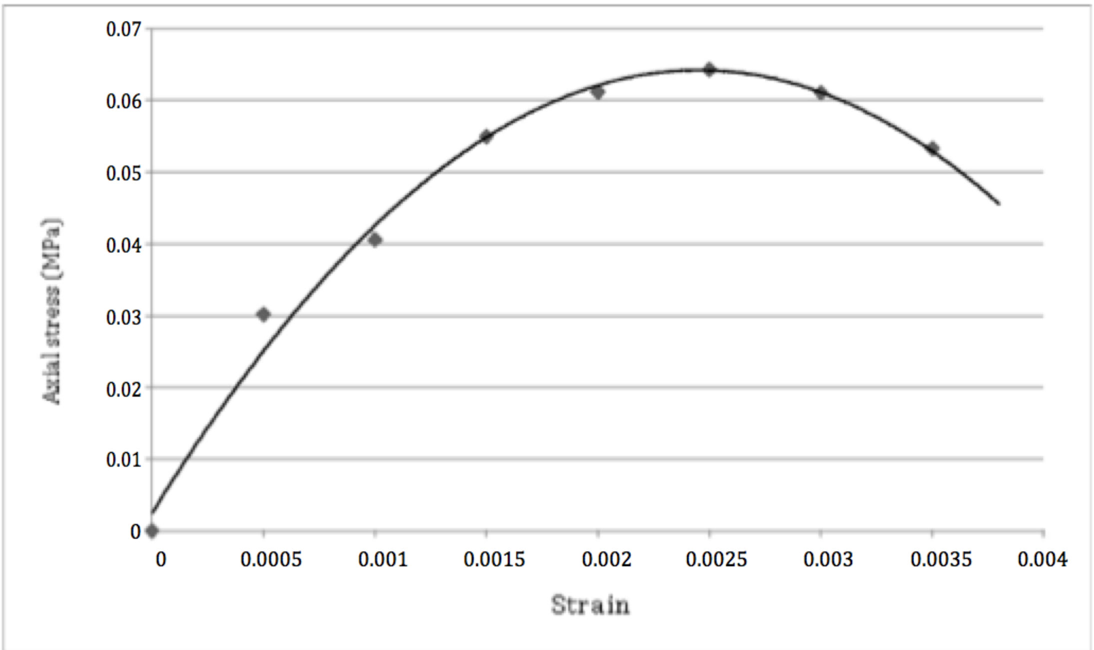
150	0.0100	94	19.92	109.6	0.0550
200	0.0133	105	20.03	122.43	0.0612
250	0.0167	110	20.13	128.26	0.0639
300	0.0200	103	20.24	120.1	0.0593
350	0.0233	92	20.34	107.27	0.0527



As obtained from graph, UCS = 0.0637 M Pa

iv. Reinforcement = 0.25%

Dial gauge Reading	Strain (ϵ)	Proving ring Reading	Corrected area	Load (N)	Axial Stress (Mpa)
50	0.0033	51	19.72	59.47	0.0302
100	0.0067	69	19.82	80.45	0.0406
150	0.0100	94	19.92	109.6	0.0550
200	0.0133	105	20.03	122.43	0.0612
250	0.0167	111	20.13	129.43	0.0643
300	0.0200	106	20.24	123.6	0.0611
350	0.0233	93	20.34	108.44	0.0533

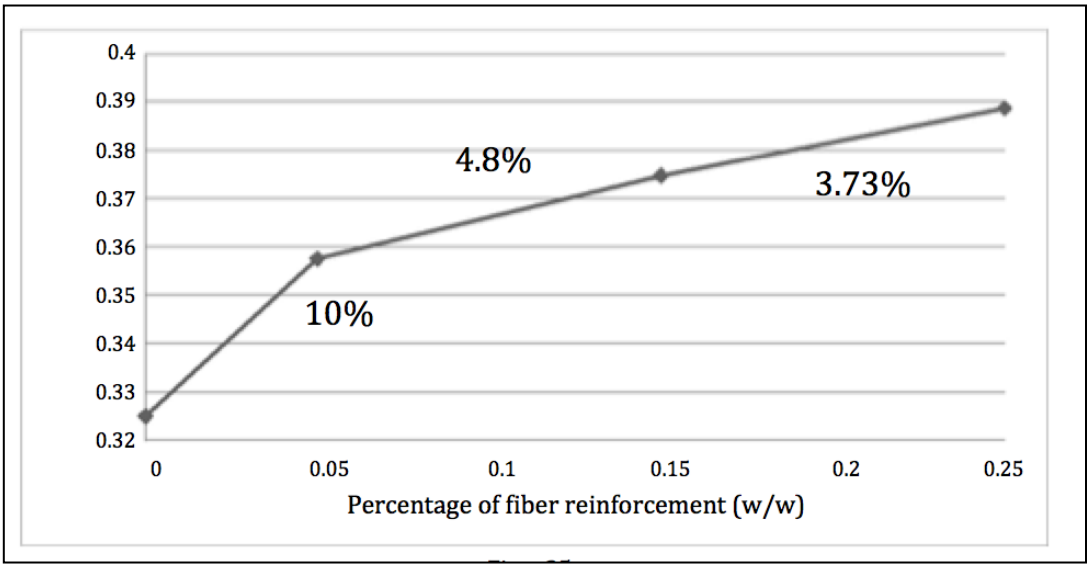


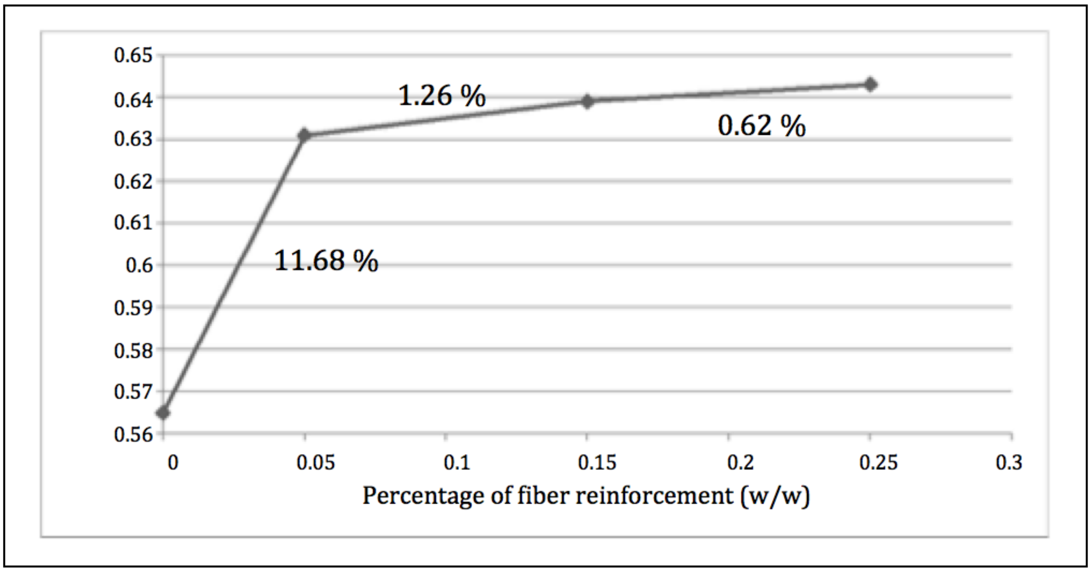
As obtained from graph, UCS = 0.0643 M Pa

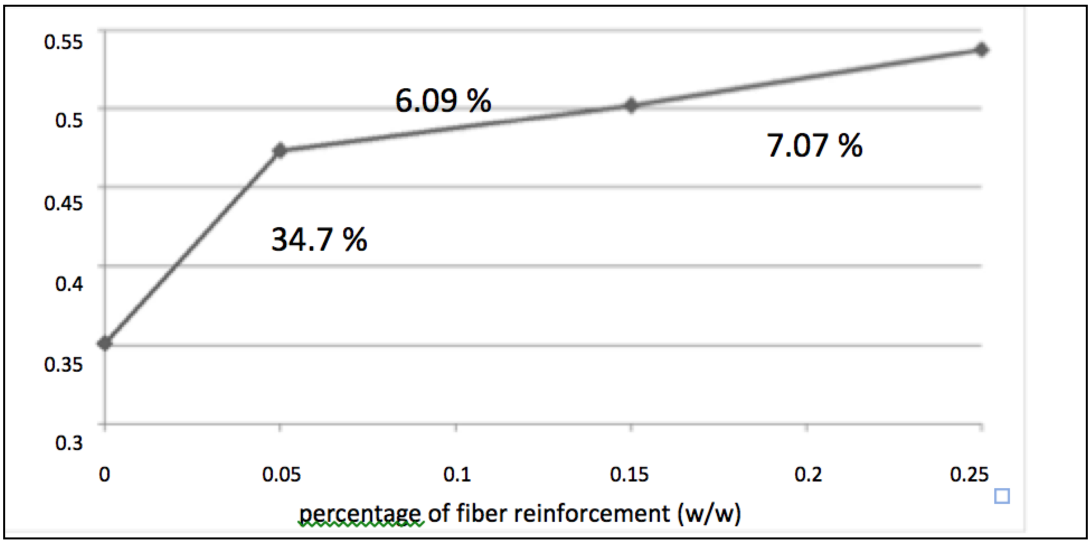
3 Discussions

The relationship between shear strength parameters and fiber content

4.1 Cohesion and fiber content







4.2 Inferences from Direct Shear Test

a) Cohesion value increases from 0.325 kg/cm2 to 0.3887 kg/cm2, a net 19.6%

b) The increment graph shows a gradual decline in slope.

c) The angle of internal friction increases from 47.72 to 48.483 degrees, a net 1.59%

d) The increment in shear strength of soil due to reinforcement is marginal.

4.3 Inferences from Unconfined Compression Test

a) UCS value increases from 0.0643 MPa to 0.0562 MPa, a net 14.4%

b) The slope of increment graph is continuously decreasing with an initially steep slope

5 CONCLUSIONS

On the basis of present experimental study, the following conclusions are drawn:

Based on direct shear test on soil sample- 1, with fiber reinforcement of 0.05%, 0.15% and 0.25%, the increase in cohesion was found to be 10%, 4.8% and 3.73% respectively (illustrated in figure- 25). The increase in the internal angle of friction (ϕ) was found to be 0.8%, 0.31% and 0. 47% respectively (illustrated in figure- 27). Since the net increase in the values of c and ϕ were observed to be 19.6%, from 0.325 kg/cm2 to 0.3887 kg/cm2 and 1.59%, from 47.72 to 48.483 degrees respectively, for such a soil, randomly distributed polypropylene fiber reinforcement is not recommended.

The results from the UCS test for soil sample- 1 are also similar, for reinforcements of 0.05%, 0.15% and 0.25%, the increase in unconfined compressive strength from the initial value are 11.68%, 1.26% and 0.62% respectively (illustrated in figure-29). This increment is not substantial and applying it for soils similar to soil sample-1 is not effective.

The shear strength parameters of soil sample- 2 were determined by direct shear test. Figure- 26 illustrates that the increase in the value of cohesion for fiber reinforcement of 0.05%, 0.15% and 0.25% are 34.7%, 6.09% and 7.07% respectively. Figure 27 illustrates that the increase in the internal angle of friction (ϕ) was found to be 0.8%, 0.31% and 0. 47% respectively. Thus, a net increase in

the values of c and ϕ were observed to be 53%, from 0.3513 kg/cm2 to 0.5375 kg/cm2 and 15.02%, from 27.82 to 32 degrees. Therefore, the use of polypropylene fiber as reinforcement for soils like soil sample- 2 is recommended.

On comparing the results from UCS test of soil sample- 2, it is found that the values of unconfined compressive strength shows a net increment of 49.8% from 0.0692 M Pa to 0.1037 M Pa (illustrated in figure- 30). This also supports the previous conclusion that use of polypropylene fibers for reinforcing soils like soil sample- 2 is recommended.

Overall it can be concluded that fiber reinforced soil can be considered to be good ground improvement technique specially in engineering projects on weak soils where it can act as a substitute to deep/raft foundations, reducing the cost as well as energy.

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