Geotechnical Behavior of Expansive Soil of Rajasthan reinforced with Natural Fibers and Comparison of these Fibers employed together with Crack Propagation Pattern

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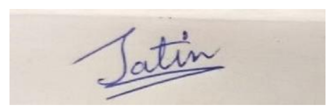
CANDIDATE'S DECLARATION

I, Jatin, Roll no. 2K21/GTE/09 student of M.Tech., Geotechnical Engineering, hereby declare that the Dissertation titled "**Geotechnical Behavior of Expansive Soil of Rajasthan reinforced with Natural Fibers and Comparison of these Fibers employed together with Crack Propagation Pattern**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma and Fellowship, or other similar title or recognition.



Place: Delhi

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CERTIFICATE

I hereby certify that the Project Dissertation titled "**Geotechnical Behavior of Expansive Soil of Rajasthan reinforced with Natural Fibers and Comparison of these Fibers employed together with Crack Propagation Pattern**" which is submitted by Jatin, Roll no. 2K21/GTE/09 [Civil Engineering], Delhi Technological University, Delhi in the partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any degree or diploma to this University or elsewhere.

Place: Delhi **(Prof. KONGAN ARYAN)**

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

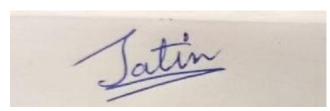
ABSTRACT

Considered as one of the notorious soil category as of swelling, shrinkage and cracking behavior eventually damaging civil engineering structures instigating wide-ranging difficulties for construction purpose. Over the years, Lime treatment has been broadly used to reinforce the soil but then again it comes with the unscrupulous effects on the soil such as carbonation or sulfate attack. This paper intends to evaluate the effect of fiber reinforcement (coir & jute fiber) obtained from Jodhpur, Rajasthan in improvement of geotechnical behavior of the natural clayey soil mixed with sand along with comparison of two natural fibers in improving soil strength. The author performed direct (UCS) strength test on reinforced and unreinforced soil. Initial test were conducted on coir by varying fiber content/percentage (2%, 2.5% and 3%) and eventually on jute fiber in varying fiber content/percentage (2%, 2.5% and 3%). The present paper indicates that in both the fiber employed for reinforcement exhibited an increment in soil strength. Among coir and jute fiber content/percentage, jute seems to have shown improvement accompanied by enhanced resistance to the cracking. Thus, natural fiber could possibly prevent the ill effects of soil strengthening mechanisms like lime treatment while used for soil reinforcement and conserve the already dilapidating Rajasthan's soil ecosystem.

ACKNOWLEDGMENT

I give thanks to the Almighty God for his blessings and grace in helping me finish my thesis. I express my sincere thanks to the University Management.

As I write this acknowledgment, I must clarify that this is not just a formal acknowledgment but also a sincere note of thanks and regards from my side. I have a strong sense of thanks and love for everyone involved in the project, without whose cooperation and direction this project could not have been successfully completed. I am grateful to Prof. Kongan Aryan of the Department of Civil Engineering at Delhi Technological University for letting me work under his supervision, which gave me the necessary confidence to complete the project. I also express my deep gratitude to the Department of Civil Engineering and all the Faculty member of Civil Engineering Delhi Technological University, Delhi for the pains taken by him to go through the manuscript and giving his useful suggestions. Last but not the least, I would like to thank my family and friends who stimulated me to bring this work to a successful close.



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CHAPTER 1

INTRODUCTION

1.1. MOTIVATION

Shear strength is a soil mechanics term that describes the magnitude of shear force that a soil can withstand. Soil shear resistance is caused by particle friction and interlocking, as well as possible cementation or bonding of particle contacts. Particulate material may expand or shrink in volume due to interlocking as it is subjected to shear stresses. When soil expands in volume, the density of the particles decreases and the strength decreases; in this scenario, the peak strength is followed by a fall in shear stress. When the material stops expanding or contracting and when interparticle links are dissolved, the stress-strain relationship reaches a plateau. The crucial state, steady state, or residual strength is the theoretical condition in which shear stress and density stay constant as shear strain rises.

Following significant study into how to fortify the expanding soil, the lime treatment or marble dust was discovered to be commonly employed in the procedure. However, with the utilization comes the disadvantages of these processes. Carbonation of soil and sulphate attack are two examples. With industrial pollution already looming big on Rajasthan's soil, this study was conducted with the goal of providing reinforcement to the vast soil of Rajasthan using natural fibers while also conserving the ecology of Rajasthan Soil.

The shear strength of the soil was employed in this study to assess if the application of reinforcement is giving appropriate soil strength, and these results were then validated by the model construction using ABAQUS software.

1.2. OBJECTIVE OF STUDY

The study's goal is to better understand the behavior of soil reinforcement using natural fibers. Jute and coir fibers were employed as soil reinforcing fibers. The fiber content of the soil mixture was altered in different quantities. This research depicts how the percentage of fiber combined with soil enhances soil strength. The fiber reinforcement of a soil sample shows a substantial variance in soil strength.

The primary goal is to examine the influence of fiber content reinforcement on soil metrics such as peak compressive strength, average strain, and modulus of resilience fluctuation. These will be investigated for jute and coir fiber reinforcing in soil. These factors are then evaluated to determine which soil is most suited for reinforcing. Furthermore, a crack propagation comparison is performed between unreinforced, jute, and coir reinforced soil samples to see which ones produce the least cracking and best resistance to the applied load. The fractures are then associated with a graphical depiction of the stress-displacement relationship of different fiber content reinforced with jute and coir fibers.

Finally, the Dassault Systems ABAQUS standard package was utilized to validate the experimental data. A cylindrical model was produced and analyzed using software to extract displacement and force data, which was then processed to provide a stress-strain plot that could be compared to the real test findings.

1.3. ORGANIZATION OF REPORT

CHAPTER 1 It explains the shear strength of the soil, the many states of the soil, and how the particles operate in the soil. It also provides a sense of the project's goal.

CHAPTER 2 Describes a literature study of several experiments done on soil samples over the last few years by famous researchers to assess the soil strength of reinforced soil samples.

CHAPTER 3 It discusses unconfined compressive strength, what it is, how UCS experimentation is carried out, what steps are included in the experiment, how to interpret the results of the experiment, and the properties of the material used in the experimentation.

CHAPTER 4 It offers an introduction to the FINITE ELEMENT ANALYSIS, including why and how it is performed, as well as an idea of the model built for the analysis and the findings utilized for result validation. Furthermore, the crack propagation pattern is introduced, and the results are analyzed for the trial.

CHAPTER 5 It examines the FINITE ELEMENT ANALYSIS of the model produced, as well as the fracture propagation pattern findings, which are cross-checked with the strength data from the UCS experiment.

CHAPTER 6 This part includes the conclusion part of the project work along with the future scope of the work done.

The last part of this thesis contains the account of several research publications has been made, which we had referred during the study.

CHAPTER 2
REVIEW OF LITERATURE

In the present study, soil strengthening problem is dealt with natural fiber reinforcement along with validation of results using Finite Element Model. This in turns reduces the issue of soil contamination, an after-effect of methods like lime treatment or marble-dust method.

Ahirwar and Chore's (2022) research on marble dust and its usage for soil strengthening found that because Rajasthan has over 4000 mines, it is feasible to employ marble dust. Mining and fishing operations generate a significant quantity of marble debris, which may subsequently be utilized to reinforce clayey soil. The experimental study was utilized to evaluate aspects such as compaction qualities and cure duration of various combinations. According to the findings of the tests, the strength of the composite mix rose as the quantity of marble dust increased.

Australia, India, and South Africa are all known to have expansive soil. This research looks at dirt from several locations of Rajasthan, India. **Purohit and Wayal (2007)** developed an experimental test for blending dune sand and gypsum to increase soil strength. According to the study, swelling pressure reduces with the mixing of dune sand and gypsum in the soil, as well as with the increase in moulding water content. Furthermore, several strategies for overcoming the swelling of expansive soil are suggested.

Numerous studies are being conducted on bentonite supplemented with soil to generate barrier material for waste disposal projects such as landfills, earthen dams, and so on. The use of marble dust in large quantities is dangerous to the environment. **Kumar and Jha (2021)** studied a sand bentonite and marble dust bentonite combination to change the behavior of marble dust with bentonite. In the laboratory, the Atterberg limit, Free Swell Index, and compaction parameters of a sand bentonite and marble dust bentonite combination were determined. It was discovered that bentonite replacement enhanced MDD, OWC, and Free Swell Index. To clarify the mechanism, physiochemical analyses of whole mixtures were undertaken.

As the population grows, so will the reliance on construction. The stability of any created building or project will be determined by the strength of its foundation. Rajasthan possesses this soil type, and this study took samples from six different locations in Rajasthan to determine the quality, strength, and bearing capacity. **Dhemla and Bundela (2015)** employed jute as an additional fibre to strengthen the soil. The authors ran CBR tests on the soil samples they collected. The soil sample from Barmer was determined to be the poorest of the six locations tested. As a result, jute fiber of various length and fibre content was introduced. It was discovered that increasing the fiber content increased the CBR value of the soil, resulting in a reduction in the thickness of the pavement subgrade.

This research looks at the effects of polyester fibre inclusion and lime stabilization on the geotechnical properties of fly-ash soil mixes. On the fly ash soil, lime fly ash soil, and lime soil composition, **Bajaj and Walia (2007)** performed compaction, unconfined compressive testing, and split tensile tests. Specimens were cured for 7, 14, and 28 days before being evaluated and optimal values for fly ash and lime were achieved. Further experiments on the aforementioned mixes were carried out using these optimal values on fly ash-lime-fiber mixture after 28 days of curing at 0.5, 1, 1.5, and 2% fibre content. Based on the positive findings obtained, it can be inferred that the combined action of fibers, lime, and fly ash may successfully stabilize the expansive soil.

There has been no serious attempt to employ simply marble dust, a waste product of marble mining and crushing, to establish its potential use as a geo-material. As a result, **Kumar Jain and Kumar Jha (2020)** attempted to clarify the role of marble dust in enhancing the geotechnical behavior of expansive soil and to comprehend the interacting process. Comprehensive geotechnical tests such as Atterberg limits, free swell index, compaction characteristics, swelling percentage, and unconfined compressive strength, as well as physio-chemical examinations such as pH and electrical conductivity, as well as micro-analyses such as mineralogical, microstructural, elemental, Fourier Transform Infra-Red, have been performed on a wide range of marble dust to optimize it for soil improvement and to understand its interactive behavior have been performed. The findings show that marble dust may be used successfully to increase soil flexibility and reduce swell behavior. It is worth noting that marble dust increases soil strength during early curing periods and that a marble dust concentration of 20% results in the best improvement in soil strength behavior. However, the minerals in the soil and marble dust, as well as other elements such as curing process, temperature, and length, appeared to impact the OMDC; consequently, they must be explored.

The effect of discrete and randomly oriented polypropylene fibre reinforcement on expanding soil stabilization was examined in this study. **Anand and Chisha (2000)** employed two expansive soils as control soils in their testing programme. For the experiment, two kinds of fibers and four fibre doses of 0, 0.3, 0.6, and 0.9 percent by dry weight of soil were evaluated. Unconfined compressive strength (UCS), volumetric shrinkage, three-dimensional free swell, and swell pressure tests were performed on both raw and fiber-reinforced clayey materials. The fibre reinforcement improved the soil's UCS and lowered the volumetric shrinkage stresses and swell pressures of the expansive clays. The fibre treatment also boosted the soils' free swell potential.

Fibre reinforcement is a possible option in projects involving localized slope rehabilitation and reinforcement of thin soil veneers where planar reinforcement, such as geotextiles and geogrids, is difficult to apply. Current design approaches allow for the determination of shear strength of fiber-soil composites in terms of the characteristics that characterize the soil matrix and fibers separately. **Chunling and Zornberg (2011)** used triaxial compression and fibre pullout experiments to determine how fibre tension is mobilized at different shear strain levels. The findings shed light on whether the shear strength of fiber-reinforced soil is dictated by the peak or residual shear strength of unreinforced soil. The individual contribution of fibers and soil matrix is assessed based on strain level in a refinement to existing design technique.

CHAPTER 3

UNCONFINED COMPRESSIVE STRENGTH AND METHODOLOGYADOPTED

3.1 INTRODUCTION

The unconfined compressive strength is the maximum axial compressive load that an expansive soil sample can bear under the loading condition of zero confining stress. The experimentation procedure was carried out in accordance with IS 2720 (Part 10): 1991.

This research was done in expressions of load, displacement responses further their analogous amplifications are documented in terms of axial stress (σ) and axial strain (ε) respectively.

Axial stress is defined as the ratio of axial force obtained using UCS apparatus to the area of the sample used. Axial strain is defined as the ratio of displacement obtained from dial gauge of UCS to length of the soil sample.

$$\sigma = \frac{\text{Axial Force}}{\text{Area of Sample}}$$

$$\varepsilon = \frac{\text{Displacement}}{\text{Length of Sample}}$$

3.2 UCS EXPERIMENTATION

For the problem statement IS 2720 (Part 10): 1991 code was used to perform the experimental procedure. The sample was cylindrical in shape with dimensions of 38 diameter and 76mm length. Two-way split mould was used to prepare the soil sample with grease as a lubricator. Hand Compaction was performed to bring evenness to the soil sample. The soil sample was prepared by mixing water at optimum values corresponding to the maximum dry density obtained from the experimentation. Two types of natural fibers were mixed with the soil sample. Fig. 3.1 shows the equipment used for soil sample testing. The equipment contains a proving ring to measure the force applied on the soil sample. The dial gauge on the

bottom plate of the equipment provides displacement readings of the soil sample. The rate of displacement was set to 1.25mm/min. The reading of both displacement and force were taken at interval of every 30 seconds. The Proving Ring possess a proving ring constant. In this study, the proving ring constant is taken to be 10.8823 N/division. The dial gauge on the bottom plate has a constant of 0.01mm/divisions. The readings are noted till the proving ring needle starts going anti-clockwise on further application of the load. The whole session is recorded with a tripod mounted camera for cracking comparison.

Fig. 3.1 UCS Experimentation Equipment

3.3 STEPS INVOLVED IN THE EXPERIMENTATION AND MATERIAL PROPERTY

The process involved consists of various steps. Firstly, soil is weighed and taken in a container. Next, water is mixed in the soil at Optimum Moisture Content corresponding to the Maximum Dry Weight. The mixture is left covered with a damp cloth until the two way mould is properly cleaned and greased. The grease is applied so as to negate the possibility of crack development while extracting cylindrical sample from the mould. Fig. 3.2 depicts two way split mould Equipment greased on the internal face. The sample is then placed in UCS machine to obtain load and displacement readings. The properties of material used in experimentation is provided in Table 3.1.

Fig. 3.2 Two way Split Mould Equipment

The soil used in this study is classified as clay with high compressibility. Two natural fibers type used for soil reinforcement are jute and coir fiber.

Table 3.1 Properties of Soil Used

Properties	Soil Sample
Specific Gravity	2.5
Liquid Limit (%)	52.9215
Plasticity Index (%)	32.2615
Soil Classification[a]	CH
Maximum dry unit weight	14.9269
Optimum Moisture Content (%)	15.3

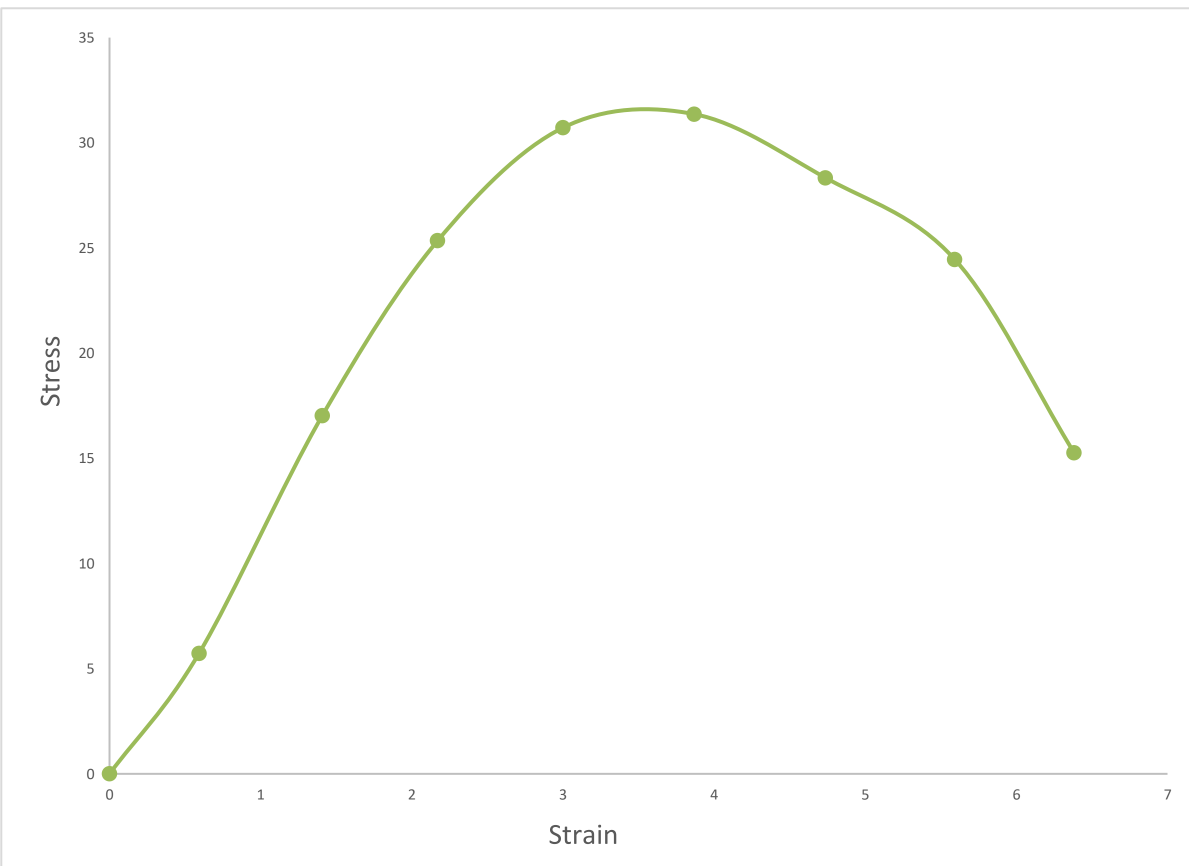
[a]According to Unified Soil Classification System (USCS)

3.4 ANALYSIS OF UCS RESULTS

Fig. 3.3 Cylindrical Soil Sample

The UCS experimentation provides Force reading from the Proving ring along with displacement from the dial gauge. The proving ring constant needs to be multiplied with the reading obtained to get Force being applied on the sample. The dial gauge constant multiplied with the readings obtained from the dial gauge at the bottom will provide the value of displacement of the soil sample. Fig. 3.3 depicts the image of sample used for experiment. Table 3.2 provides analysis of the results obtained from the testing. The Load (P) is obtained by multiplying readings with the proving ring constant. The Displacement is obtained by multiplying dial gauge readings with constant. Displacement

Fig. 3.4 Stress-Strain Curve



divided by Height of soil sample provides Axial Strain. Axial Stress is obtained by dividing Load with Corrected Area. The readings of Axial Stress and Axial Strain are plotted on the graph to obtain Stress-Strain curve. The maximum value of the graph obtained is Unconfined Compressive Strength magnitude of the soil. Fig. 3.4 depicts the stress strain curve of the table 3.2 readings.

Proving Ring (1 div = 1.1093/kg)	Dial Gauge (1 div = 0.01mm)	Load (P) (kg)	Displacement (D) (mm)	Axial Strain (ε% = [D/H]*100)	Corrected Area (A = A_o/[1-ε/100]	Axial Stress ([P*1000*9.81]/A)
6	45	6.6558	0.45	0.5921	11408.65	5.7231
18	107	19.9674	1.07	1.4078	11503.03	17.0285
27	165	29.9511	1.65	2.1710	11592.77	25.3451
33	228	36.6069	2.28	3	11691.85	30.7148
34	294	37.7162	2.94	3.8684	11797.47	31.3623
31	360	34.3883	3.6	4.7368	11905.01	28.3367
27	425	29.9511	4.25	5.5921	12012.87	24.4587
17	485	18.8581	4.85	6.3815	12114.6	15.2712

Table 3.2 Readings of UCS Experimentation

CHAPTER 4

FINITE ELEMENT ANALYSIS AND CRACK PROPAGATION COMPARISON

1.1.FINITE ELEMENT ANALYSIS

The goal of finite element analysis is to forecast how an object will respond under various physical conditions through calculations, models, and simulations. It can be performed using a variety of software like Autodesk AutoCAD, ANSYS, OpenFOAM, ABAQUS and so on. In this study, ABAQUS package by Dassault Systems was used for analysis of the soil. The analysis is using ABAQUS standard package and is of general non-linear static in nature. A cylindrical model of the soil is created with diameter of 38mm and height of 76mm for static analysis. The load application is such that one end is applied with uniformly increasing load while the other end is kept constrained in the Z axis. Post analysis values of displacement and force applied on the model are extracted and analyzed to match with the experimentation work. Fig. 4.1 represents the model used for analysis in ABAQUS.

Fig. 4.1 Model used for ABAQUS Analysis

1.2.CRACK PROPAGATION COMPARISON

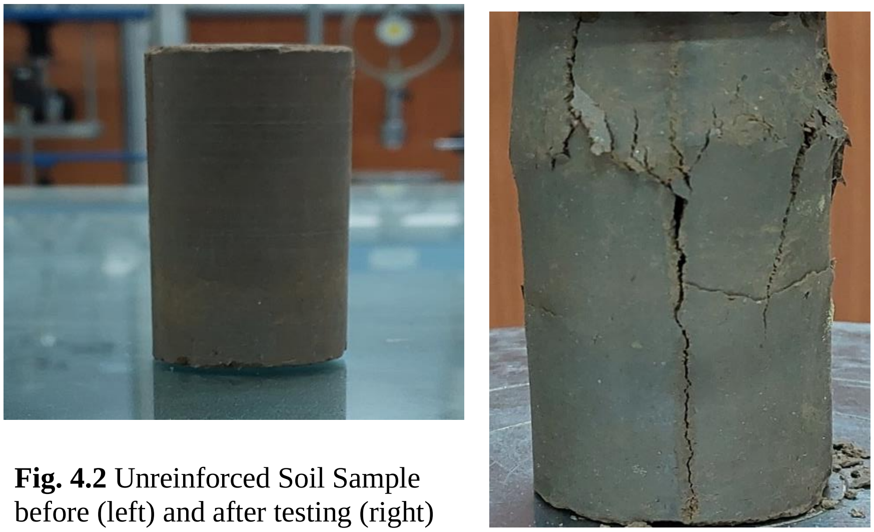


Fig. 4.2 Unreinforced Soil Sample before (left) and after testing (right)

The whole session of UCS experimentation is recorded with a tripod mounted camera and pictures were taken at the end for the comparison. Adobe Photoshop was used on the images obtained to enhance its clarity. Pictures were taken for both unreinforced and reinforced soil samples of jute and coir fiber. Fig. 4.2 illustrates the unreinforced soil sample before testing and cracking after testing. Since two fibers were employed for testing therefore cracking comparison is done between the unreinforced and reinforced (both coir and jute) fiber plus amongst jute and coir reinforced soil sample.

CHAPTER 5
RESULT DISCUSSION

5.1. UCS TEST RESULTS

The results obtained by the UCS experimentation is compared on basis of few parameters like fiber content and displacement. Table 5.1 is the summary of test program conducted during the experimentation.

Table 5.1 Summary of Test Results

Test legend	σ_{pc} (kN/m^2)	ε_a (%)	$\sigma_{pc\,f}$ / $\sigma_{pc\,u}$	$\varepsilon_{a\,f}$ / $\varepsilon_{a\,u}$	$U_{r\,f}$ / $U_{r\,u}$
T1	18.4	4.5789	-	-	-
T2	29.569	6.6184	-	-	-
T3	31.362	3.8684	-	-	-
T4	41.2885	10.3552	1.32	2.27	1.66
T5	44.7516	11.9342	1.43	2.61	2.50
T6	55.7183	7.8289	1.77	1.80	2.98
T7	57.0383	9.9342	1.82	2.17	2.44
T8	65.0553	13.0789	2.08	2.86	3.94
T9	69.7868	10.2105	2.23	2.23	5.35

There are 3 parameters used in analysis of the results obtained from the experimentation. These are peak compressive strength (σ_{pc}), average strain (ε_a) and Modulus of Resilience (U_r). The strain was obtained from the experimental observation. The displacement readings obtained from the experimentation is employed to obtain the strain (**ε_a**) as shown in the Table 3.2. For each test run, an axial stress- strain graph was plotted. The peak value of this graph is called as peak compressive strength (**σ_{pc}**). Modulus of resilience (U_r) is the maximum energy that can be absorbed by the material without creating permanent distortion or damage. It is calculated by integrating the area of stress-strain curve till elastic limit. The author used graph plotting package of Origin Pro software by OriginLab for computing the modulus of resilience values in each case. As depicted in table 3, the author used the values obtained in ratio rendering comparison easy.

Test legend	Soil type	*f* (%)	Fiber Category (mm)	*l* (mm)
T1	Soil 1	-	-	-
T2	Soil 1	-	-	-
T3	Soil 1	-	-	-
T4	Soil 2	2.0	Coir	10
T5	Soil 2	2.5	Coir	10
T6	Soil 2	3.0	Coir	10
T7	Soil 3	2.0	Jute	10
T8	Soil 3	2.5	Jute	10
T9	Soil 3	3.0	Jute	10

Table 5.2 Summary of Test Program

Table 5.2 indicates the tests performed by the author in this study. There are 3 soil types: Soil 1 is unreinforced soil. Soil 2 is reinforced with coir fiber at 2, 2.5 and 3% fiber content. Jute was used to wear in Soil 3 with same fiber content as in coir fiber. The fiber length is kept constant at 10 mm length.

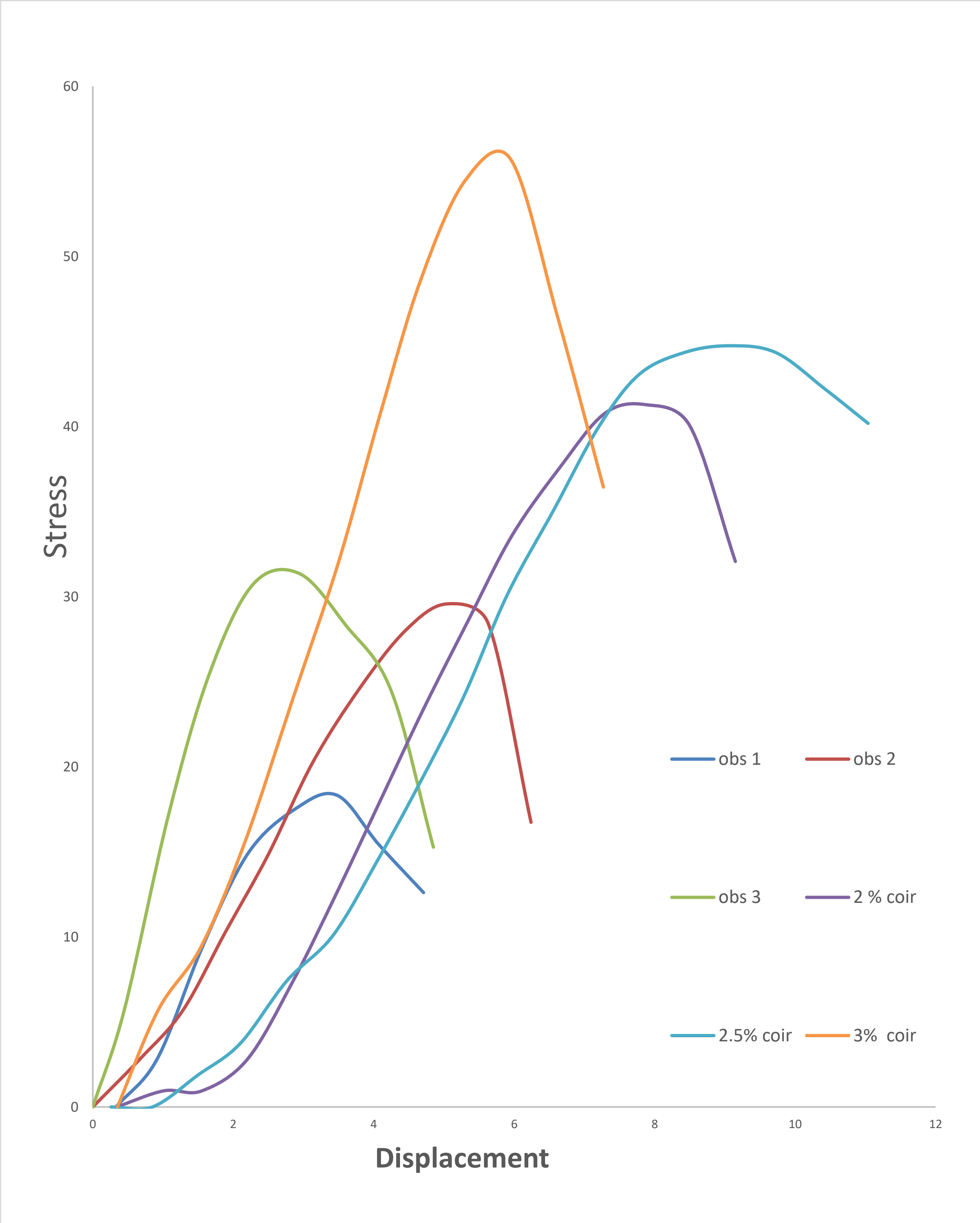


Fig. 5.1 Comparison between coir and unreinforced soil

5.1.1.**Influence of *f***

For study of influence of fiber length in Soil 2 and Soil 3 graphical representations are plotted between stress and displacement of the soil. Fig. 5.1 represents the comparison

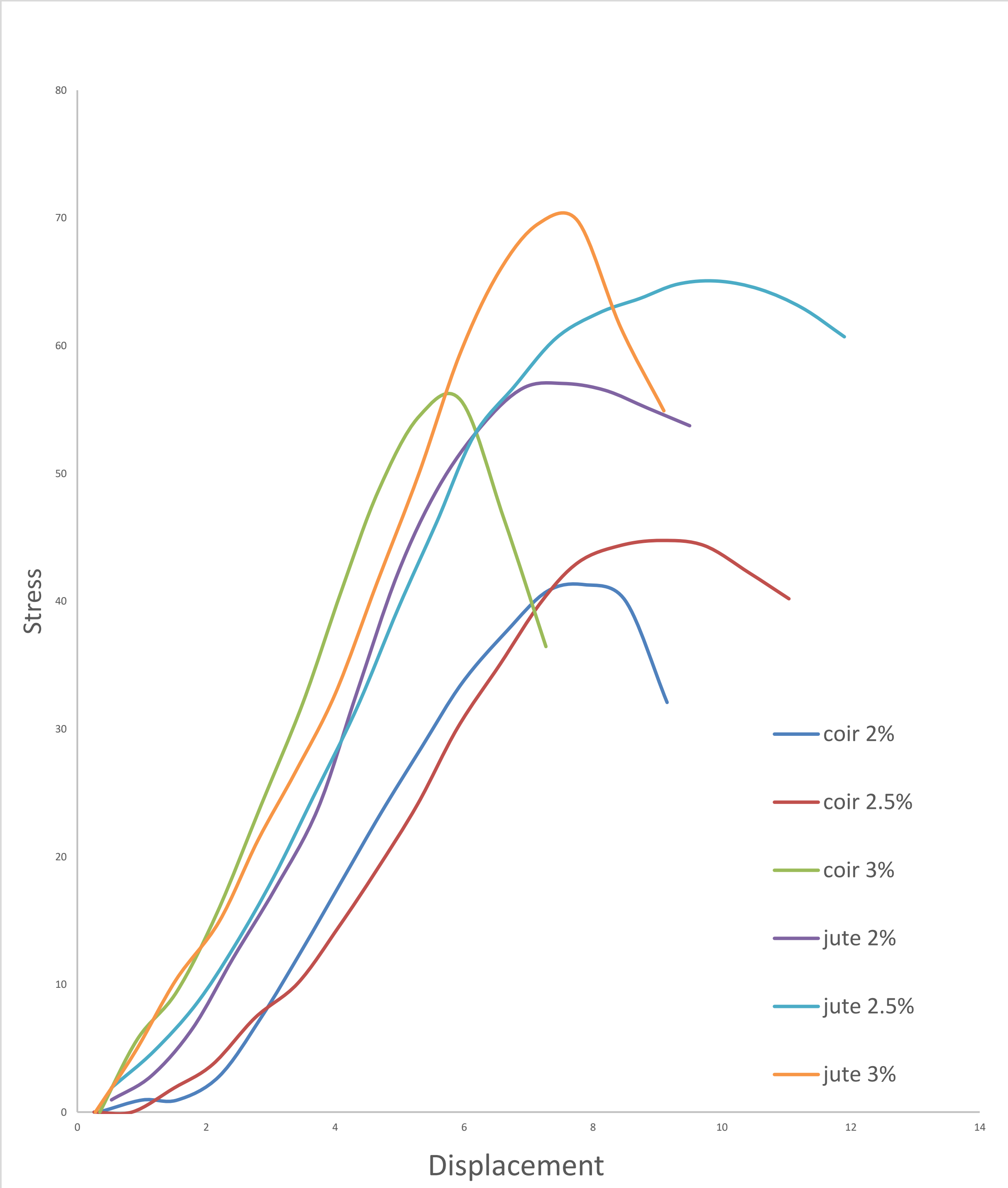


Fig. 5.2 Comparison between jute and coir fiber reinforced soil

between coir and unreinforced soil sample. The Soil 1 with highest fiber content peaks at 30-40 kPa and then falls sharply. On the other hand, the Soil 2 reinforced with coir fiber at 3% fiber content provides a maximum strength of 50-60 kPa which is almost the 2 times of what the unreinforced soil provides implying a significant increase in the strength of the soil. Fig. 5.3 portrays the graph between jute (Soil 3) and unreinforced

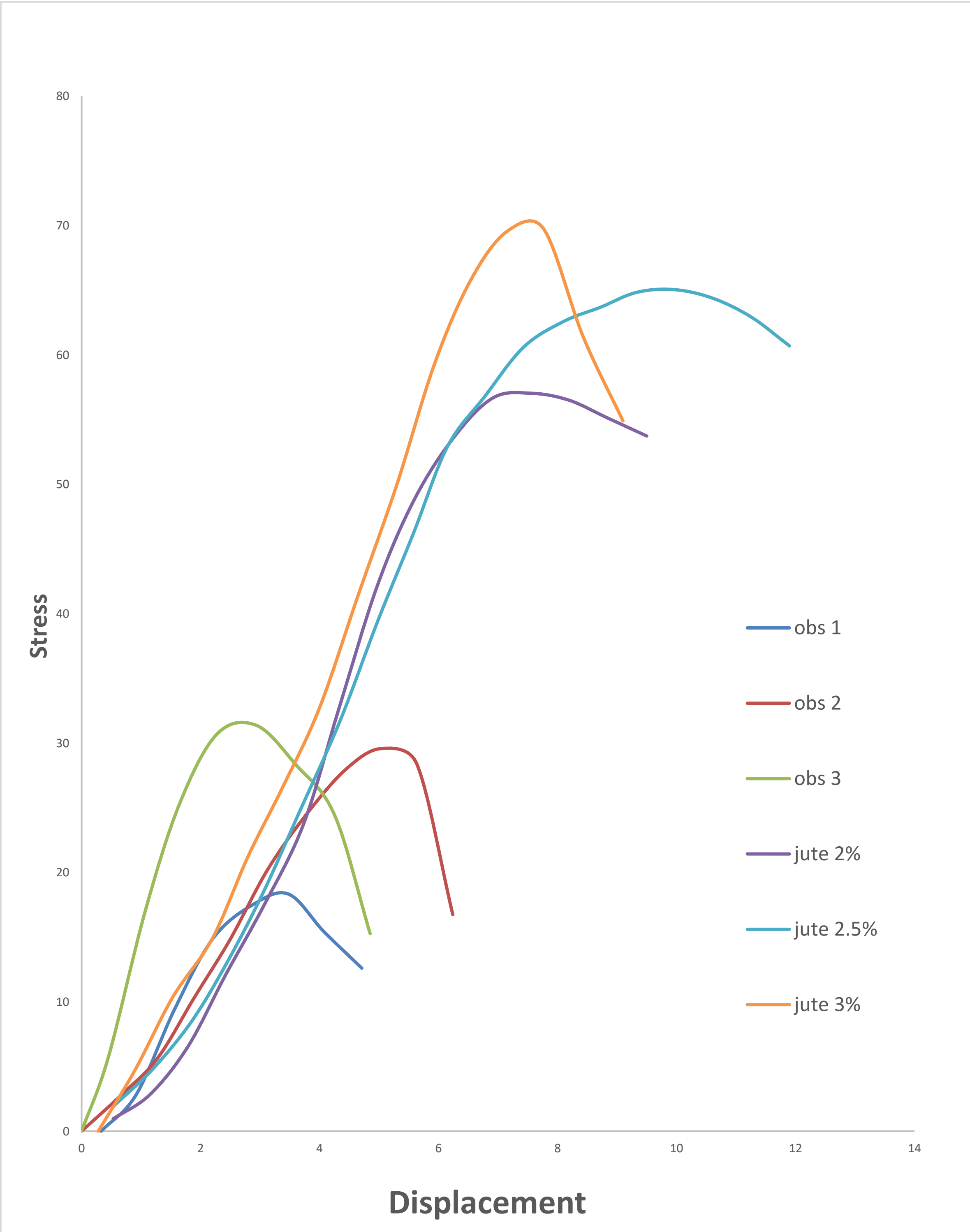


Fig. 5.3 Comparison between jute and unreinforced fiber

soil (Soil 1). It is clearly evident that while the Soil 1 is attains a peak at 30-40 kPa with sharp decrease in the strength, Soil 3 tends to achieve peak in the range of 70-80 kPa all the implications being interpreted at 3% fiber content. This point towards the fact that

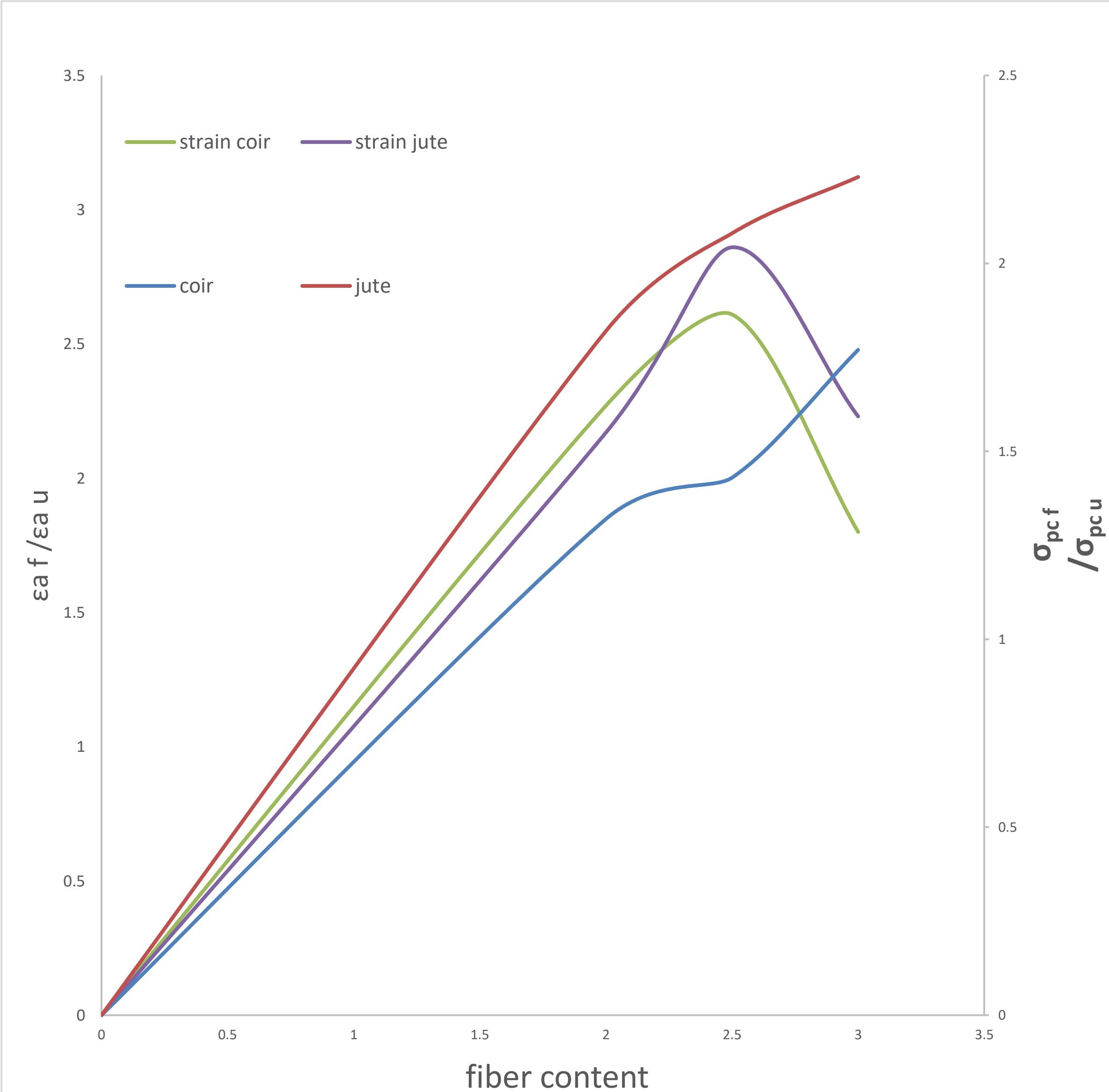


Fig. 5.4 Comparison of peak stress and strain for jute and coir reinforced fiber

soil achieved a 2.23 times increment in soil strength when reinforced with jute fiber along with enhanced resistance to cracking. Fig. 5.2 signifies the contrast between coir fiber and jute fiber reinforced soil. At 3% fiber content reinforcement, the coir seems to have attained a peak in range of 50-60 kPa with sharp decline on further loading. On the contrary, the jute fiber have reached the highest load in range of 70-80 kPa. This signifies that although both coir and jute fiber seems to have shown improvement in strength increment of the soil the later one has shown improvement by 1.2 times as compared to former ones when mixed with the soil sample. In the Fig. 5.4 the

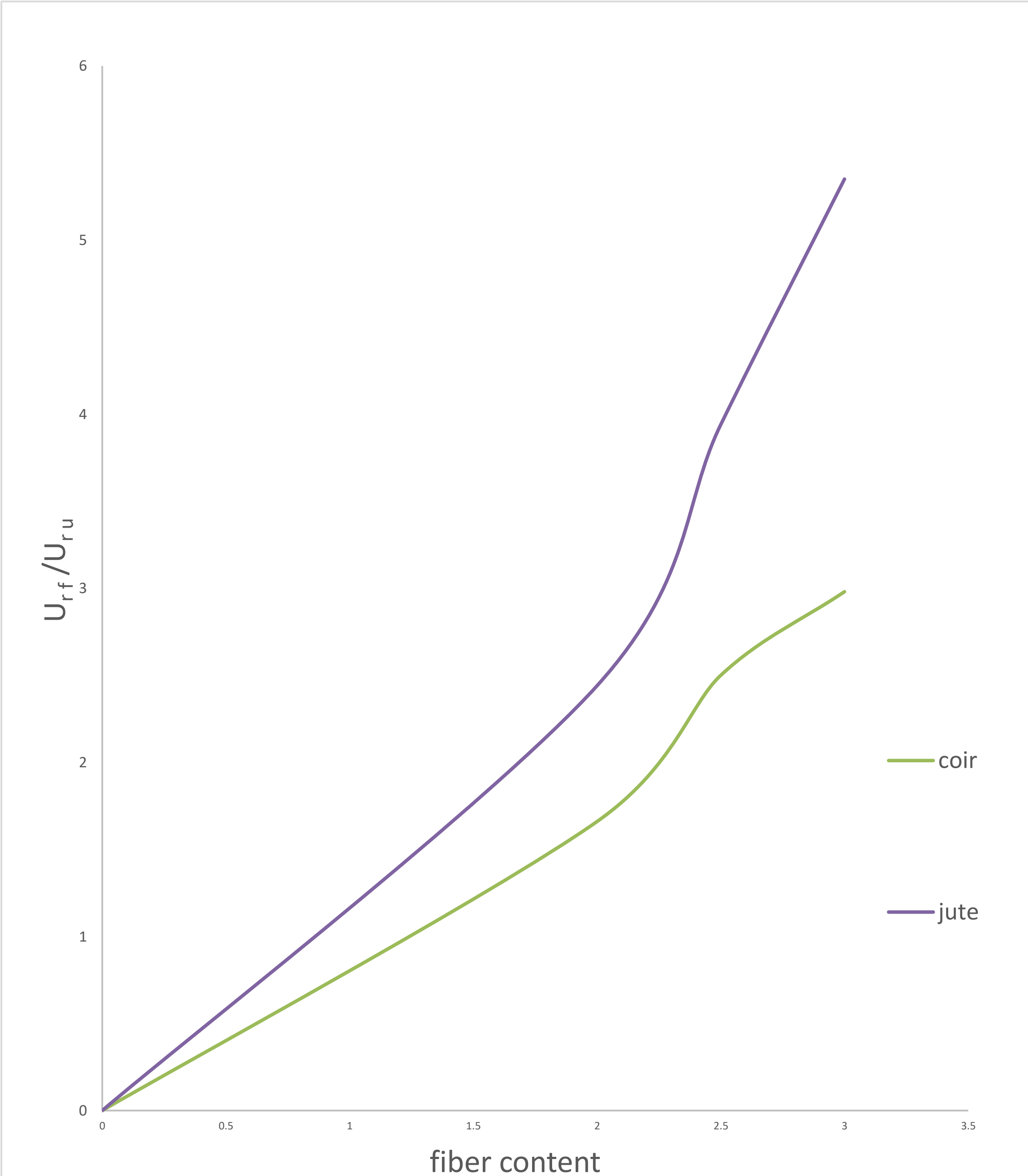


Fig. 5.5 Modulus of Resilience Comparison of jute and coir reinforced fiber

comparison of both peak stress and strain is performed for both coir and jute fiber. For peak stress it can be observed that jute provides larger value of fiber to unreinforced ratio than coir does at 3% fiber content. It indicates the fact that with increase in fiber content the soil is able to bear more stress and hence provide more resistance to failure and cracking as compared to coir fiber. The jute fiber has been able to bear 1.26 times more stress as compared to the coir fiber indicating jute being superior fiber than coir for reinforcement. Moreover, the strain component of jute also shows a significant increase as of 1.25 times as compared to coir fiber in 3% fiber content category. Thus, jute is more suitable when it comes to soil reinforcement. Fig. 5.5 is the modulus of resilience comparison for both coir and jute fiber. Modulus of resilience being the ability of soil to bear strain without getting permanently deformed. More the U_r, more will be the soil strength. In the Fig. it is clearly visible that jute fiber provides 1.8 times more value of modulus of resilience than coir fiber at 3% fiber content of the respective fibers used for soil reinforcement. Therefore, jute is more suitable for soil reinforcement as compared to coir fiber.

5.2. CRACK PROPAGATION RESULTS

For comparison of crack propagation, images captured by a tripod-mounted camera at the conclusion of the experiment are employed. Images for jute and coir fiber reinforced at 2, 2.5, and 3% fiber content were captured. One of the major problems with expanded soil stability is these fissures. The soil tends to fracture throughout its alternating dry and wet cycles as a result of recurrent expansion and contraction brought on by weather changes, which makes it difficult for engineers to deal with the expansive soil. Following are the images captured for comparison.

Fig. 5.6 Comparison between Unreinforced (left) and coir reinforced sample (2% *f*) (right)

A comparison between an unreinforced soil sample and a soil sample reinforced with coir fiber at 2% fiber content is shown in Fig. 5.6. In comparison to the unreinforced soil sample, it is evident from Fig. 5.7 that coir reinforcement resulted in less bulging and cracking in the sample. The unreinforced soil sample in Fig. 13 has a stress range of 30-35 kPa, whereas the sample reinforced with 2% coir fiber has a stress range of 40-45 kPa confirming the decrease in cracking as a result.

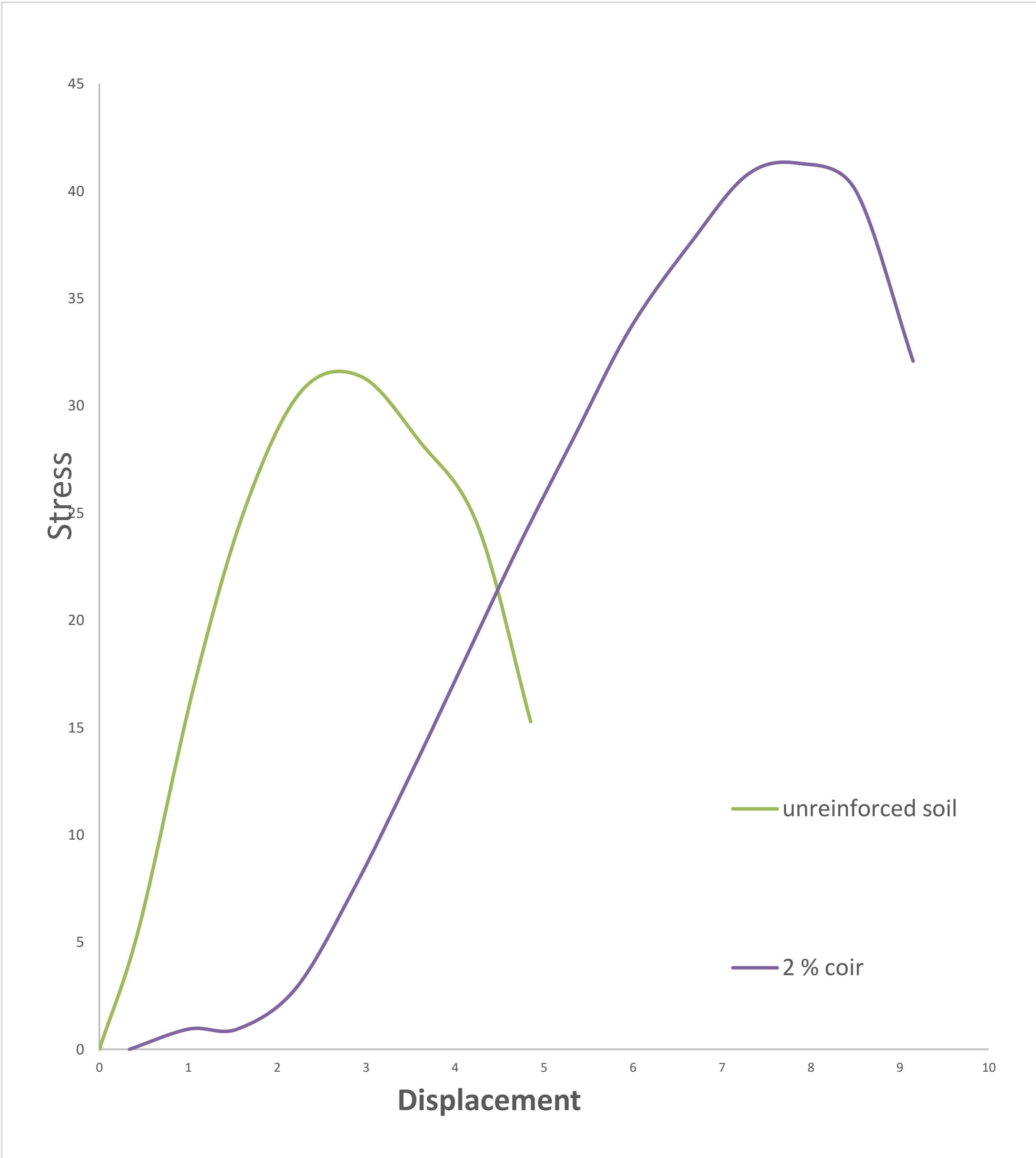


Fig. 5.7 Comparison between Coir and Unreinforced fiber

Fig. 5.8 Comparison between Unreinforced (left) and coir reinforced sample (2.5% *f*) (right)

Fig. 5.8 compares the sample images of reinforced soil with 2.5% coir fiber content with unreinforced soil. It is obvious that reinforced soils break less frequently than unreinforced ones, and that more of the sample is saved from cracking, showing an improvement in the soil's ability to support more weight as reinforcement fiber concentration rose to 2.5% from 2%. As can be seen in Fig. 5.9, the shear stress for the 2.5% coir reinforced soil sample is 40–45 kPa, whereas the shear stress for unreinforced soil is 30-35 kPa. When the soil sample's fiber content increased by 0.5%, it demonstrated an improvement of 1.5 times over the unreinforced soil.

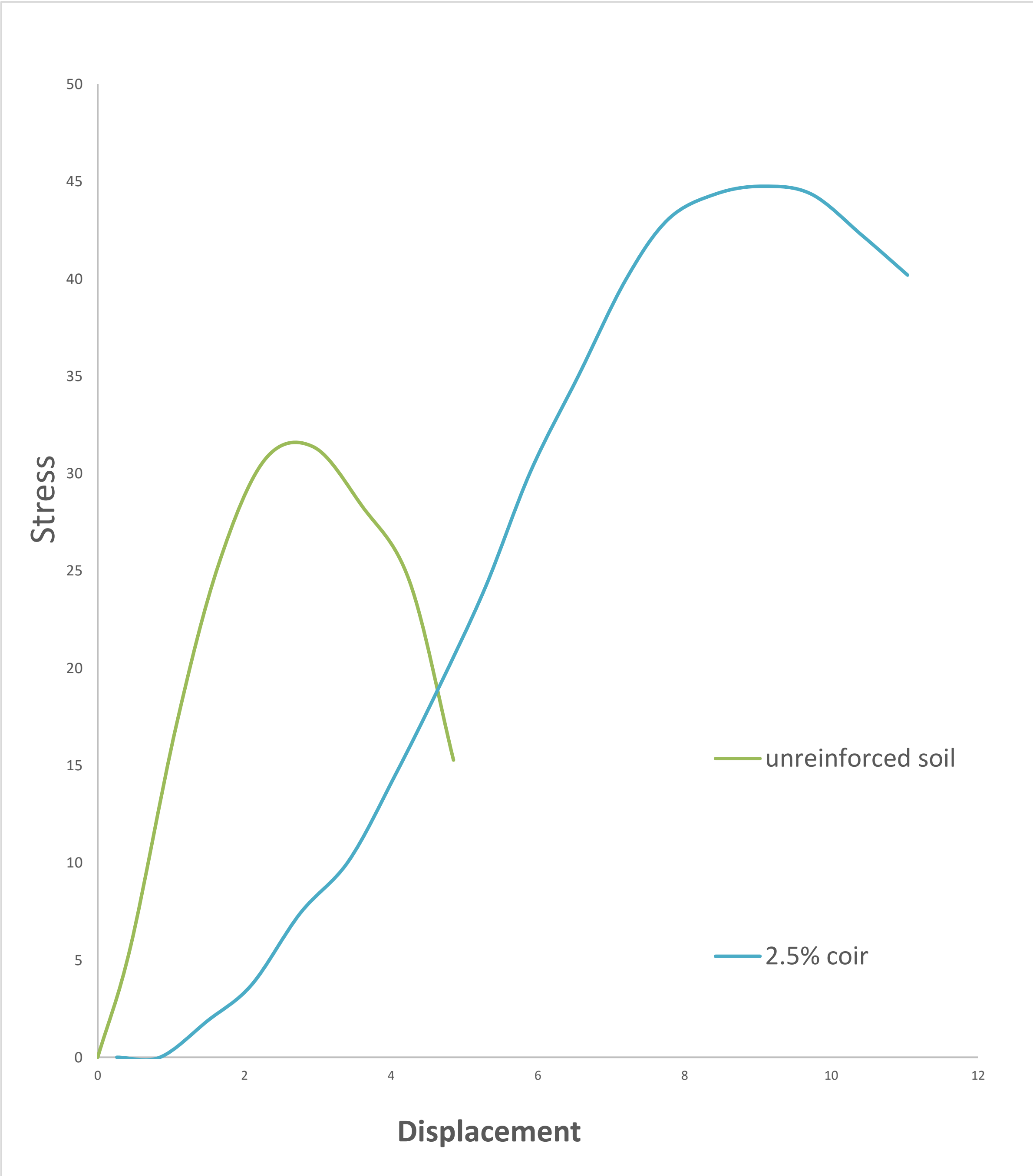


Fig. 5.9 Comparison between Unreinforced and coir reinforced sample (2.5% *f*)

Fig. 5.10 Comparison between Unreinforced (left) and coir reinforced sample (3% *f*) (right)

Figure 5.10 contrasts a 3% fiber content, coir-reinforced soil sample with an unreinforced soil sample. It is clear that samples reinforced with 3% coir fiber showed less cracking and preserved a greater portion of the soil sample as compared to an unreinforced soil sample. The graph in Fig. 5.11 compares a soil sample with 3% fiber content to one with no reinforcing. It is clear that whereas the stress range for the unreinforced sample is between 30 and 40 kPa, the range for the coir-reinforced soil sample with a 3% fiber content is between 50 and 60 kPa. The reinforced soil sample showed a 1.78 times greater soil stress tolerating value than the unreinforced soil sample.

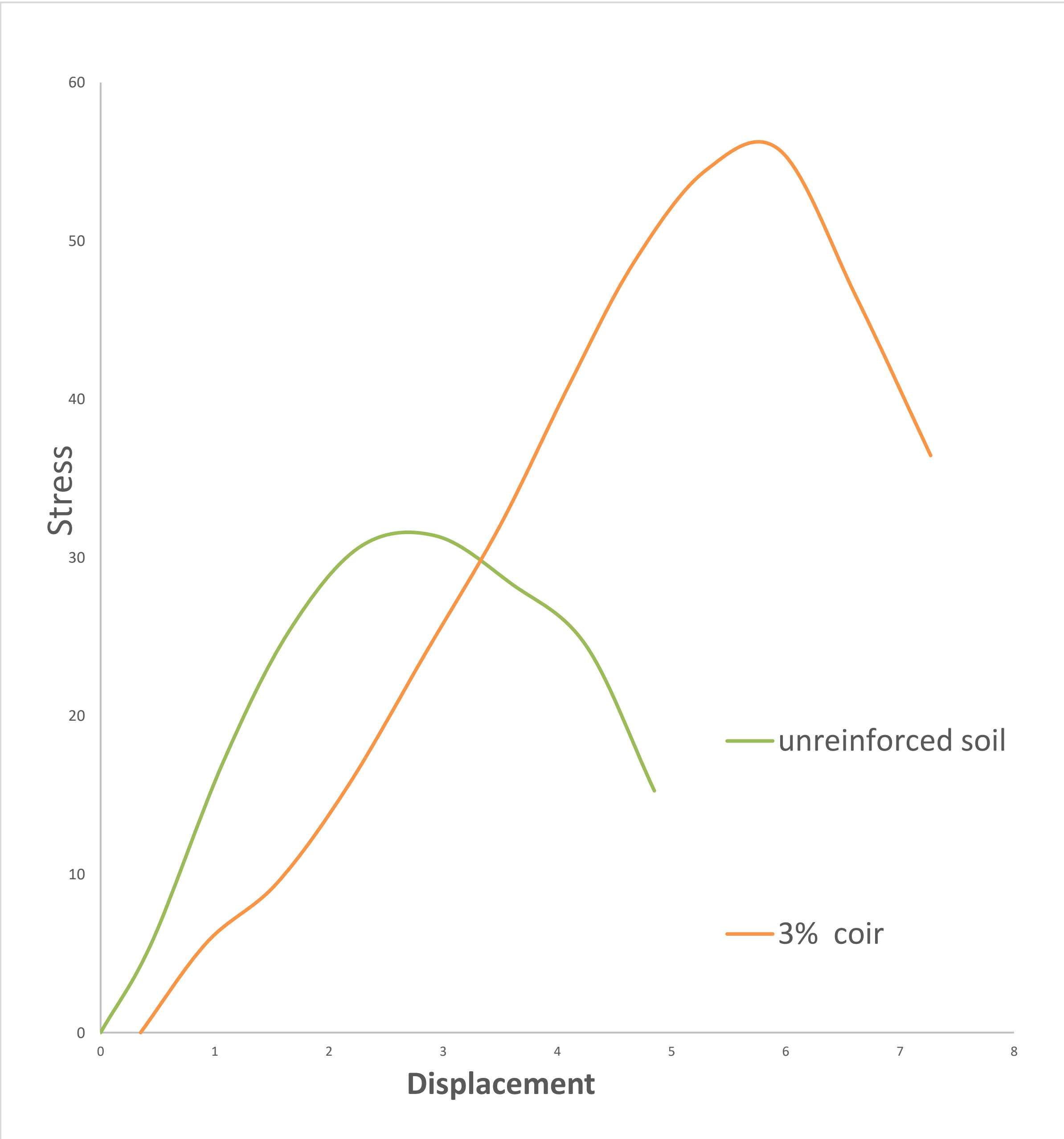


Fig. 5.11 Comparison between Unreinforced and coir reinforced sample

Fig. 5.12 Clockwise from top: 2% coir fiber reinforced soil; 2.5% coir fiber reinforced soil; 3% coir fiber reinforced soil.

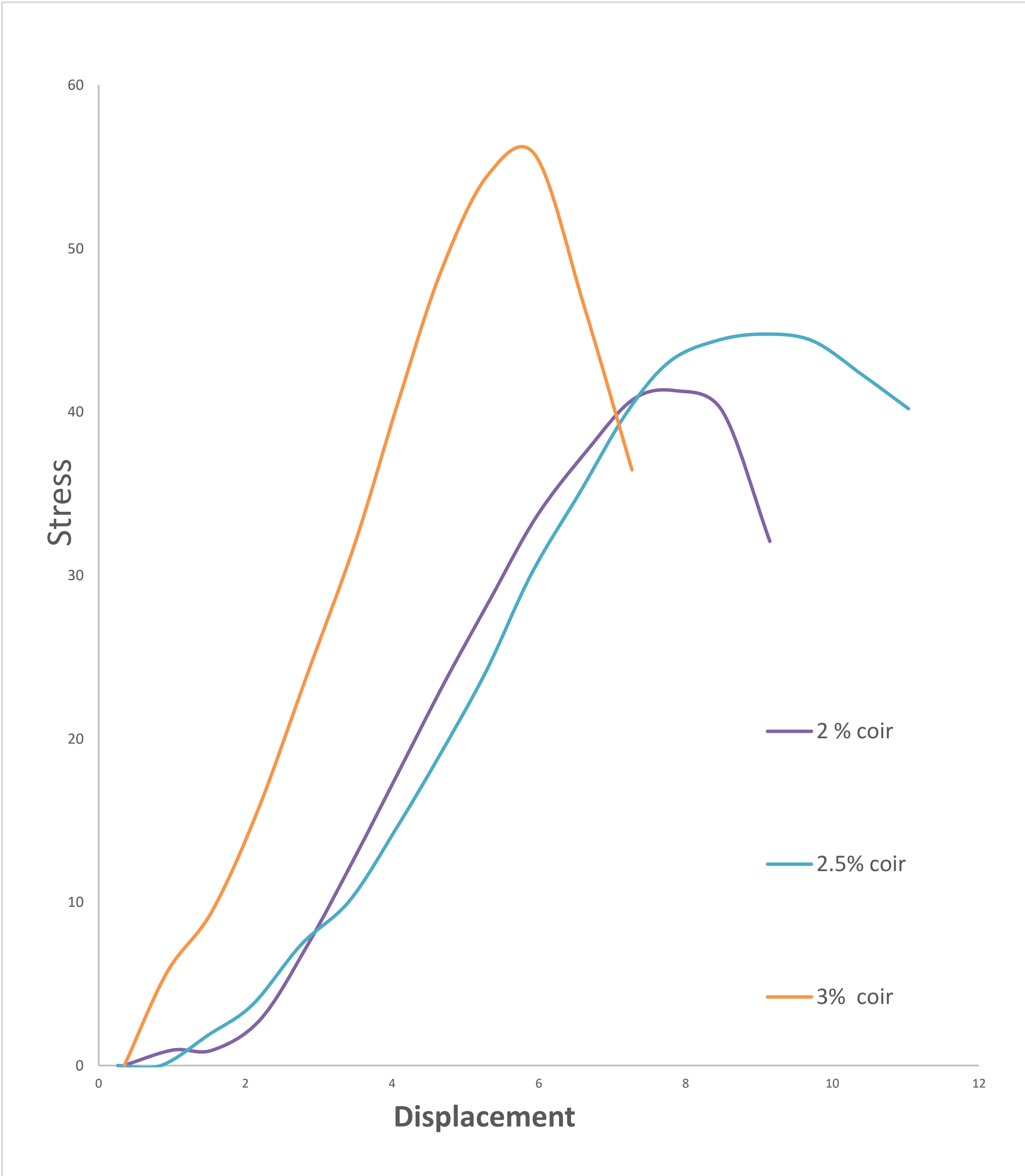


Fig. 5.13 Comparison of 2%, 2.5% and 3% coir fiber reinforced soil.

The comparison of the spread of cracks in a soil sample reinforced with coir fibers at different fiber contents (2, 2.5, and 3%) is shown in Fig. 5.12. From the observation, it is evident that samples reinforced with 3% coir fiber appear to have cracked less frequently than samples with 2.5 and 2% fiber content. This is supported by Fig. 5.13, which shows a visual comparison of soil samples reinforced with 2, 2.5, and 3% fiber. While 2% fiber reinforced soil showed a stress range of 30–40 kPa, 2.5% fiber reinforced soil showed a range of 40–50 kPa in the soil sample. The 50–60 kPa stress range, on the other hand, was revealed by a 3% fiber content reinforced soil sample, which is 1.24 times more than a 2.5% coir fiber reinforced soil sample and 1.4 times greater than a 2% fiber reinforced soil sample. As a result, a soil sample reinforced with coir fiber at a 3% fiber content appears to have superior fracture resistance and offers more shear strength value than the other two, making it appropriate for reinforcing in expansive soil.

Fig. 5.14 Comparison between Unreinforced (left) and jute reinforced sample (2% *f*) (right)

Fig. 5.14 compares a sample of unreinforced soil with a sample of soil that has been reinforced with jute fiber at a 2% fiber concentration. It is clear from Fig. 5.15 that the jute reinforcement caused the soil sample to break less than the unreinforced soil sample did. The soil sample in Fig. 5.15 that is not reinforced has a stress range of 30-35 kPa, but the sample that has been reinforced with 2% jute fiber has a stress range of 50-60 kPa, demonstrating the reduction in cracking as a consequence. The latter exhibits a 1.81-fold increase over the former one, making jute fiber more suited for soil reinforcement.

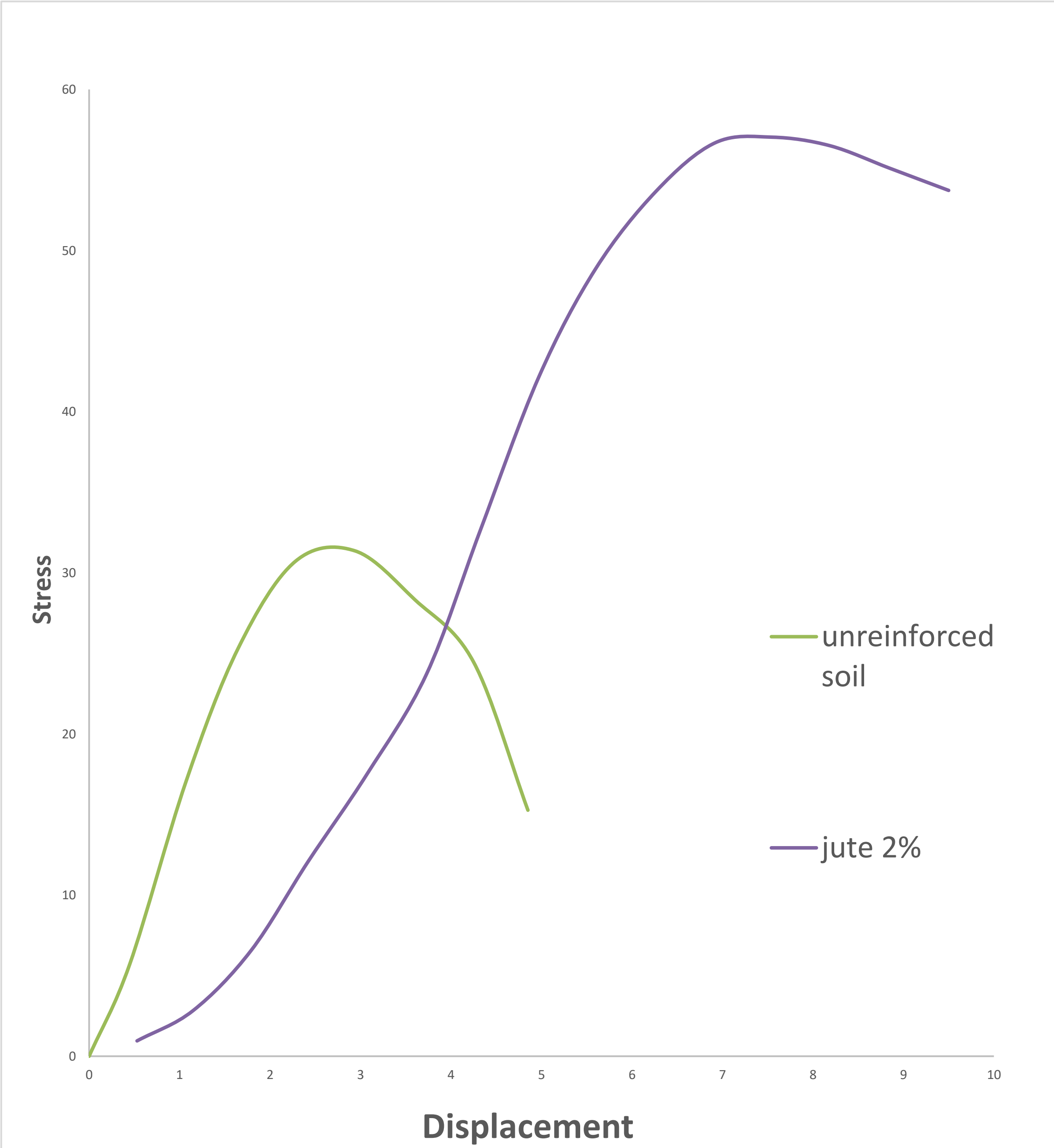


Fig. 5.15 Comparison between Unreinforced and jute reinforced sample

Fig. 5.16 Comparison between Unreinforced (left) and jute reinforced sample (2.5% *f*) (right)

Fig. 5.16 contrasts the sample photos of 2.5% jute fiber-reinforced soil with those of unreinforced soil. As reinforcement fiber content increased from 2% to 2.5%, the soil's ability to hold additional weight was demonstrated by the fact that reinforced soils crack less frequently than unreinforced ones and that more of the sample is preserved from cracking. In contrast to unreinforced soil, which has a shear stress of 30 to 40 kPa, the 2.5% jute-reinforced soil sample has a shear stress of 60 to 70 kPa, as shown in Fig. 5.17. The soil sample showed a 2.1 times improvement over unreinforced soil when the fibre content was raised by 0.5%.

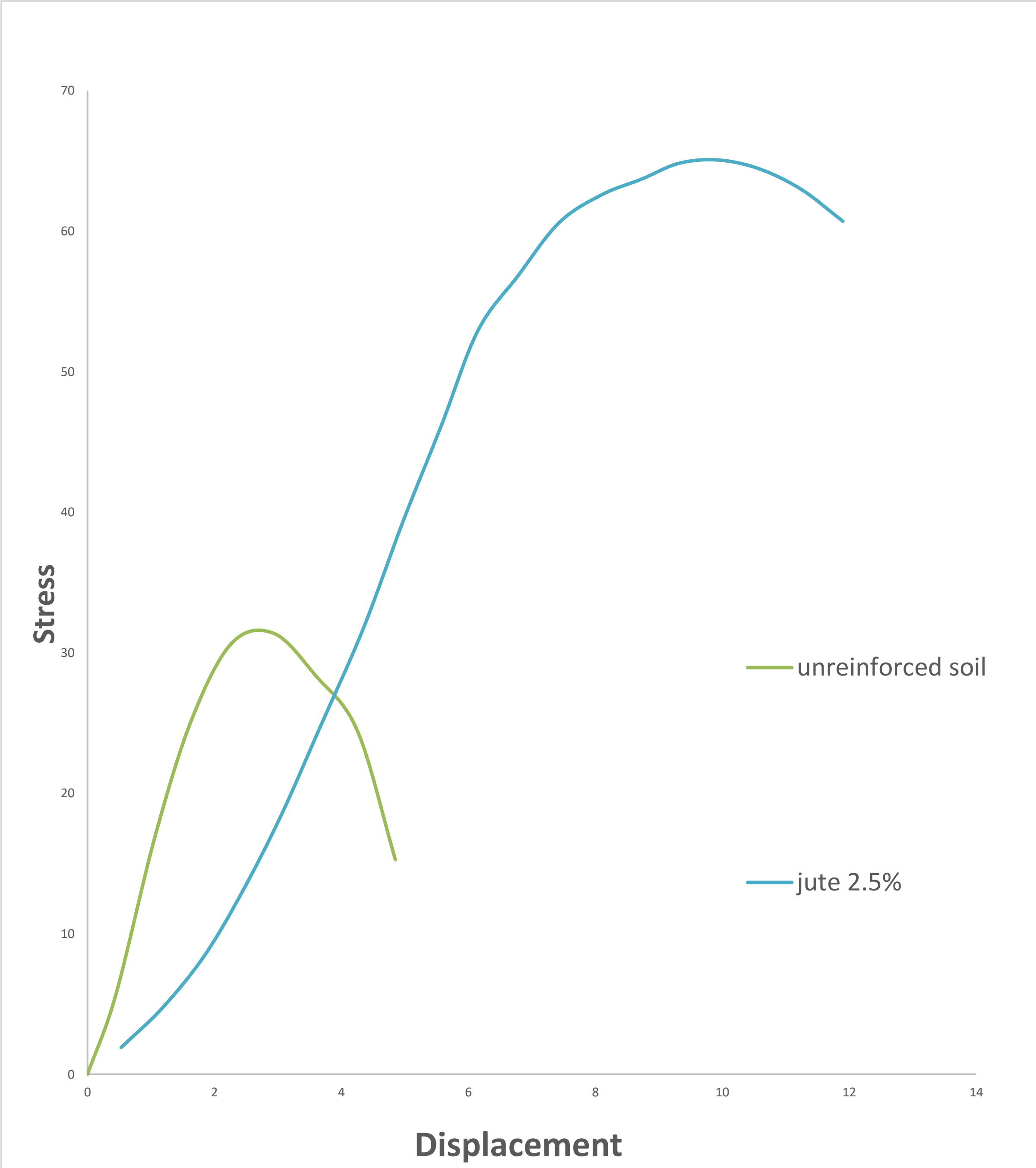


Fig. 5.17 Comparison between Unreinforced and jute reinforced sample

Fig. 5.18 Comparison between Unreinforced (left) and jute reinforced sample (3% *f*) (right)

Figure 5.18 compares a jute-reinforced soil sample with 3% fiber content to an unreinforced soil sample. When compared to an unreinforced soil sample, samples reinforced with 3% jute fiber exhibited less cracking and maintained a greater amount of the soil sample. Figure 5.19 shows a graph that compares a soil sample with 3% fiber content to one with no reinforcing. The stress range for the unreinforced sample is clearly between 30 and 40 kPa, whereas the range for the jute-reinforced soil sample with a 3% fiber content is between 70 and 80 kPa. The reinforced soil sample had a soil stress tolerating value that was 2.22 times larger than unreinforced soil sample.

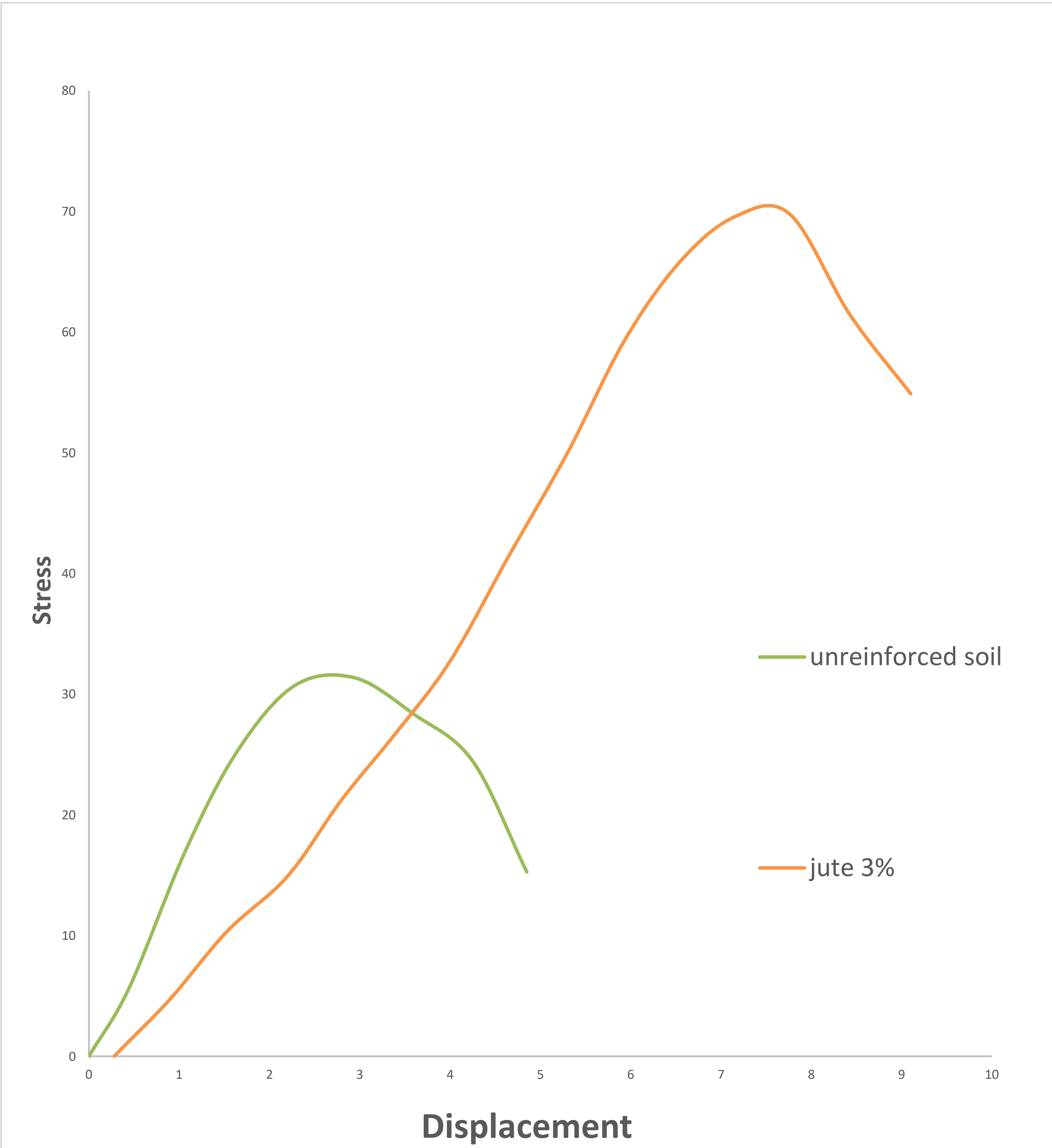


Fig. 5.19 Comparison between Unreinforced and jute reinforced sample

Fig. 5.20 Clockwise from top: 2% jute fiber reinforced soil; 2.5% jute fiber reinforced soil; 3% jute fiber reinforced soil.

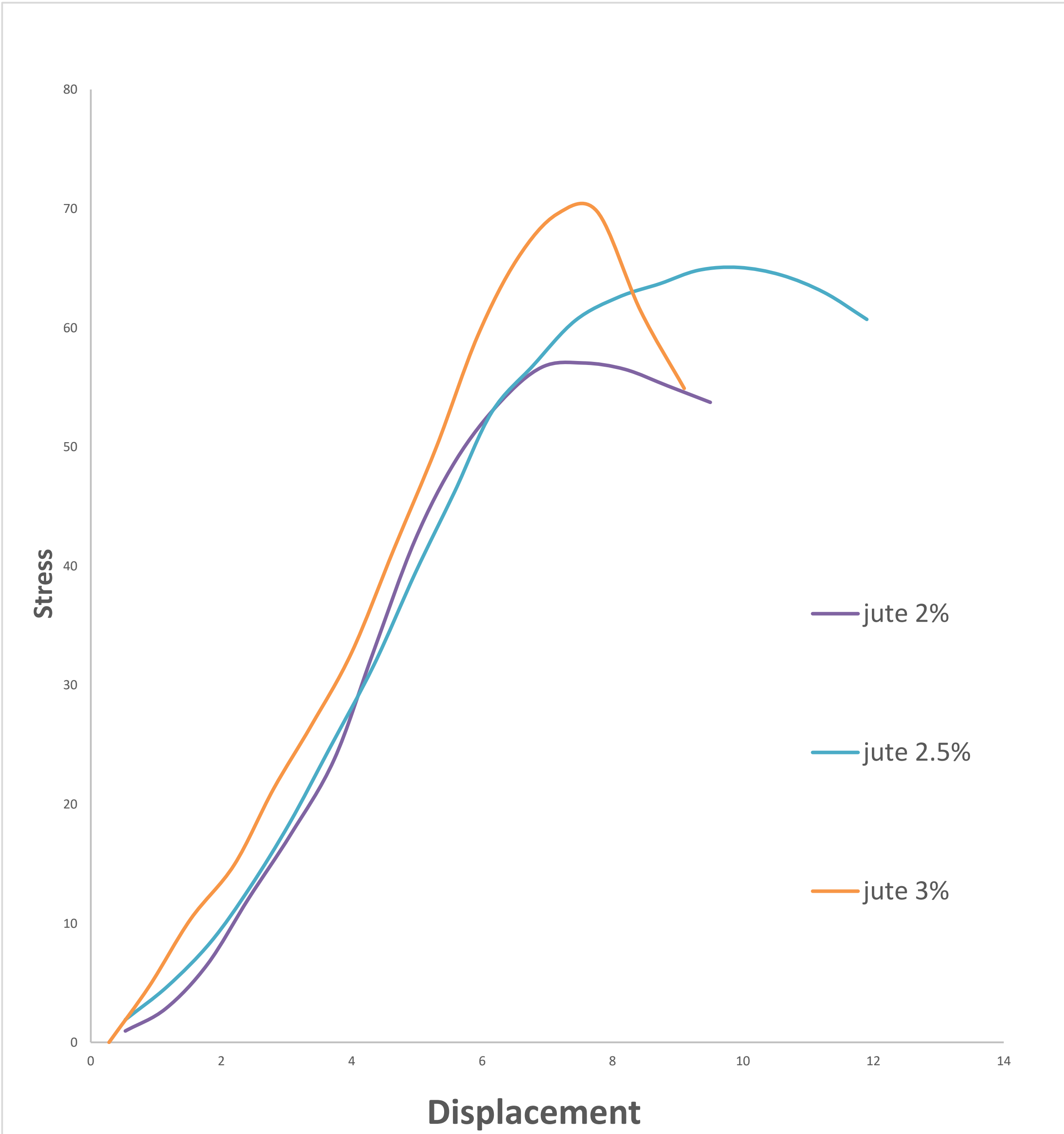


Fig. 5.21 Comparison of 2%, 2.5% and 3% jute fiber reinforced soil.

Figure 5.20 depicts a comparison of the propagation of fractures in a soil sample reinforced with jute fibers at varied fiber levels (2, 2.5, and 3%). According to the findings, samples reinforced with 3% jute fiber fractured less frequently than samples with 2.5 and 2% fiber content. Fig. 5.21 illustrates a visual comparison of soil samples reinforced with 2, 2.5, and 3% fiber. While 2% fiber reinforced soil had a stress range of 50-60 kPa in the soil sample, 2.5% fiber reinforced soil had a stress range of 60-70 kPa. A 3% fiber content reinforced soil sample, on the other hand, indicated a 70-80 kPa stress range, which is 1.07 times more than a 2.5% coir fiber reinforced soil sample and 1.23 times greater than a 2% fiber reinforced soil sample. As a consequence, a soil sample reinforced with 3% coir fiber appears to have greater fracture resistance and shear strength value than the other two, making it suitable for reinforcing in expansive soil.

Fig. 5.22 Comparison between Coir Reinforced (3% *f*) (left) and Jute reinforced sample (3% *f*) (right)

In the final comparison, it can be seen that the 3% fiber content in both coir and jute fiber appears to have offered the best resilience to cracking and capacity to carry the weight after reinforcing. In this scenario, the crack propagation comparison for coir and jute fiber at 3% fiber content is shown in Fig. 5.22. The photographs clearly reveal that jute fiber appears to have displayed the least breaking and that more sample was saved after the trial. This is connected to Fig. 5.23, which shows a graphical comparison of the stress value of jute and coir reinforced fiber at 3% fiber content. While coir fiber has a stress range of 50-60 kPa, jute fiber has a stress range of 70-80 kPa, which is 1.2 times greater load bearing capability than the former. As a consequence, it can be inferred that jute fiber is a superior fiber for soil reinforcement, with fiber content kept at 3% to provide better outcomes.

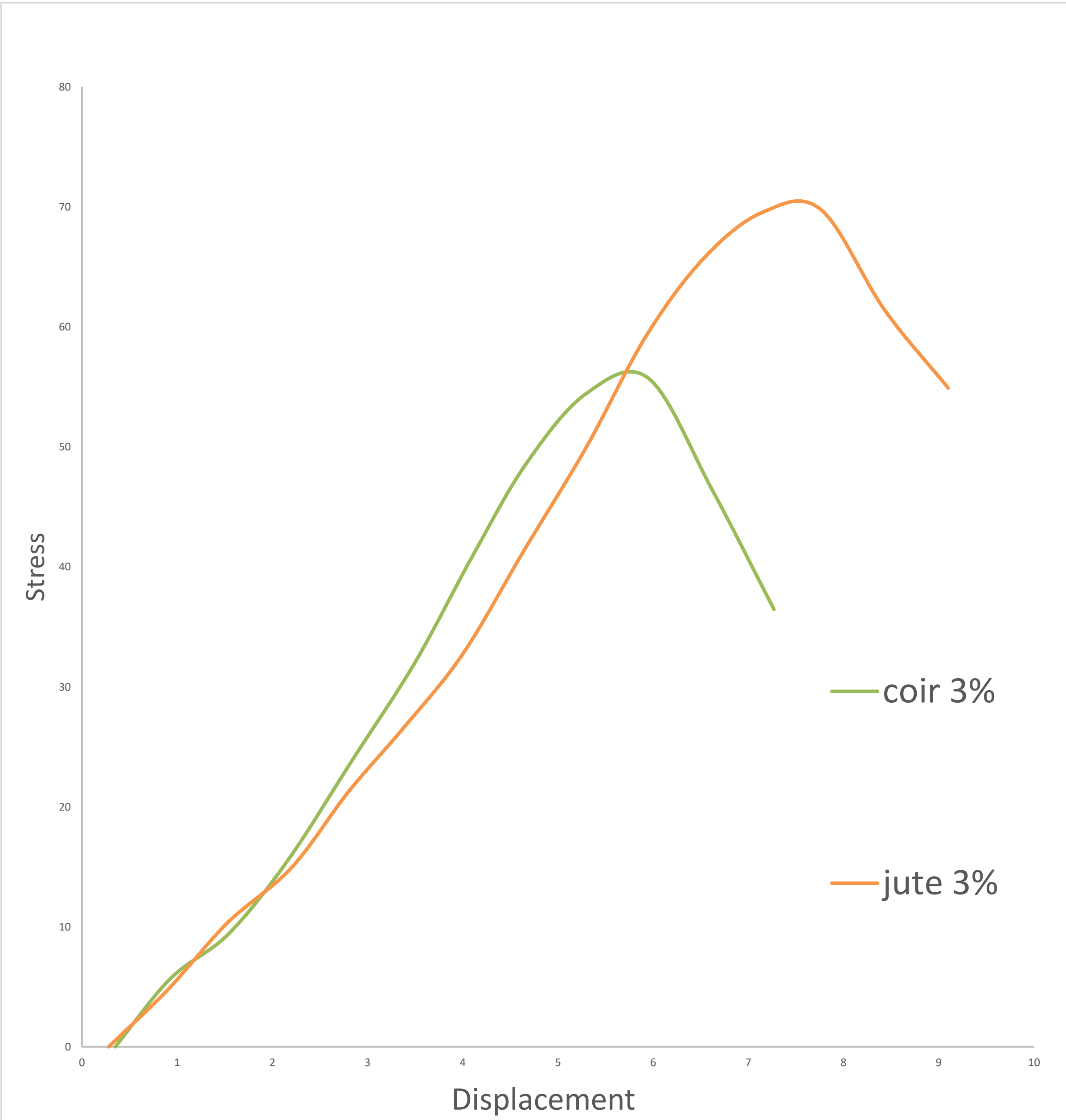


Fig. 5.23 Comparison between jute and coir fiber at 3% fiber content

5.3. FINITE ELEMENT RESULTS

The goal of finite element analysis is to forecast how the object will respond under various physical conditions through calculation, models and simulations. With variety of software available for finite element analysis such as Autodesk AutoCAD 3D FEA, ANSYS, OpenFOAM, ABAQUS and so on. In this study, the software used is ABAQUS standard package by Dassault Systems. For analysis, there are 2 types called as Static analysis or Dynamic analysis. For this one, static analysis was used. It is accomplished by time independent integration scheme using static general steps in ABAQUS standard. Static analysis further can be linear Static analysis or Non- linear Static analysis. For present research Non- linear Static analysis was used for model analysis.

Fig. 5.24 ABAQUS Model used for FINITE ELEMENT ANALYSIS

Fig. 5.24 is the ABAQUS model used for FINITE ELEMENT ANALYSIS in this research. A cylindrical figure having fixed dimensions of diameter 38mm and length of 76mm. It has been analyzed using static general steps in ABAQUS standard. With loading conditions constrained along Z axis from the one side, other side being applied a uniformly increasing load. The static analysis performed on the Model was non-linear in nature. Meshing was done using global seeding tool. An 8 node non-linear element with hourglass control was used for meshing. Post Analysis the readings of Force and Displacement were extracted from the software and further analyzed to obtain stress and strain readings and graph for comparison with the experimentation results. Fig. 5.25 depicts the displacement magnitude of the model used.

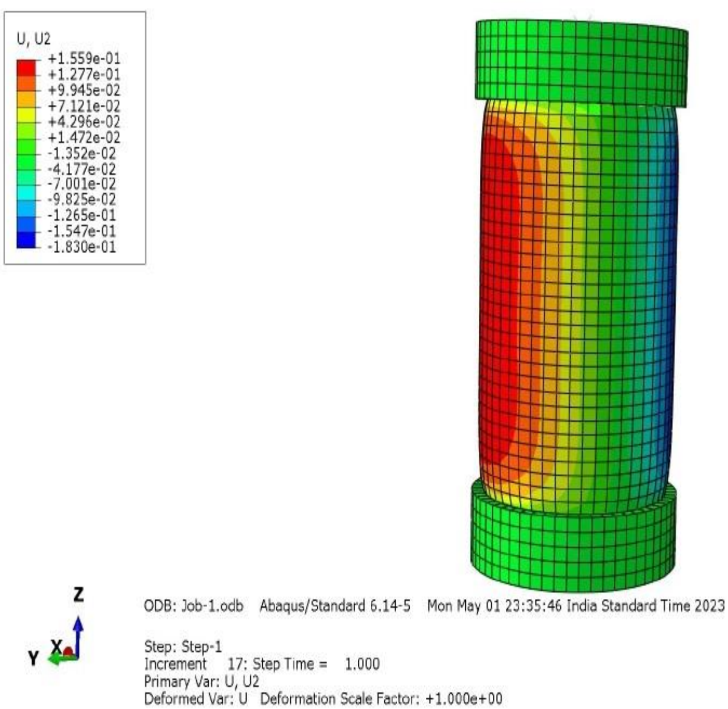


Fig. 5.25 Displacement Magnitude using ABAQUS analysis

Force	Displacement	Strain	Corrected Area	Stress
0	0.3648	0.48	11395.80	0
3.539937	0.91162	1.1995	11478.79	3.0253
11.29817	1.613404	2.1229	11587.08	9.5654
17.4343	2.127164	2.7989	11667.67	14.6585
21.46085	2.88686	3.7985	11788.90	17.8584
22.09471	3.419164	4.4989	11875.36	18.252
19.46286	3.96036	5.211	11964.57	15.958
14.80049	4.632504	6.0954	12077.26	12.022

Table 5.3 Results of ABAQUS Analysis Accomplished

Table 5.3 displays the findings of the model's study. Initially, force and displacement values were collected from the study and then processed to generate a stress-strain graph and compare it to the original experiment results. The relationship between the experimental and ABAQUS results is depicted in Fig. 5.26. The experimental and ABAQUS outcomes are obviously in good agreement with one other. As a consequence, it validates the experimentation outcomes.

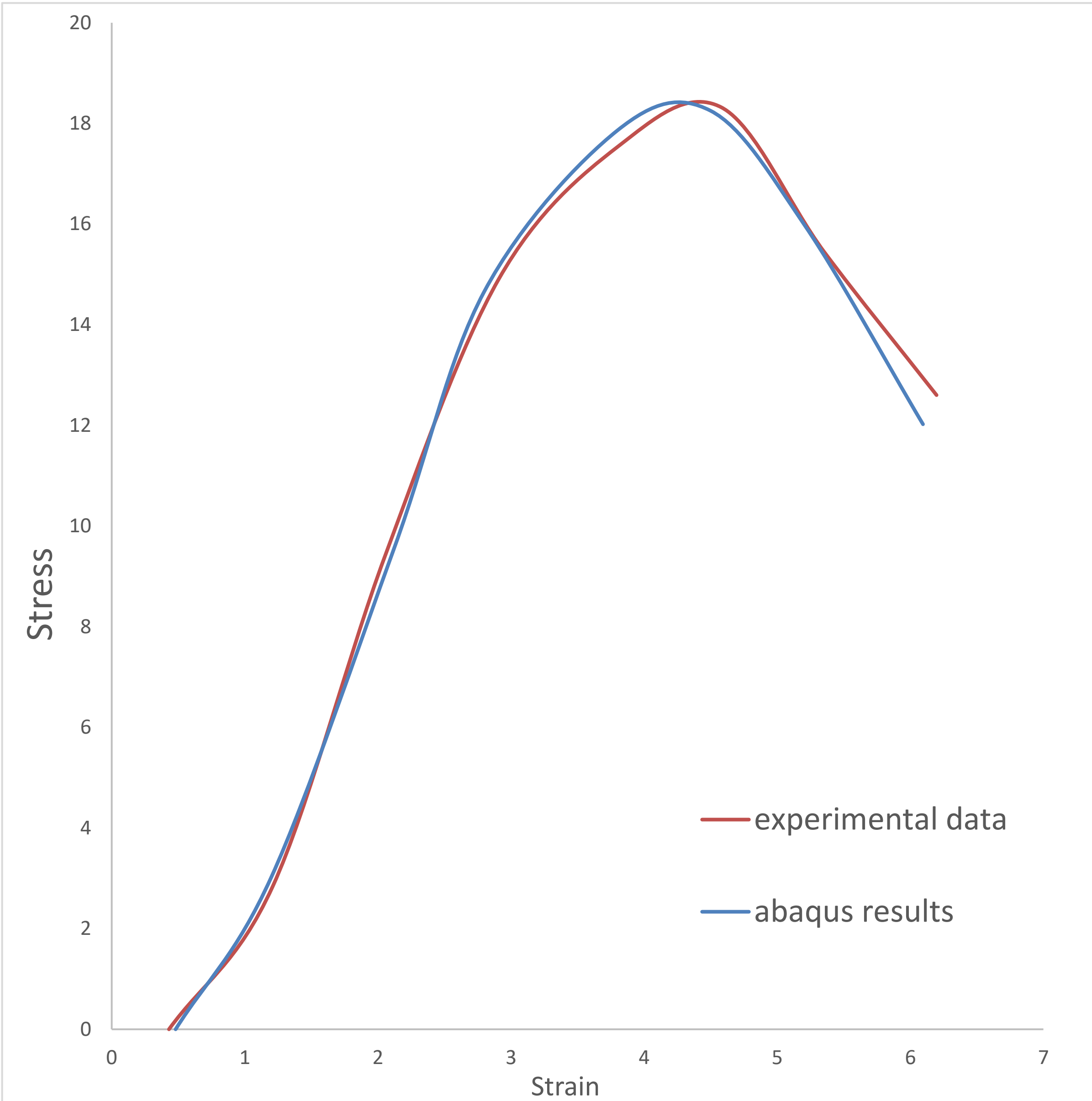


Fig. 5.26 Results of ABAQUS analysis compared with Experimental Results

CHAPTER 6
CONCLUSION

6.1. CONCLUSION

By this study following conclusion can be reached based on the analysis and interpretation of the results:

1. Reinforcing the vast soil of Rajasthan with natural fibres like coir and jute will increase its resilience.
2. The peak strength σ_{pc}, Average strain ε_a and modulus of resilience U_r increases with fiber reinforcement. The 3 parameters mentioned depicts the best strength capacity in 3% fiber content reinforcement.
3. The Soil 2 depicts the strength capacity increase of almost 2 times the Soil 1 with increase in fiber content lead to higher value of the σ_{pc}, ε_a and U_r.
4. For same fiber content jute is found to have provided better results than the coir fiber. It has been found that jute is able to bear 1.2 times excess of load than the coir fiber within the same fiber content categories.
5. It implies that jute serves as a better fiber for reinforcement as compared to coir fiber.

The verification of experimental results by ABAQUS model further concretes the fact that natural fibers can not only be an alternative to the lime or fly ash treatment in the Rajasthan's soil but also a improved way to conserve the already degrading soil bionetwork of the Rajasthan. Thus, the fibers can be economical and eco-friendly in use as compared to the prevalent methods in the market

6.2. FUTURE SCOPE

- This study can be used in conserving Rajasthan's Ecosystem from further degradation of soil and its elements.

- Because working with substances such as marble dust and lime can result in respiratory disorders, carcinogenic diseases, and even blindness in rare situations. These effects can be eliminated simply by replacing lime or marble dust with natural fibers.
- Application and study of use of natural fibers in reinforcement of expansive soil in layers form can be studied.
- A comparison of several natural fiber combinations for soil reinforcement can be investigated to determine the ideal fiber combination delivering greatest strength.

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