Major Project-II Report On

LABORATORY EVALUATION OF FIBRE REINFORCED SOIL

Submitted in Partial Fulfillment for the Award of the Degree of

MASTERS OF TECHNOLOGY

IN

CIVIL ENGINERING

With Specialization In

GEOTECHNICAL ENGINEERING

By

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CERTIFICATE

This is to certify that the Major Project-II Report entitled "**LABORATORY EVALUATION OF FIBRE REINFORCED SOIL**" is a bona fide record of work carried out by Swapneel Kalra (Roll No. 2K13/GTE/20) under my guidance and supervision, during the session 2015 in partial fulfillment of the requirement for the degree of Master of Technology (Geotechnical Engineering) from Delhi Technological University, Delhi.

The work embodied in this Major Project-II has not been submitted for the award of any other degree to the best of my knowledge.

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ACKNOWLEDGEMENT

As I write this acknowledgement, I must clarify that this is not just a formal acknowledgement but also a sincere note of thanks and regard from my side. I feel a deep sense of gratitude and affection for those who were associated with the project and without whose co-operation and guidance this project could not have been conducted properly.

Words fail me to express my gratitude towards my project guide, **Dr. A. K. Gupta,** Professor, Civil Engineering Department, Delhi Technological University, New Delhi for giving me an opportunity to work under his guidance, which really instilled in me the requisite confidence.

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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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DECLARATION

I hereby declare that the work being presented in this Project Report entitled "**LABORATORY EVALUATION OF FIBRE REINFORCED SOIL"** is a bona fide record of work carried out by me as a part of Major Project-II in partial fulfillment of the requirement for the degree of Masters of Technology in Geotechnical Engineering.

I have not submitted the matter presented in this report for the award of any degree.

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ABSTRACT

We all know that the soil is good in compression, but very weak in tension. This weakness of the soil restricts its use in certain civil engineering applications such as steep slopes in which generally shear failure occurs. Thus arises the need for the modification of soil strength parameters for its improved performance in desired areas.

This deficiency of soil can be eradicated by reinforcing the soil; i.e. the introduction of an external material into the soil. The main aim is the creation of such a material/system that will hold under the design use conditions and for the designed life of the engineering project.

The concept of earth reinforcement with the help of fibrous materials is an ancient technique and has been demonstrated abundantly in nature by animals, birds and the action of tree roots. This fibrous reinforcement resists tensile stress developed within the soil mass thereby restricting shear failure.

In this investigation, Recron 3S polypropylene fibre manufactured by Reliance India Ltd., has been used. Polypropylene Fibres are engineered micro fibers with a unique "Triangular" Cross-section shape and are widely used in construction, mining, agricultural, textile and automotive industry.

An experimental investigation was undertaken to study the effect of polypropylene fibre inclusion on the interface shear strength of soil. Test specimens were prepared with varying percentages of 6 mm PP fibre (non-reinforced, 0.25%and 0.50%) by the weight of dry soil. A series of Direct Shear Tests & Unconsolidated-Undrained Triaxial tests were conducted on randomly distributed fibre reinforced soil and the effect of various proportions of polypropylene fibre on the properties of soil were noted. The soil was obtained from a proposed Nuclear Power plant site in Gorakhpur, Haryana.

The shear strength parameters were measured using a standard size (60 mm*60 mm) Direct Shear box test. The tests were conducted on three different normal stress i.e. 0.1, 0.2 & 0.3 N/mm^2 and the angle of internal friction and cohesion intercept values were obtained by plotting a straight line through the plot of shear stress versus the normal stress.

Also the Mohr failure envelope was plotted by conducting UU Triaxial tests at three different confining pressures; i.e. 0.1, 0.2 & 0.3 N/mm^2. The variation in the cohesion & angle of internal friction of the unreinforced soil and fibre reinforced soil were compared.

There was increase in the compressive strength & shear strength value of the soil on the addition of fibre. Also the cohesion intercept of the reinforced soil increased slightly. But the angle of internal friction reduced for the fiber reinforced soil. Scanning Electron Micrographs indicated that the obtained results were due to the special cross-section of the polypropylene fibre.

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CHAPTER-1

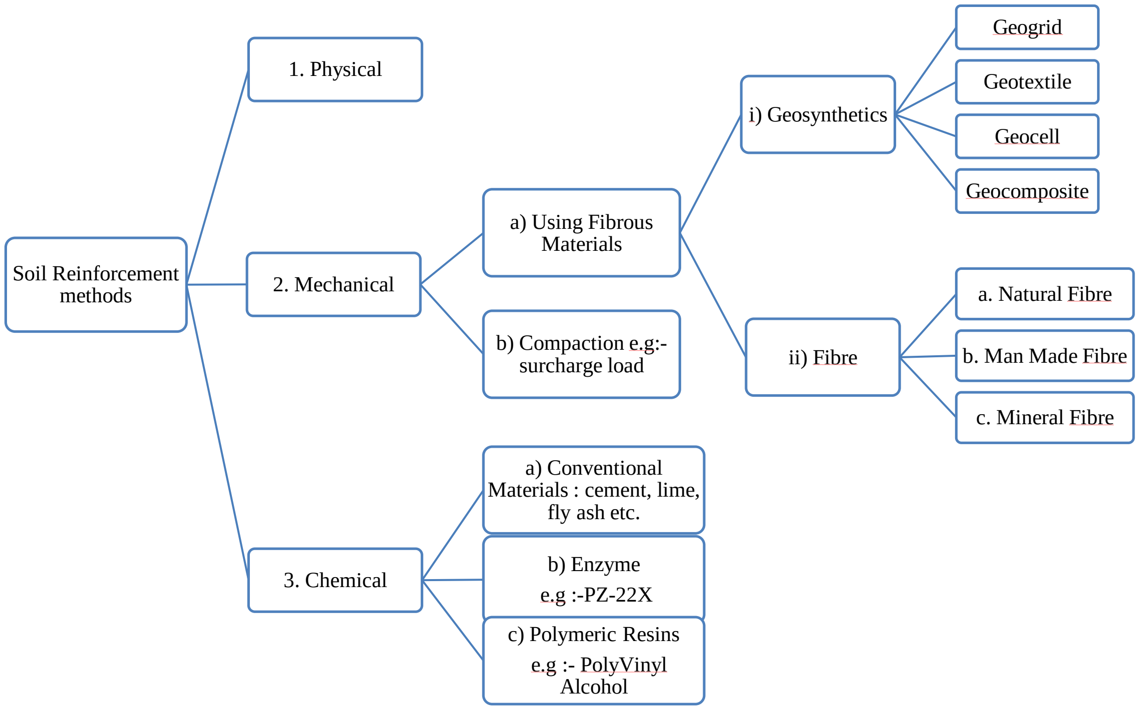
INTRODUCTION

Due to the fast growth of human population and the need of good quality of life, there have been an exponential increase in the constructional activity. Due to this fast expansion and restriction of land, different civil engineering structures have to be constructed even where the soil cannot sufficiently bear the load of the superstructure. Thus the need arises for soil improvement.

We all know that the soil is good in compression, but very weak in tension. This weakness of the soil restricts its use in certain civil engineering applications such as steep slopes in which generally shear failure occurs. Thus arises the need for the modification of soil strength parameters for its improved performance in desired areas. This deficiency of soil can be eradicated by reinforcing the soil; i.e. the introduction of an external material into the soil.

Composite materials can be defined as those materials which combine the strength of two or more materials in a supplementary way. These composite materials are widely used in various fields of engineering. The main aim is the creation of such a material/system that will hold under the design use conditions and for the designed life of the engineering project.

Soil reinforcement basically means the introduction of an external material into the soil, in such a manner that the overall behavior of soil is significantly improved.



Mechanically Reinforced soils can be of two types, depending on the type of external material and the layout by which it is introduced in the soil.

1. Systematically Reinforced Soil
2. Randomly Reinforced Soil

Systematically Reinforced Soils are those in which continuous reinforcement are introduced in a predetermined and a defined pattern. For e.g.: - Reinforcement with Geosynthetics.

Randomly reinforced soils are those in which the reinforcing material is not placed in a defined pattern, rather it is mixed into the soil uniformly. For e.g.:- Reinforcement with different type of fibres.

Reinforcement with an external material improves the overall capacity of the composite system, or reduces the probability of potential failure.

Advantages of soil reinforcement:-

1. It improves the overall strength of the soil, thus increasing its bearing capacity.
2. It is more economical to enhance the soil, rather than going for a deep or raft foundation.
3. It is one of the best methods for improving the slope stability in soils.
4. It reduces the probability of failure of soil along its weaker plane.

Inclusion of external material into soil improve its load deformation behavior by interacting with soil particles mechanically either through surface friction or interlocking or both. The transfer of stress from the soil to the reinforcing material helps in mobilizing the tensile strength of the external material. Thus the formation of such a system takes place which helps utilize both the benefits of soil and the external reinforcing material.

1.1 FIBRE REINFORCED SOIL

1.1.1 INTRODUCTION

Randomly distributed fibre reinforced soil-termed as RDFS is among the latest ground improvement techniques in which fibres of desired type and quantity are added in soil, mixed randomly and laid in a random position after compaction. RDFS is different from other types of soil reinforcing methods in its orientation. In reinforced earth, the reinforcement in the form of strips, sheets, etc. is laid horizontally at specific intervals and in specific directions, where as in RDFS fibres are mixed randomly in soil thus making a homogeneous mass and maintain the isotropy in strength. Modern geotechnical engineering has focused on the use of planar reinforcement (e.g. metal strips, sheet of synthetic fabrics). However reinforcement of soil with discrete fibres is still a relatively new technique in a geotechnical engineering project.

1.1.2 ADVANTAGES OF FIBRE-REINFORCED SOIL

Randomly distributed fibre reinforced soil (RDFS) offers many advantages as listed below:

- Beneficial for all types of soil (i.e. sand, silt, clay).
- Increases shear strength with the maintenance of strength isotropy.
- Reduces post peak strength loss.
- Increases ductility
- Increases seismic performance
- Great potential to use waste materials such as coir fibres, shredded tires.
- Reduces shrinkage and swell pressure of expansive soil.
- Provide erosion control and facilitate vegetation development.
- No appreciable change in permeability.
- Unlike cement, lime and other chemical stabilization methods, the construction using fibre-reinforcement is not significantly affected by weather conditions.
- Fibre-reinforcement has been reported to be helpful in eliminating the shallow failure on slope face and thus reducing the cost of maintenance.

1.1.3 BASIC MECHANISM OF RDFS

Randomly oriented discrete inclusions incorporated into soil improve its load-deformation behavior by interacting with the soil particles mechanically through surface friction and also by interlocking. The function of the bond or interlock is transfer of stress from the soil to the discrete inclusions by mobilizing the tensile strength of discrete inclusion. Thus fibre reinforcement works as a frictional and tension resistance elements.

1.1.4 DIRECTION OF PLACEMENT

Fibres can be oriented or randomly mixed in soil. In oriented category, the inclusions are placed within the soil at specific positions and direction where as in random category, inclusions, are mixed with soil and placed within probable shear zone similar to the placing of geotextiles along slops and retaining walls. In the field placing the fibres at some orientation is a tedious task. In reinforced soil the added material (the geosynthetics sheet, etc.) is layered at a specific direction and position, which may keep the soil weaken in some other direction. Where as in randomly reinforced soil, the fibre is mixed randomly into the soil by a fixed predetermined proportionand helps to maintain the strength isotropy.

Random reinforcement has been provided to different types of soil in form of mesh elements, discrete fibres, continuous yarn/ filament, waste tire-chips waste plastic strips, etc. by various investigations.

1.1.5 FACTORS AFFECTING THE STRENGTH CHARACTERISTICS OF ENGINEERING PROPERTIES OF RDFS

The factors on which the strength characteristics and other engineering properties of RDFS depend are as follows:

- Type of soil: It includes soil gradation expressed in terms of mean grain size (D_{10}) and Uniformity coefficient (C_U).
- Type of fibre: Monofilament or fibrillated.
- Denier of fiber: It is the weight of fibre (in grams) of 900-meter long fibre.
- Aspect ratio: It is defined as ratio of length of fibre to its diameter
- Fibre soil surface friction.

1.2 POLYPROPYLENE FIBRE

1.2.1 INTRODUCTION

Polypropylene fibre was first produced back in 1951 and is the second most important plastic with revenues expected to exceed US$145 billion by 2019. The sales of this material are forecast to grow at a rate of 5.8% per year until 2021. Its fibre found its first use in the civil industry in the year 1965 as an admixture in concrete by the USACE (U.S. Corps of Engineers).

Polypropylene is a synthetic fiber derived from coal, air, water, and petroleum. Developed in a 20th-century laboratory, polypropylene fibers are formed from a chemical reaction between an acid and alcohol. In this reaction, two or more molecules combine to make a large molecule whose structure repeats throughout its length.

1.2.3. SHAPE OF POLYPROPYLENE FIBRES

Polypropylene fibres have a unique triangular cross-section, which gives 40% more surface area for bonding compared to other shapes. Polypropylene fibres is designed in such a way that the fibre stays dimensionally straight and uniformly dispersed, so as to safe guard against balling, curling and bunching.

1.2.4. WORKING OF POLYPROPYLENE FIBRES

Polypropylene fibres when mixed with cement in the concrete batch mixing/ mortar preparation stage, spreads throughout the matrix and gives three-dimensional secondary reinforcement. It is also known to improve workability. The early micro-cracks formed due to heat of hydration, shrinkage and expansion before and post-hardening are avoided by the presence of polypropylene fibre, which acts as a barrier for further propagation of cracks.

1.2.5. APPLICATIONS OF POLYPROPYLENE FIBRE IN CONSTRUCTION

- RCC, PCC like lintel, beam, column, flooring & wall plastering
- Manhole covers, tanks, foundations and tiles
- Plastering
- Roads and pavements

1.2.6. ROLE OF POLYPROPYLENE FIBRE IN CONSTRUCTION INDUSTRY

Polypropylene fibre is added at a small dosage of 0.25% on the weight of cement, helping in various ways to improve quality of construction as well as raw material, labour, time and money saving.

- Controls cracking
- Reduces water permeability
- Reduces rebound loss - Brings direct savings and gains
- Increases flexibility
- Increased abrasion resistance

1.2.7. USE OF POLYPROPYLENE FIBRE IN PLASTERING

- Use of Polypropylene fibre checks plastic and drying shrinkage cracks and plastic settlement cracks.
- It helps in reducing the water seepage through the micro-cracks formed in plaster and thus protects the iron rebar from corrosion.
- Polypropylene fibre reduces the rebound loss of material by 50-70%. This result in direct saving of raw material, bringing back the cost of Polypropylene fibre added, resulting in equal amount of money saving. The faster pace of work and the saving in labour are added cost savings.
- The plaster free from micro-cracks also improves the aesthetics and helps avoid the expense on frequent repainting and repair work.

1.2.8. ROLE OF POLYPROPYLENE FIBRE IN CONCRETE

- Cracks in concrete are accepted by construction industry to be natural to its use. Polypropylene fibre developed by Reliance helps in avoiding the micro-cracks in the structure improving longevity.
- The micro-cracks formed in the plastic stage, at the cement curing stage and drying stage are arrested by the physical presence of Polypropylene fibre in three dimensions throughout the matrix.
- The corrosion of primary reinforcement over a period of time through seepage of water from the micro-cracks is avoided. The rust stains free structure gives

added quality to the construction.

- Polypropylene fibre also significantly improves resistance impact and abrasion improving life of road, flooring etc.
- Other improvements seen in fibre reinforced concrete :-
  - ➢ Improved flexural strength
  - ➢ Better abrasion than plain concrete.

1.3 NECESSITY OF STUDY

- Higher subgrade strength lowers the thickness of overlying layers hence makes the road construction economical.
- Large types of synthetic fibres are available in market easily at an economical price.
- Placing randomly distributed fibres in soil are easy as compared to the reinforced soil in which the added material (the geosynthetics sheet, etc.) is layered at a specific direction and position, which may keep the soil weaken in some other direction. Where as in ply soil, the isotropy in strength is maintained.

OBJECTIVES OF THE STUDY

- To study the effect of content of polypropylene fibre addition on the shear strength of soil by conducting Direct Shear Tests.
- To study the effect of content of polypropylene fibre addition on the compressive and shear strength of soil by conducting UU Tests.
- To draw a comparison between shear strength parameters of both unreinforced and fibre reinforced soil.
- To study the difference in shear strength parameters obtained by Direct Shear tests & UU tests.
- To notice the soil-fibre abrasion effect by conducting SEM (Scanning Electron Microscope) tests

CHAPTER-2

LITERATURE REVIEW

Reinforcement with polypropylene fibre is a relatively new concept. Its first use in Civil engineering was as an admixture in concrete mainly to resist the development of micro cracks. The fibre found its use in soil as a reinforcing material in the late 20th century.

Previous studies have shown that reinforcement with fibres have increase the shear and compressive strength of soil. Also the effect of fibre addition on the change in the soil shear parameters were studied. In case of dense sands, the addition of fibre could reduce soil brittleness by providing a smaller loss of post peak strength. Other studies have shown increased CBR values, unconfined strength, axial strain at failure, etc. The application of fibre in various geotechnical aspects can be quite diverse and the future scope of this type of reinforcement is convincing.

Following is a brief literature review of some of the previous work conducted on soil reinforcement with the help of Polypropylene fibres.

Review of Literature:

K. Furumoto et al. (2002) have conducted a study on short fiber reinforced soil aiming to improve the roughness and strength of soil by adding fibre to the soil. Their work constituted of permeability tests to find out the piping resistance of the fibre-reinforced soil. Furthermore, large-scale levee model tests were done to find out the applicability of the fiber reinforced soil layer to the river levee structure. It was observed that the short fiber reinforced soil layer increased the stability of levee against seepage of rainfall and flood also it was observed that the short fiber reinforced soil had high piping resistance.

Yetimoglu et al. (2002) conducted direct shear tests on sand reinforced with randomly distributed discrete fibers. The effect of fibre reinforcement was studied. The results indicated that the peak shear strength and initial stiffness was not affected. However, fibre reinforced soil reduced soil brittleness providing a smaller loss of post peak strength.

Cai et al. (2006) investigated the effect of mixture of polypropylene fibre and lime on the engineering properties of soil. The test conducted were unconfined compression, direct shear, swelling and shrinkage tests. On the basis of SEM, it was found that the presence of fibre contributed to the physical interaction b/w the fibre and soil whereas lime produced a chemical reaction between lime and soil and changed the soil fabric significantly.

Tang et al. (2007) studied the effect of inclusion of Polypropylene fibre on the mechanical behavior of both uncemented and cemented clayey soil. The test results indicated that on the addition of polypropylene fibre within the soil, caused an increase in the UCS, shear strength, and axial strain at failure, decreased the stiffness and the loss of post peak strength.

B.V.S. Viswanadham et al. (2009) have studied the effect of discrete and randomly distributed geo fibers in restraining cracking tendency of clay barrier subjected to differential settlements, reducing swelling tendency of moist compacted expansive soil, and Efficacy of geofiber-reinforced soil as a fill material through laboratory model studies. For this purpose, a number of tests were carried-out for finding out the influence of geo fibers having various length and dosages. Two types of geofibers namely polypropylene and proplylene fibers were used. Three types of soils were used. It can be clearly stated that the geofiber-reinforced soil is a very effective method and which helps to restrain cracking of clay barrier at the onset of differential settlements, to use the expansive soil deposits at the construction sites, and to promote geofiber reinforced soil as a fill material.

Attom et al. (2010) studied the effect of two types of polypropylene fibre on the shear strength of sandy soil. It was noted that that the crimpled stiff profile fiber increased the shear strength of the sand under high normal loads, and has very small effect on sand at low aspect ratio under low normal loads.

G.P. Dall'aqua et al. (2010) have studied to assess the effect of fiber on laterite & kaolinite stabilized with both cement and lime subjected to repeated loading. Crimped monofilament of 12 mm long polypropylene fiber with a diameter of 18 microns was used to reinforce both the soils at concentration of 0.3% stabilized with 4% and 6% of lime and cement. Results show that kaolinite soils reinforced with 0.3% of fibers together stabilized with 6% cement under repeated axial load test deform less than 1% after 3,600 load cycles and could be used in pavement construction.

Kalpana Maheshwari et al. (2011) have conducted a series of model footing tests were conducted to check the feasibility of using polypropylene fibers as a reinforcing material below footing with the idea of upgrading the engineering behavior of clayey soil as subsoil for the foundation. Total nine model footing tests on fiber reinforced soil with three different fibers content (0.25%, 0.50%, 1.00%) and three depths of placement of fiber reinforced soil (b/4, b/2, b, where b is width of footing). The actual full-scale load tests with the optimum fiber content (0.50%) and optimum depth of placement of fiber-reinforced soil (b/4) were conducted to verify small-scale laboratory results. The bearing capacity of un-reinforced soil was found to be 64 kN/m^2, which increased to 250 kN/m^2 with the inclusion of polypropylene fibers.

S. Twinkle et al. (2011) have studied the effect of polypropylene fiber and lime admixture on engineering properties of expansive soil. In the case of lime stabilization in black cotton soil, the optimum moisture content increases and the maximum dry density decreases. In case of polypropylene fiber it is observed that as the fiber content increases, optimum moisture content increases and maximum dry density decreases. With lime stabilization the liquid limit of soil decreases but plastic limit increases. Thus plasticity index of soil decreases. In UCC, the optimum lime dosage level was noted at 6% lime with a strength increase of about 3.8 times compared to untreated soil for 28 days curing period. The peak UCC value is obtained at 0.75% for all the cases of polypropylene fiber reinforced soil and polypropylene plus lime content stabilized soil. In CBR, the optimum lime dosage level was noted at 6% lime with a strength increase of about 3.19 times compared to untreated soil. The CBR value is highest at 0.75% for all the cases of polypropylene fiber reinforced and polypropylene plus lime stabilized soil.

M. Heeralal et al. (2011) have studied to investigate the effects of discrete short polypropylene fiber (PP-fiber) on the strength and mechanical behavior of soil and soil + cement kiln dust (CKD) mix. In there investigation the soil samples were prepared at three different percentages of PP-fiber content (i.e. 0.25%, 0.5%, 1.0% by weight of the soil) and three different percentages of cement kiln dust content (3%,5%,8% by weight of the soil) and unconfined compressive strength, direct shear test and CBR tests were carried out. The test results indicated that the inclusion of fiber reinforcement within soil and soil-CKD mix caused an increase in the unconfined compressive strength (UCS), shear strength, axial strain at failure, decreased the stiffness, and changed the elemental soil's brittle behavior to a more ductile one and C.B.R value increases even for unsoaked condition. The inclusion of fiber reinforcement within soil and CKD soil mix caused an increase in the UCS; shear strength and axial strain at failure. Increasing fiber content could increase the peak axial stress and decreases the stiffness and the loss of post-peak strength, weakens the brittle behavior of cemented soil. The increase in strength of combined fiber and CKD inclusions is much more than the sum of the increase caused by them individually.

Mona Malekzadeh et al. (2012) have studied the effect of polypropylene fiber on swell and compressibility of expansive soils. There study demonstrated the influence of polypropylene fiber on swelling, compressibility and hydraulic conductivity of expansive soils. The results indicated that primary swell and secondary swell percentages decreased considerably with increase in fiber addition. The time of primary swell however increased with 0.5% and 0.75% fiber inclusion, while a significant reduction occurred with 1% fiber inclusion. The same behavior was observed in compression index results. Hydraulic conductivity showed another erratic behavior, increasing with 0.75% fiber content, whereas with 1% fibre content a reduction in three fold occurred. It can be concluded that there is a potential for use of polypropylene fiber to reinforce expansive soils. 1% fiber content is suitable for the soil in this study to have low amount of swell, compressibility, and hydraulic conductivity.

S. K. Tiwari et al. (2013) have studied the individual and mutual influence of arbitrarily distributed fiber reinforcements and cement stabilization on the geotechnical properties of fly ash-soil mixtures. It was found out that the fly ash fiber composite can sustain large axial strain exhibiting greater ductility in the composite and results in significant improvement in stress-strain behavior, causing substantial increase in shear strength compared to that in unreinforced specimen. The increase in unconfined compressive strength and secant modulus (Y) of fly ash-soil mixtures with time can be assumed to be hyperbolic. The increase in strength and secant modulus depends on the fly ash and amount of cement. The increase in strength and secant modulus, increases as amount of cement increases, but decrease as amount of fly ash increases. The effect of amount of cement is more pronounced in comparison to the content of fly ash. The moisture content of a fly ash-soil blend is dependent on the curing time and amount of cement. The water content reduces as curing time and amount of cement increases. The moisture content reduces as curing time and amount of cement increases. The cement content has a significantly higher influence as compared to the time of curing. The unconfined compressive strength of fly ash-soil blends increases due to addition of cement and fibers. The gain in unconfined compressive strength caused by the mutual action of cement and fibers is either more than or nearly equal to sum of the increase caused by them individually, depending on the duration of curing and type of the blend.

Li et al. (2014) studied he tensile behavior of unreinforced and reinforced soil. They developed a tensile apparatus to determine the tensile strength characteristics of fibre reinforced soil. The results indicated that the test apparatus was applicable for determining the tensile strength of soils. The tensile strength of the fibre reinforced soil increased with increasing fibre content, also it increased with the increasing dry density and decreasing water content.

Given above was a highlight of some of the previous research conducted on fiber reinforced soil. In fact of the numerous research and its use in concrete, its practical usage in soil application is very less as compared to other soil reinforcing materials. Maybe it is due to the low cost/benefit ratio of polypropylene fibre reinforcement as compared to other reinforcement such as geotextiles etc. But, overall the benefit of using polypropylene fibre as a reinforcing material has numerous benefits as described above. Following is the experimental programme which was undertaken to evaluate the behavior of fiber reinforced soil.

CHAPTER-3

MATERIALS USED

3.0 INTRODUCTION

In the following chapter description of the materials used in the current investigation has been given. The properties of the soil used and the type and source of the fibre is given.

3.1 POLYPROPYLENE FIBRE AS REINFORCEMENT

Polypropylene Fibres are engineered micro fibers with a unique “Triangular” Cross-section, used in Secondary Reinforcement of Concrete. It complements Structural Steel in enhancing Concrete’s resistance to Shrinkage Cracking and improves mechanical properties such as Flexural / Split Tensile and Transverse Strengths of Concrete along with the desired improvement in Abrasion and Impact Strengths.

Reliance Industry Limited (RIL) has launched polypropylene fibres under the brand name of “**RECRON® 3S**” with the objective of improving the quality of plaster and concrete. The Reliance Group, founded by Mr Dhirubhai H. Ambani, is India's largest business house with total revenues of Rs 65,000 crores. The group's activities span petrochemicals, synthetics fibres, fibre intermediates, gas, power, telecom, etc. Reliance is 4th largest polymer player in the world and our experience and research in Polymer field supports Polypropylene as better polymer for concrete than polypropylene. Polypropylene fibre has a unique triangular cross-section, which gives 40% more surface area for bonding compared to other shapes. Polypropylene fibre is also designed so that the fibre stays dimensionally straight and uniformly dispersed, so as to safe guard against balling, curling and bunching.

The unique triangular shape of Polypropylene fibre is designed to improve the adhesion in the cement matrix. It also helps in better operability and dispersion, which is key to performance of any secondary reinforcement.

The Polypropylene fibre retains its performance over a long period of time and does not deteriorate for years.

3.2 PROPERTIES OF POLYPROPYLENE FIBRE

Table 1: Properties of Recron-3S Fibre

Material	Polypropylene
Shape/ Cross Section	Triangular
Effective Diameter	10-40 Microns
Length	6 / 12 / 18 mm
Specific Gravity	1.31-1.39
Melting Point	150-160^{o}C
Tensile strength	4-6 MPa
Young`s Modulus	>5000 MPa

Figure 1: Recron-3S Fibre (6mm) used in the following experimental programme

3.3 SOIL

In the current investigation two types of soil has been used.

- Soil – Silty Sand (SM) obtained from a proposed Nuclear Power plant site in Gorakhpur, Haryana.

Following are the results of various test carried out on the soil.

Table 2: Summary of the test results carried out for the soil

PROPERTY OF THE SOIL	RESULT
Specific Gravity	2.61
I.S. Classification	Silty Sand (SM)
Maximum Dry Density	15.92 kN/m^3
Optimum Moisture Content	12.74 %
Effective size, D_{10}	0.189 mm
D_{30}	0.30 mm
D_{60}	0.41 mm
Coefficient of Uniformity, C_u	2.17
Coefficient of Curvature, C_c	1.16

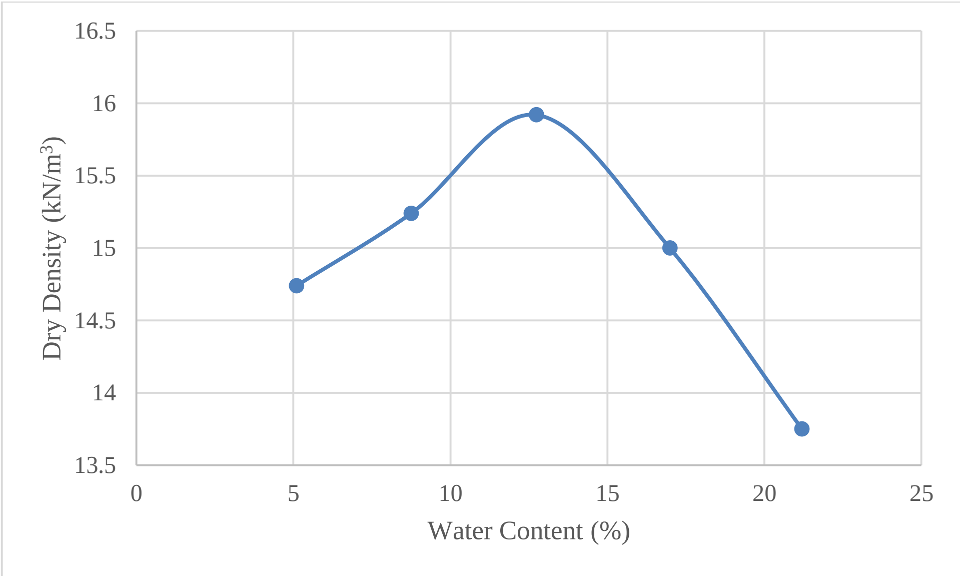


Fig.2: Dry Density v/s Water Content

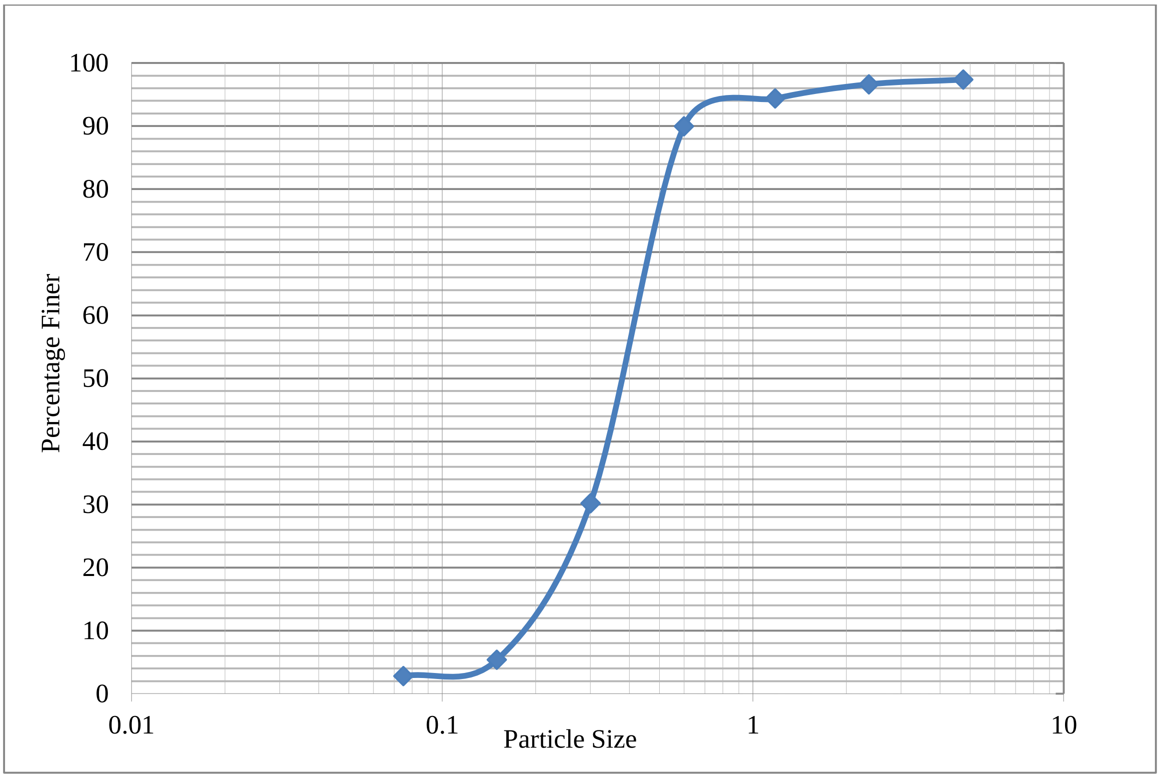


Fig.3: Particle Size Distribution Curve

CHAPTER-4

EXPERIMENTAL PROGRAMME

4.0 INTRODUCTION

In the following chapter description of methodology and experimental programme has been given. Description of the procedure of the various tests has been stated.

4.1 TESTS CARRIED OUT FOR THE INVESTIGATION

Following test have been carried out on both unreinforced and reinforced soil with different percentage of fibre addition.

- **Direct Shear Test**
- **Triaxial Test (Unconsolidated Undrained)**

4.2 METHODOLOGY

Direct Shear Test

- This test is carried out on soil to determine the shear parameters of soil.
- A standard size (60mm*60mm) Direct Shear box was used for the investigation.
- The tests were conducted on three different normal stress i.e. 0.1, 0.2 & 0.3 N/mm^2 and the angle of internal friction and cohesion intercept values were obtained by plotting a straight line through the plot of shear stress versus the normal stress.
- Direct Shear tests were performed strictly according to IS 2720: part 13 (1986).

Triaxial Test

- In this investigation Unconsolidated-Undrained Triaxial tests were conducted in order to determine the compressive and shear strength of the soil.
- While conducting the tests the valves were closed during both the stages, in order to prevent the dissipation of pore water.

- The specimen of aspect ratio 2 was used i.e. diameter of 38mm and a length of 76mm.
- The tests were conducted on three different confining pressure (σ_3) i.e. 0.1, 0.2 & 0.3 N/mm^2; thus three different deviatoric stress (σ_d) were obtained.
- By using the Minor Principal Stress as σ_3 and Major Principal Stress as ($\sigma_1 = \sigma_3 + \sigma_d$), Mohr circle is drawn.
- A tangent is drawn on the above Mohr Circle to obtain the Mohr failure envelope. The angle of internal friction and cohesion intercept values can be recorded from the failure envelope itself.
- UU tests were performed strictly according to IS 2720: part 11 (1993).
- Effect of addition of fibre has been observed on the change in values of angle of internal friction and cohesion in both the tests and a comparison has been drawn.

4.3 EXPERIMENTAL INVESTIGATION

4.3.1 TRIAXIAL TESTS

Table 3: Load-Displacement Response of Unreinforced Soil (P_f = 0%) at Normal Stress = 0.1 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	19.62	0.33	1137.85	0.02
0.50	39.24	0.66	1141.62	0.03
0.75	78.48	0.99	1145.41	0.07
1.00	186.39	1.32	1149.23	0.16
1.25	284.49	1.64	1153.08	0.25
1.50	353.16	1.97	1156.94	0.31
1.75	392.40	2.30	1160.84	0.34
2.00	421.83	2.63	1164.76	0.36
2.25	441.45	2.96	1168.71	0.38
2.50	461.07	3.29	1172.69	0.39
3.00	480.69	3.95	1180.72	0.41
3.50	490.50	4.61	1188.86	0.41
4.00	490.50	5.26	1197.12	0.41
4.50	500.31	5.92	1205.49	0.42
5.00	500.31	6.58	1213.98	0.41
5.50	510.12	7.24	1222.59	0.42
6.00	510.12	7.89	1231.32	0.41
7.00	510.12	9.21	1249.16	0.41
8.00	519.93	10.53	1267.53	0.41
9.00	529.74	11.84	1286.45	0.41
10.00	539.55	13.16	1305.94	0.41
11.00	549.36	14.47	1326.04	0.41
12.00	539.55	15.79	1346.76	0.40

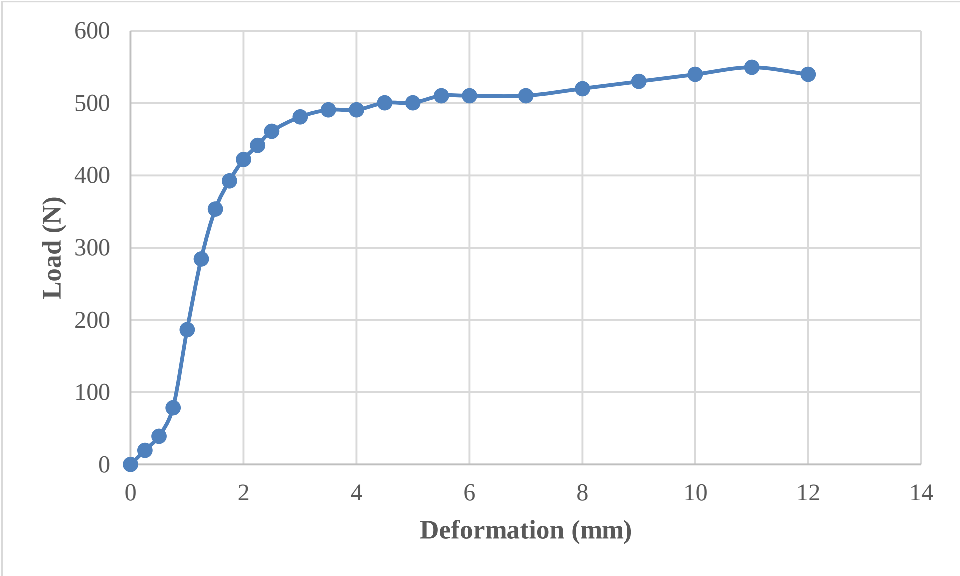


Fig.4: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.1 N/mm^2

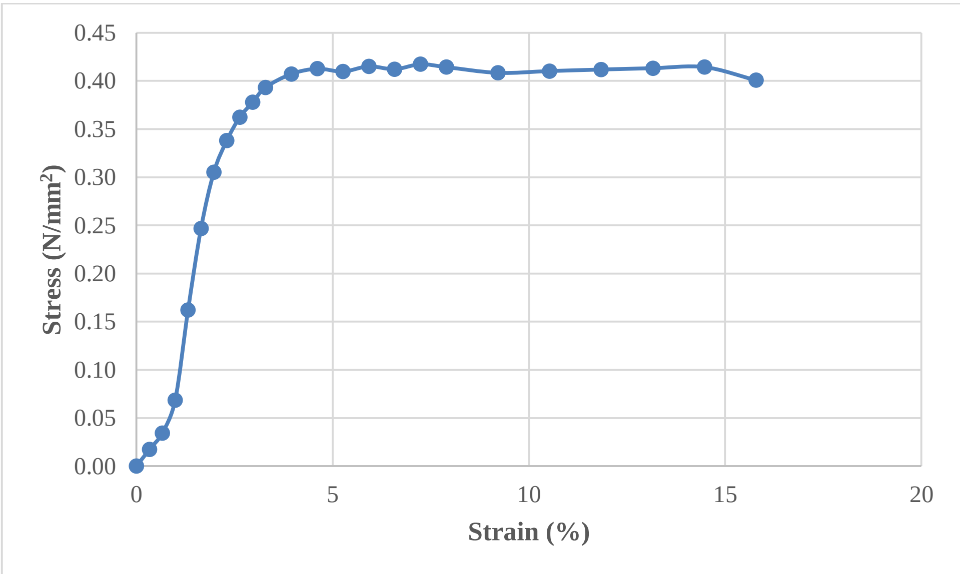


Fig.5: Stress-Strain Curve of Unreinforced Soil (P_f =0%) at Normal Stress = 0.1 N/mm^2

Table 4: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.2 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	29.43	0.33	1137.85	0.03
0.50	49.05	0.66	1141.62	0.04
0.75	88.29	0.99	1145.41	0.08
1.00	215.82	1.32	1149.23	0.19
1.25	323.73	1.64	1153.08	0.28
1.50	382.59	1.97	1156.94	0.33
1.75	421.83	2.30	1160.84	0.36
2.00	451.26	2.63	1164.76	0.39
2.25	480.69	2.96	1168.71	0.41
2.50	500.31	3.29	1172.69	0.43
3.00	549.36	3.95	1180.72	0.47
3.50	568.98	4.61	1188.86	0.48
4.00	598.41	5.26	1197.12	0.50
4.50	618.03	5.92	1205.49	0.51
5.00	637.65	6.58	1213.98	0.53
5.50	647.46	7.24	1222.59	0.53
6.00	657.27	7.89	1231.32	0.53
7.00	686.70	9.21	1249.16	0.55
8.00	706.32	10.53	1267.53	0.56
9.00	725.94	11.84	1286.45	0.56
10.00	755.37	13.16	1305.94	0.58
11.00	774.99	14.47	1326.04	0.58
12.00	804.42	15.79	1346.76	0.60
13.00	814.23	17.11	1368.13	0.60
14.00	814.23	18.42	1390.20	0.59
15.20	804.42	20.00	1417.64	0.57

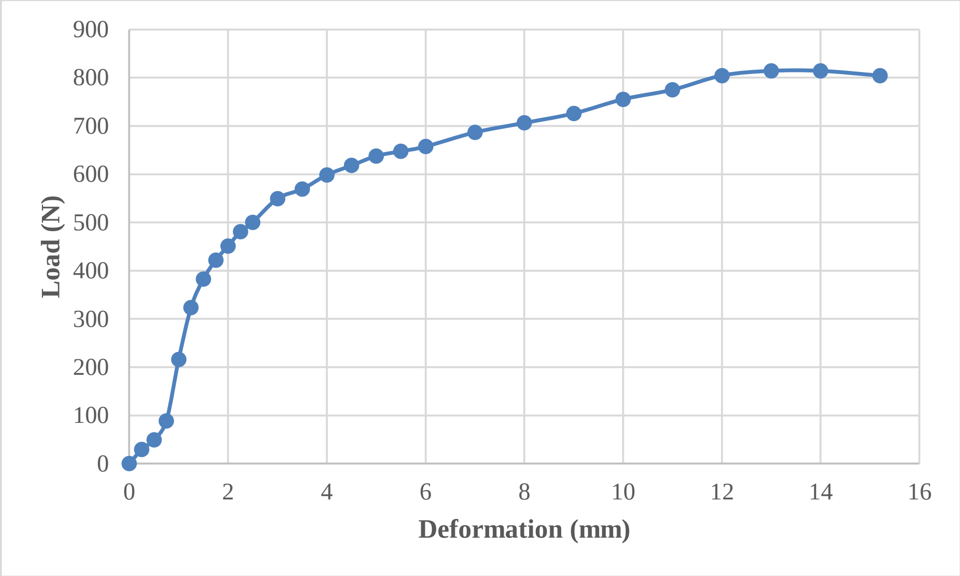


Fig.6: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.2 N/mm^2

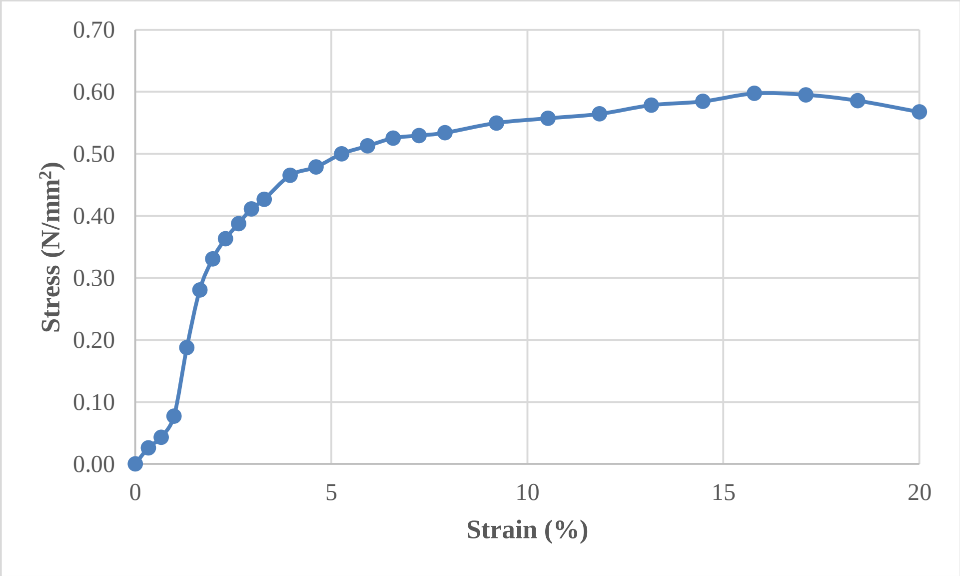


Fig.7: Stress-Strain Curve of Unreinforced Soil (P_f =0%) at Normal Stress = 0.2 N/mm^2

Table 5: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.3 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	39.24	0.33	1137.85	0.03
0.50	58.86	0.66	1141.62	0.05
0.75	176.58	0.99	1145.41	0.15
1.00	421.83	1.32	1149.23	0.37
1.25	598.41	1.64	1153.08	0.52
1.50	745.56	1.97	1156.94	0.64
1.75	833.85	2.30	1160.84	0.72
2.00	912.33	2.63	1164.76	0.78
2.25	961.38	2.96	1168.71	0.82
2.50	1000.62	3.29	1172.69	0.85
3.00	1069.29	3.95	1180.72	0.91
3.50	1118.34	4.61	1188.86	0.94
4.00	1157.58	5.26	1197.12	0.97
4.50	1187.01	5.92	1205.49	0.98
5.00	1216.44	6.58	1213.98	1.00
5.50	1255.68	7.24	1222.59	1.03
6.00	1294.92	7.89	1231.32	1.05
7.00	1314.54	9.21	1249.16	1.05
8.00	1324.35	10.53	1267.53	1.04
9.00	1343.97	11.84	1286.45	1.04
10.00	1353.78	13.16	1305.94	1.04
11.00	1383.21	14.47	1326.04	1.04
12.00	1402.83	15.79	1346.76	1.04
13.00	1412.64	17.11	1368.13	1.03
14.00	1422.45	18.42	1390.20	1.02
15.20	1432.26	20.00	1417.64	1.01

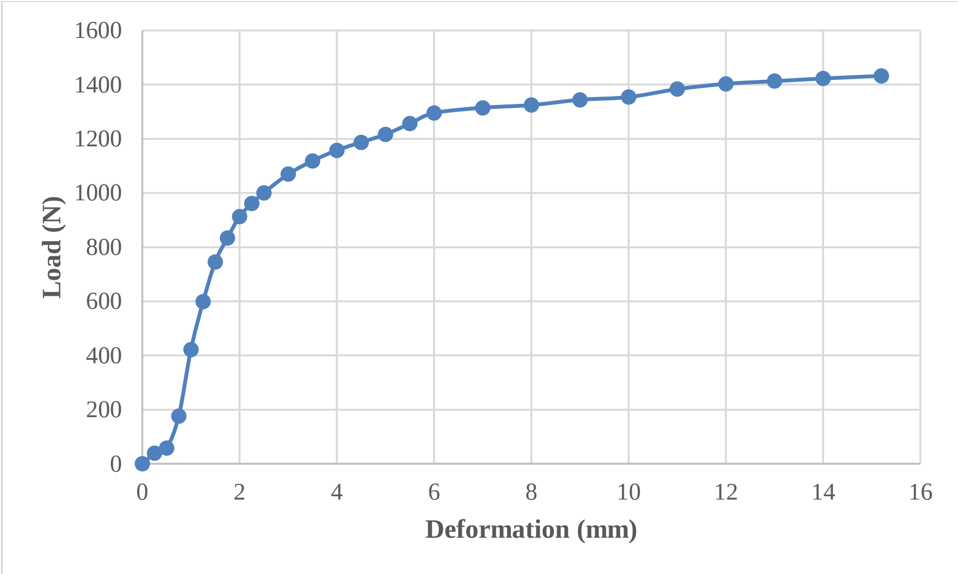


Fig.8: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.3 N/mm^2

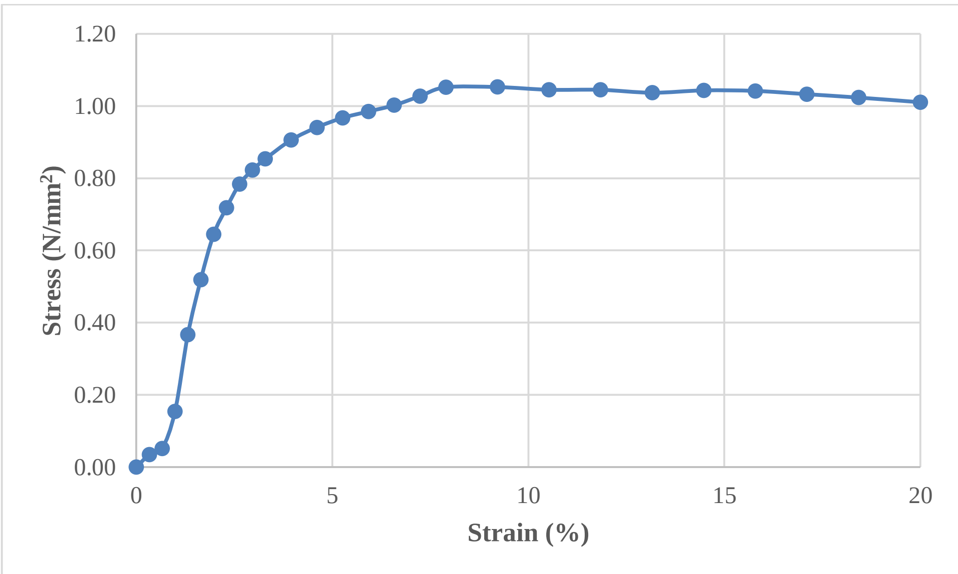


Fig.9: Stress-Strain Curve of Unreinforced Soil (P_f =0%) at Normal Stress = 0.3 N/mm^2

Table 6: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.1 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	29.43	0.33	1137.85	0.03
0.50	58.86	0.66	1141.62	0.05
0.75	127.53	0.99	1145.41	0.11
1.00	206.01	1.32	1149.23	0.18
1.25	284.49	1.64	1153.08	0.25
1.50	362.97	1.97	1156.94	0.31
1.75	431.64	2.30	1160.84	0.37
2.00	480.69	2.63	1164.76	0.41
2.25	510.12	2.96	1168.71	0.44
2.50	539.55	3.29	1172.69	0.46
3.00	568.98	3.95	1180.72	0.48
3.50	598.41	4.61	1188.86	0.50
4.00	627.84	5.26	1197.12	0.52
4.50	637.65	5.92	1205.49	0.53
5.00	647.46	6.58	1213.98	0.53
5.50	657.27	7.24	1222.59	0.54
6.00	667.08	7.89	1231.32	0.54
7.00	676.89	9.21	1249.16	0.54
8.00	686.70	10.53	1267.53	0.54
9.00	696.51	11.84	1286.45	0.54
10.00	696.51	13.16	1305.94	0.53
11.00	706.32	14.47	1326.04	0.53
12.00	716.13	15.79	1346.76	0.53
13.00	725.94	17.11	1368.13	0.53
14.00	725.94	18.42	1390.20	0.52
15.20	725.94	20.00	1417.64	0.51

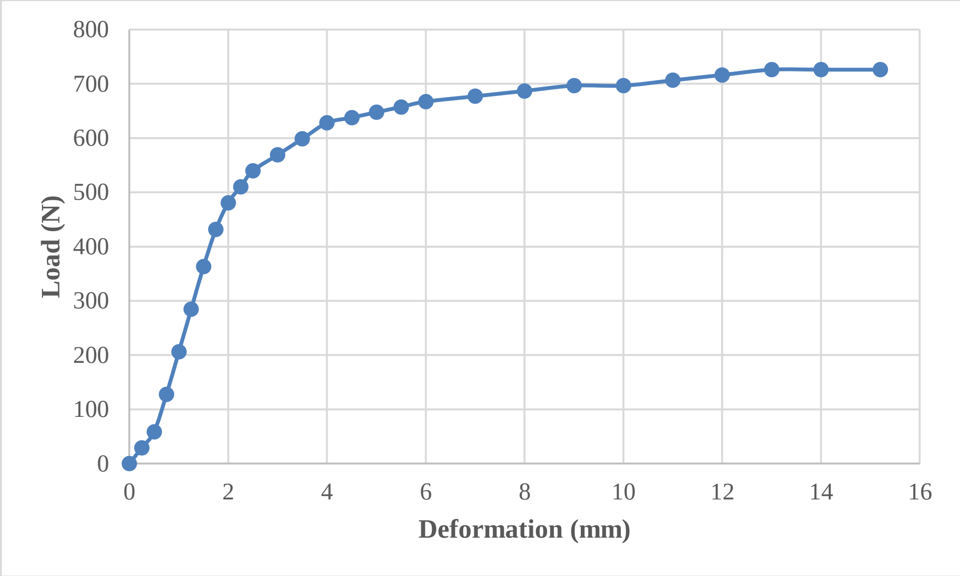


Fig.10: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.1 N/mm^2

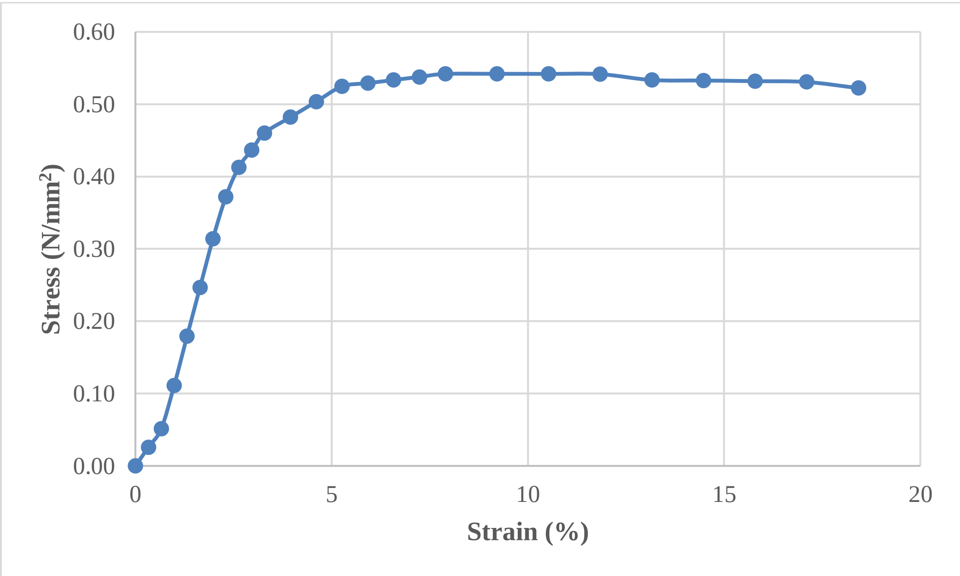


Fig.11: Stress-Strain Curve of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.1 N/mm^2

Table 7: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.2 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	19.62	0.33	1137.85	0.02
0.50	58.86	0.66	1141.62	0.05
0.75	137.34	0.99	1145.41	0.12
1.00	215.82	1.32	1149.23	0.19
1.25	304.11	1.64	1153.08	0.26
1.50	382.59	1.97	1156.94	0.33
1.75	451.26	2.30	1160.84	0.39
2.00	500.31	2.63	1164.76	0.43
2.25	549.36	2.96	1168.71	0.47
2.50	578.79	3.29	1172.69	0.49
3.00	627.84	3.95	1180.72	0.53
3.50	667.08	4.61	1188.86	0.56
4.00	696.51	5.26	1197.12	0.58
4.50	716.13	5.92	1205.49	0.59
5.00	735.75	6.58	1213.98	0.61
5.50	755.37	7.24	1222.59	0.62
6.00	774.99	7.89	1231.32	0.63
7.00	804.42	9.21	1249.16	0.64
8.00	824.04	10.53	1267.53	0.65
9.00	833.85	11.84	1286.45	0.65
10.00	843.66	13.16	1305.94	0.65
11.00	853.47	14.47	1326.04	0.64
12.00	863.28	15.79	1346.76	0.64
13.00	873.09	17.11	1368.13	0.64
14.00	892.71	18.42	1390.20	0.64
15.20	912.33	20.00	1417.64	0.64

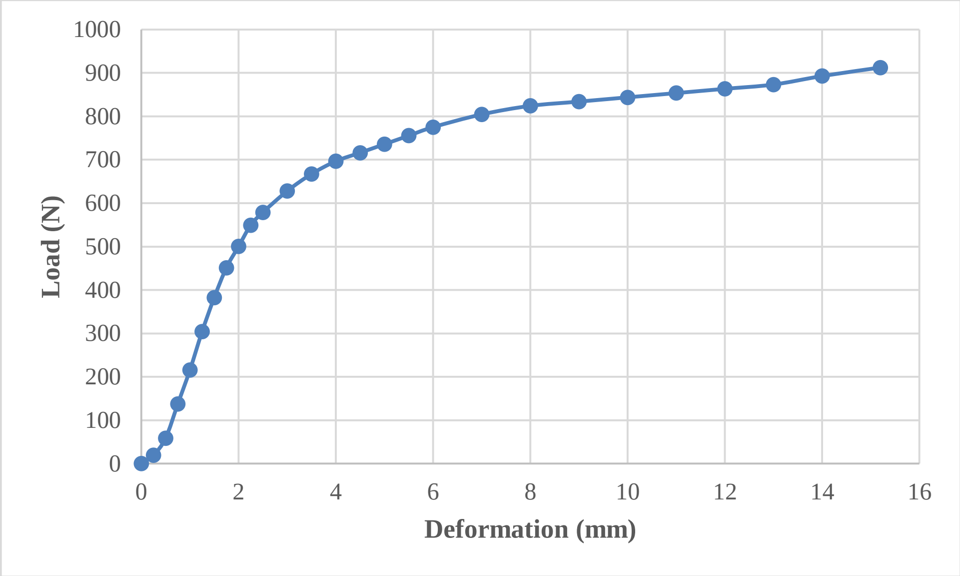


Fig.12: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.2 N/mm^2

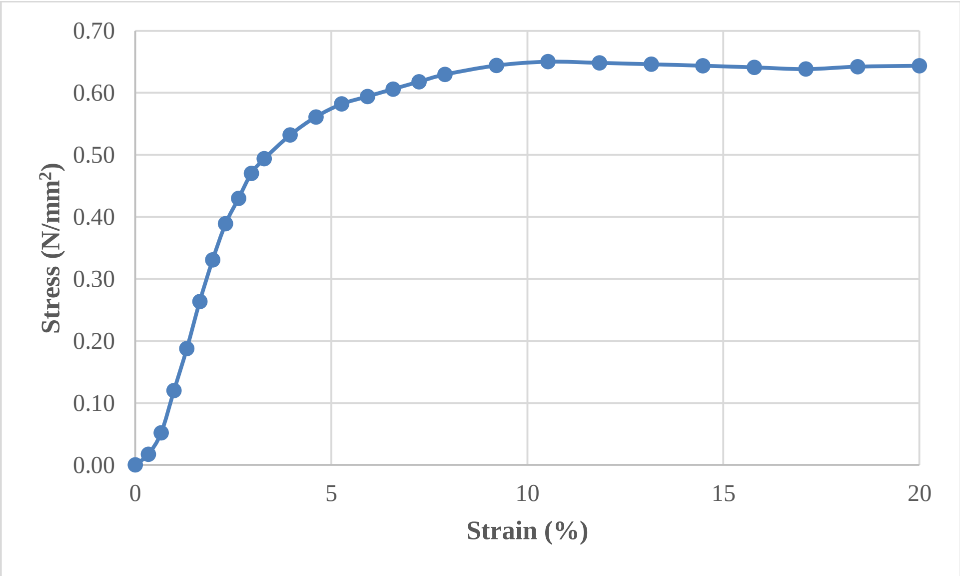


Fig.13: Stress-Strain Curve of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.2 N/mm^2

Table 8: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.3 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	19.62	0.33	1137.85	0.02
0.50	78.48	0.66	1141.62	0.07
0.75	176.58	0.99	1145.41	0.15
1.00	294.30	1.32	1149.23	0.26
1.25	362.97	1.64	1153.08	0.31
1.50	392.40	1.97	1156.94	0.34
1.75	421.83	2.30	1160.84	0.36
2.00	451.26	2.63	1164.76	0.39
2.25	519.93	2.96	1168.71	0.44
2.50	568.98	3.29	1172.69	0.49
3.00	608.22	3.95	1180.72	0.52
3.50	647.46	4.61	1188.86	0.54
4.00	686.70	5.26	1197.12	0.57
4.50	725.94	5.92	1205.49	0.60
5.00	755.37	6.58	1213.98	0.62
5.50	804.42	7.24	1222.59	0.66
6.00	863.28	7.89	1231.32	0.70
7.00	912.33	9.21	1249.16	0.73
8.00	951.57	10.53	1267.53	0.75
9.00	990.81	11.84	1286.45	0.77
10.00	1030.05	13.16	1305.94	0.79
11.00	1069.29	14.47	1326.04	0.81
12.00	1088.91	15.79	1346.76	0.81
13.00	1108.53	17.11	1368.13	0.81
14.00	1128.15	18.42	1390.20	0.81
15.20	1147.77	20.00	1417.64	0.81

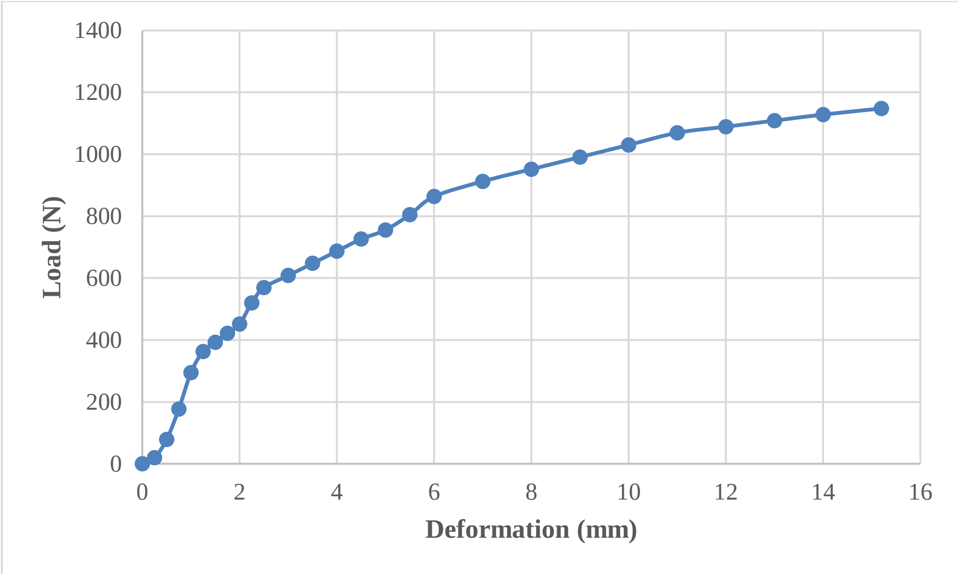


Fig.14: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.3 N/mm^2

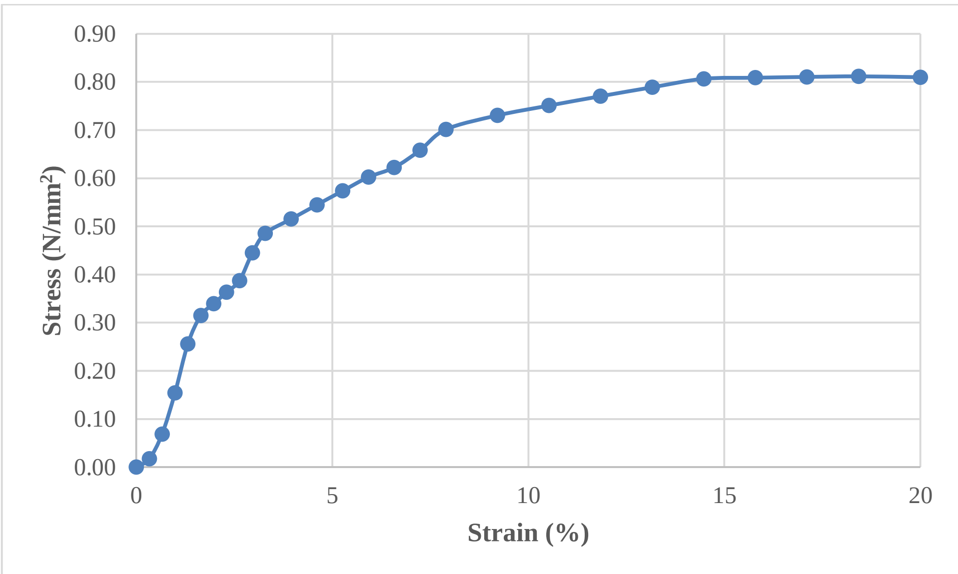


Fig.15: Stress-Strain Curve of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.3 N/mm^2

Table 9: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.1 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	9.81	0.33	1137.85	0.01
0.50	19.62	0.66	1141.62	0.02
0.75	39.24	0.99	1145.41	0.03
1.00	78.48	1.32	1149.23	0.07
1.25	49.05	1.64	1153.08	0.04
1.50	117.72	1.97	1156.94	0.10
1.75	176.58	2.30	1160.84	0.15
2.00	235.44	2.63	1164.76	0.20
2.25	274.68	2.96	1168.71	0.24
2.50	333.54	3.29	1172.69	0.28
3.00	382.59	3.95	1180.72	0.32
3.50	431.64	4.61	1188.86	0.36
4.00	451.26	5.26	1197.12	0.38
4.50	470.88	5.92	1205.49	0.39
5.00	519.93	6.58	1213.98	0.43
5.50	549.36	7.24	1222.59	0.45
6.00	568.98	7.89	1231.32	0.46
7.00	608.22	9.21	1249.16	0.49
8.00	627.84	10.53	1267.53	0.50
9.00	647.46	11.84	1286.45	0.50
10.00	667.08	13.16	1305.94	0.51
11.00	686.70	14.47	1326.04	0.52
12.00	706.32	15.79	1346.76	0.52
13.00	735.75	17.11	1368.13	0.54
14.00	735.75	18.42	1390.20	0.53
15.20	745.56	20.00	1417.64	0.53

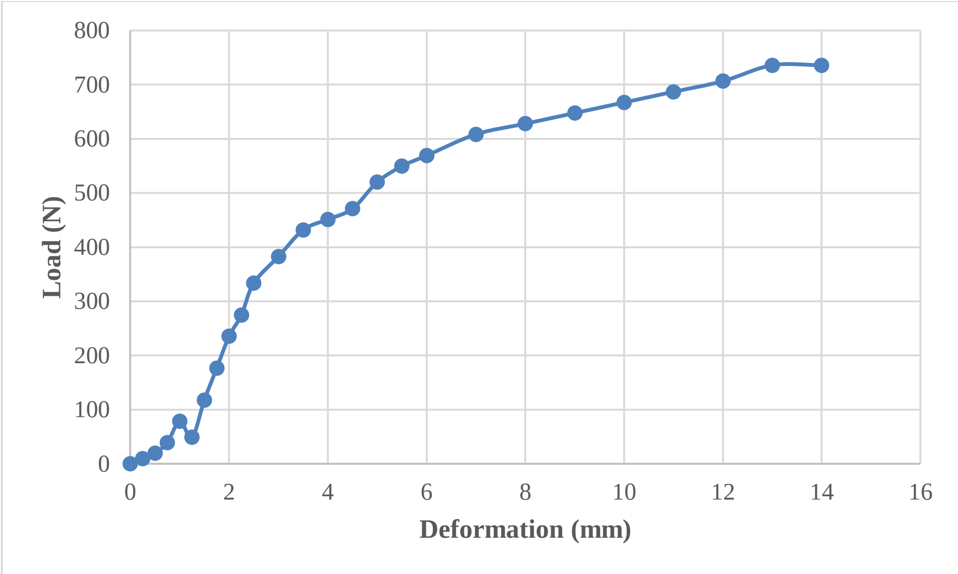


Fig.16: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.1 N/mm^2

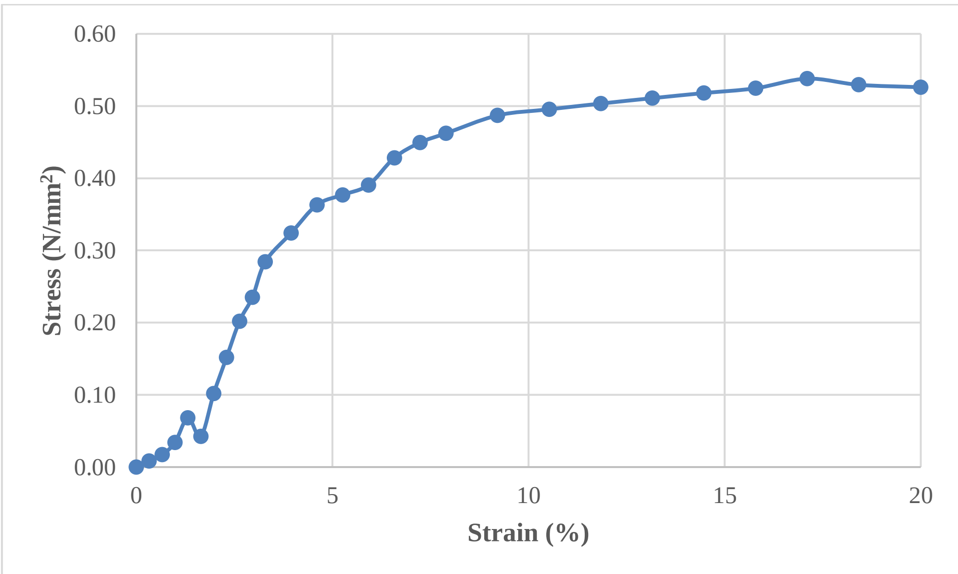


Fig.17: Stress-Strain Curve of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.1 N/mm^2

Table 10: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.2 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	29.43	0.33	1137.85	0.03
0.50	29.43	0.66	1141.62	0.03
0.75	39.24	0.99	1145.41	0.03
1.00	39.24	1.32	1149.23	0.03
1.25	107.91	1.64	1153.08	0.09
1.50	176.58	1.97	1156.94	0.15
1.75	215.82	2.30	1160.84	0.19
2.00	264.87	2.63	1164.76	0.23
2.25	304.11	2.96	1168.71	0.26
2.50	343.35	3.29	1172.69	0.29
3.00	412.02	3.95	1180.72	0.35
3.50	470.88	4.61	1188.86	0.40
4.00	519.93	5.26	1197.12	0.43
4.50	568.98	5.92	1205.49	0.47
5.00	608.22	6.58	1213.98	0.50
5.50	696.51	7.24	1222.59	0.57
6.00	774.99	7.89	1231.32	0.63
7.00	853.47	9.21	1249.16	0.68
8.00	912.33	10.53	1267.53	0.72
9.00	951.57	11.84	1286.45	0.74
10.00	1010.43	13.16	1305.94	0.77
11.00	1059.48	14.47	1326.04	0.80
12.00	1088.91	15.79	1346.76	0.81
13.00	1137.96	17.11	1368.13	0.83
14.00	1177.20	18.42	1390.20	0.85
15.20	0.00	20.00	1417.64	0.84

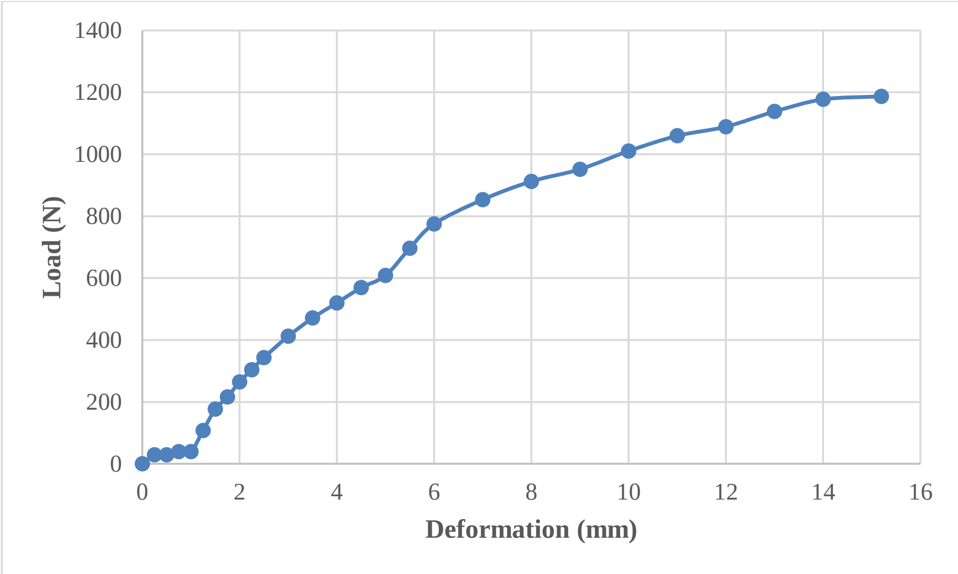


Fig.18: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.2 N/mm^2

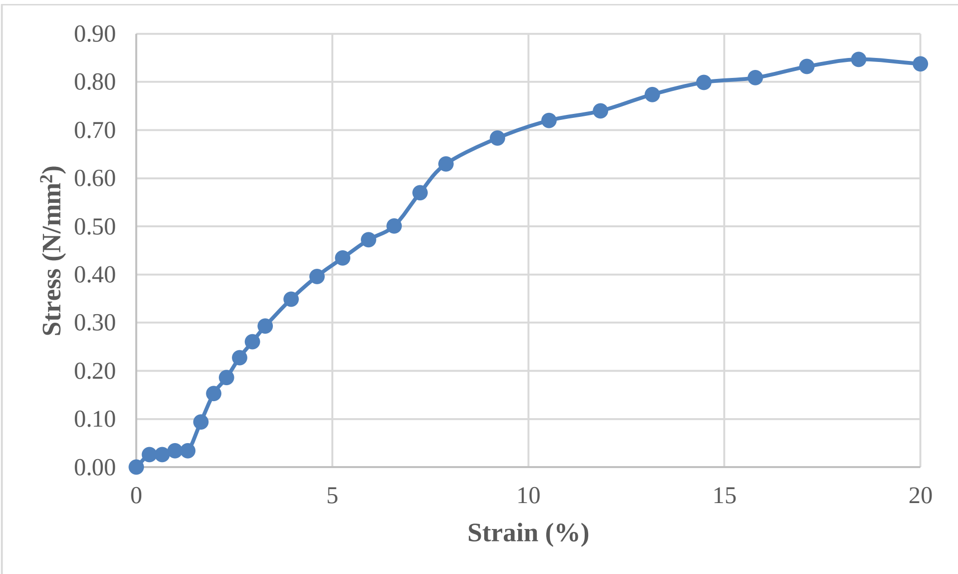


Fig.19: Stress-Strain Curve of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.2 N/mm^2

Table 11: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.3 N/mm^2

Deformation (mm)	**Load (N)**	**Strain (%)**	**Corrected Area (mm^2) A'=A/(1-ε)**	**Stress (N/mm^2) = (Load/Corrected Area)**
0.00	0.00	0.00	1134.11	0.00
0.25	19.62	0.33	1137.85	0.02
0.50	49.05	0.66	1141.62	0.04
0.75	156.96	0.99	1145.41	0.14
1.00	274.68	1.32	1149.23	0.24
1.25	392.40	1.64	1153.08	0.34
1.50	500.31	1.97	1156.94	0.43
1.75	598.41	2.30	1160.84	0.52
2.00	686.70	2.63	1164.76	0.59
2.25	765.18	2.96	1168.71	0.65
2.50	824.04	3.29	1172.69	0.70
3.00	941.76	3.95	1180.72	0.80
3.50	1030.05	4.61	1188.86	0.87
4.00	1108.53	5.26	1197.12	0.93
4.50	1236.06	5.92	1205.49	1.03
5.00	1294.92	6.58	1213.98	1.07
5.50	1343.97	7.24	1222.59	1.10
6.00	1432.26	7.89	1231.32	1.16
7.00	1510.74	9.21	1249.16	1.21
8.00	1569.60	10.53	1267.53	1.24
9.00	1638.27	11.84	1286.45	1.27
10.00	1697.13	13.16	1305.94	1.30
11.00	1736.37	14.47	1326.04	1.31
12.00	1775.61	15.79	1346.76	1.32
13.00	1814.85	17.11	1368.13	1.33
14.00	1844.28	18.42	1390.20	1.33
15.20	1854.09	20.00	1417.64	1.31

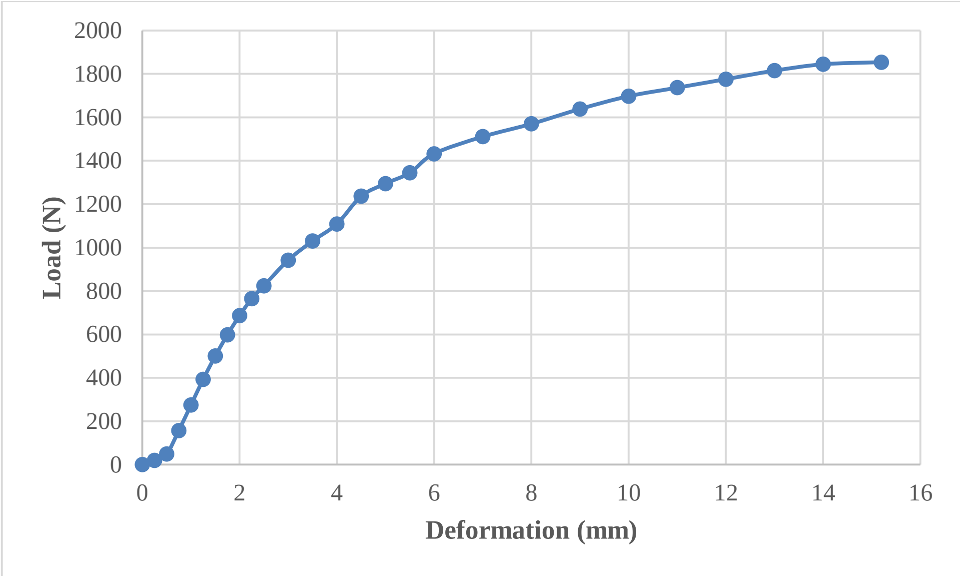


Fig.20: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.3 N/mm^2

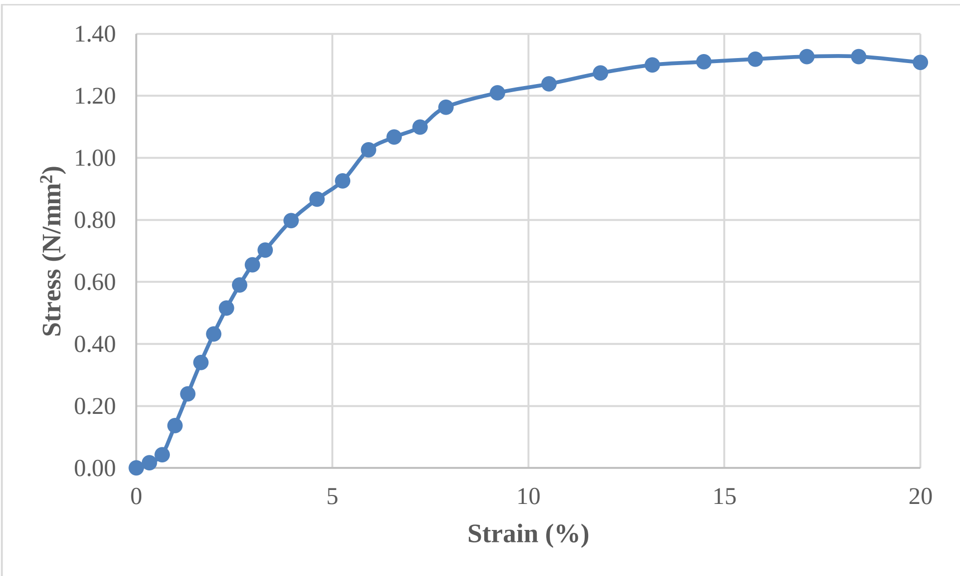


Fig.21: Stress-Strain Curve of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.3 N/mm^2

4.3.2 DIRECT SHEAR TESTS

Table 12: Load-Displacement Response of Unreinforced Soil

Horizontal Displacment (mm)	Load (N)		
	σ_n=0.1N/mm^2	σ_n=0.2N/mm^2	σ_n=0.3N/mm^2
0	0.00	0.00	0.00
0.1	49.05	123.61	64.75
0.25	92.21	188.35	204.05
0.5	125.57	274.68	310.00
0.75	147.15	321.77	382.59
1	162.85	361.99	436.55
1.25	176.58	392.40	481.67
1.5	185.41	412.02	515.03
1.75	193.26	433.60	545.44
2	200.12	447.34	567.02
2.25	205.03	457.15	575.85
2.5	210.92	464.99	594.49
3	217.78	474.80	606.26
3.5	222.69	480.69	607.24
4	226.61	476.77	609.20
4.5	231.52	471.86	616.07
5	235.44	470.88	623.92
5.5	235.44	471.86	620.97
6	236.42	472.84	614.11
6.5	236.42	472.84	602.33
7	236.42	471.86	596.45
7.5	236.42	471.86	586.64
8	238.38	471.86	585.66
9	236.42	471.86	574.87
10	235.44	472.84	562.11
11	233.48	474.80	542.49
12	233.48	475.79	514.04

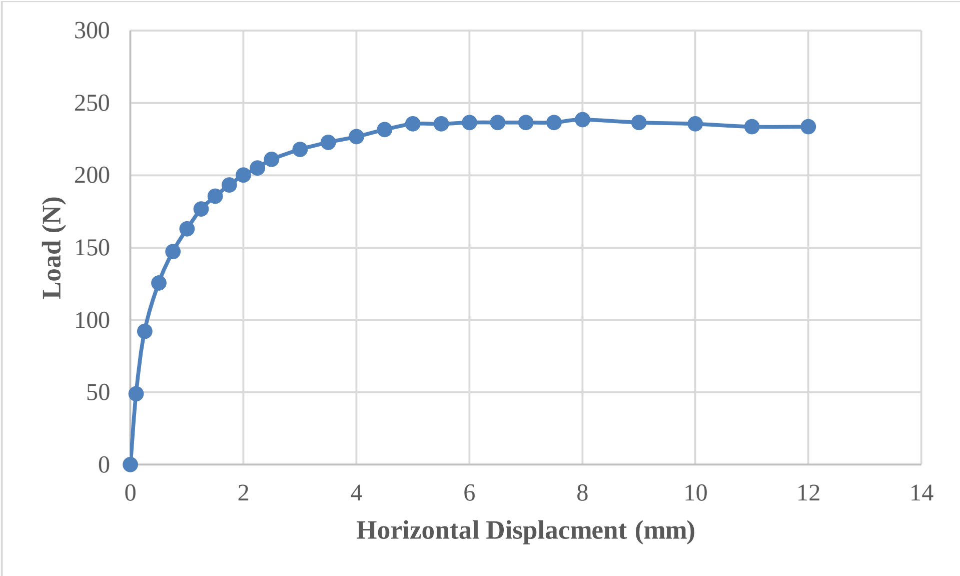


Fig.22: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.1 N/mm^2

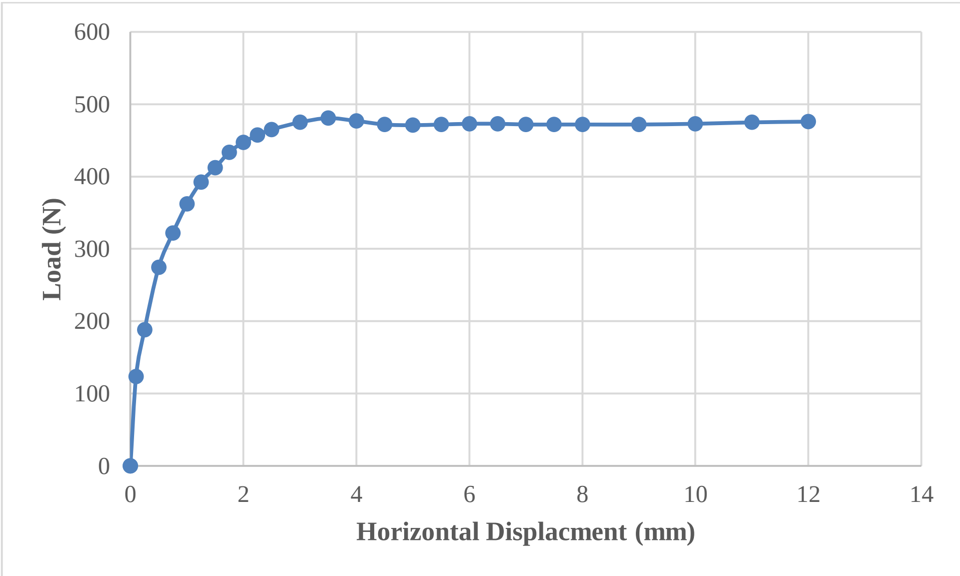


Fig.23: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.2 N/mm^2

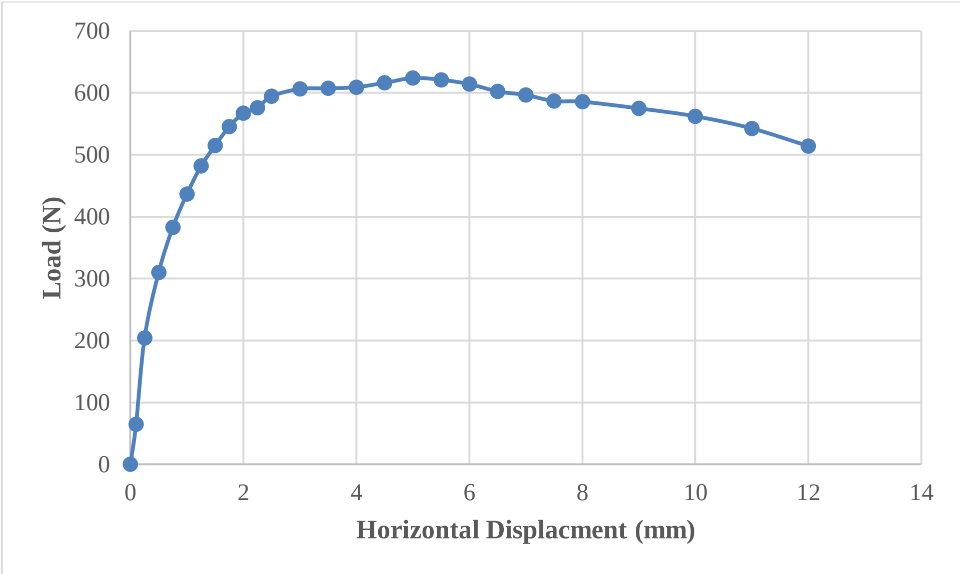


Fig.24: Load-Displacement Response of Unreinforced Soil (P_f =0%) at Normal Stress = 0.3 N/mm^2

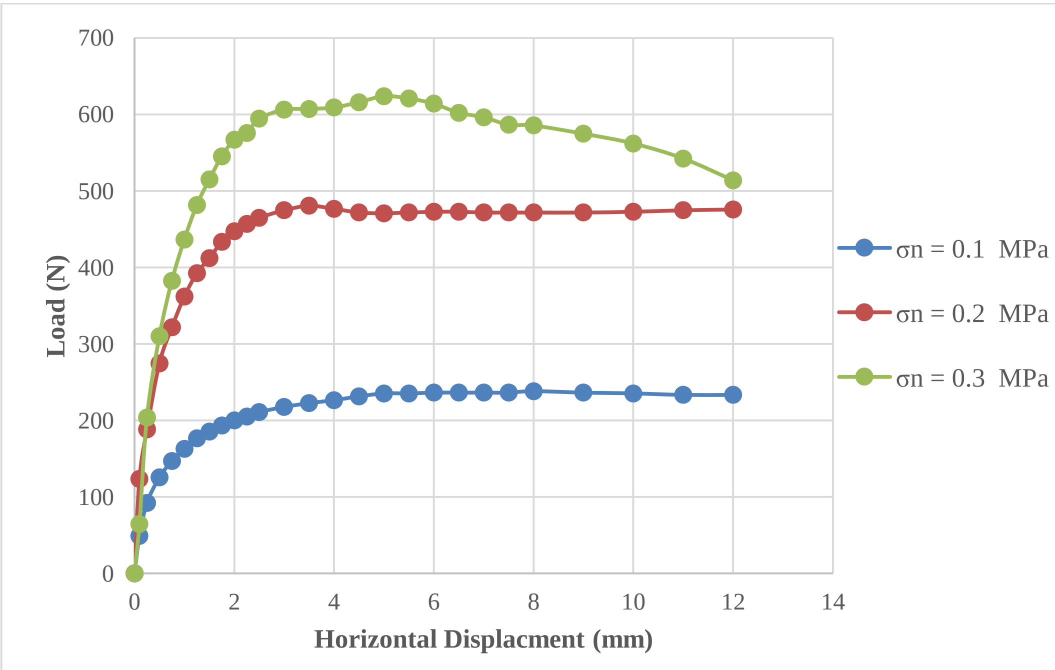


Fig.25: Load-Displacement Response of Unreinforced Soil

Table 13: Load-Displacement Response of Reinforced Soil (P_f =0.25%)

Horizontal Displacment (mm)	**Load (N)**		
	σ_n=0.1N/mm^2	**σ_n=0.2N/mm^2**	**σ_n=0.3N/mm^2**
0	0.00	0.00	0.00
0.1	59.84	72.59	127.53
0.25	103.01	173.64	208.95
0.5	149.11	217.78	300.19
0.75	177.56	257.02	356.10
1	196.20	290.38	398.29
1.25	210.92	317.84	436.55
1.5	218.76	338.45	469.90
1.75	225.63	360.03	499.33
2	232.50	376.70	531.70
2.25	237.40	389.46	558.19
2.5	242.31	400.25	583.70
3	248.19	420.85	632.75
3.5	254.08	434.58	669.04
4	261.93	443.41	695.53
4.5	269.78	450.28	725.94
5	273.70	454.20	742.62
5.5	276.64	459.11	762.24
6	278.60	468.92	782.84
6.5	282.53	483.63	795.59
7	284.49	496.39	807.36
7.5	285.47	507.18	815.21
8	285.47	515.03	824.04
9	289.40	533.66	843.66
10	293.32	546.42	866.22
11	294.30	552.30	886.82
12	296.26	559.17	901.54

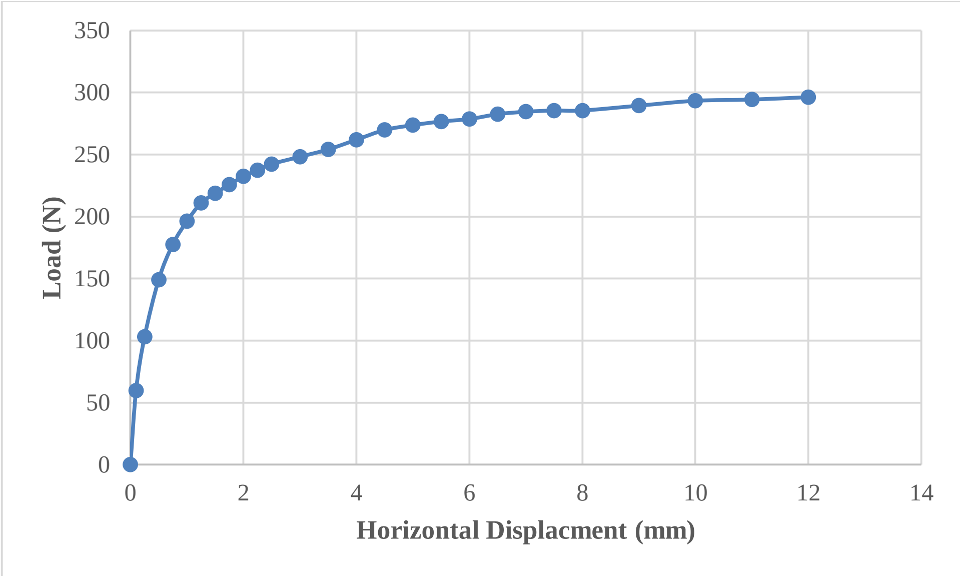


Fig.26: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.1 N/mm^2

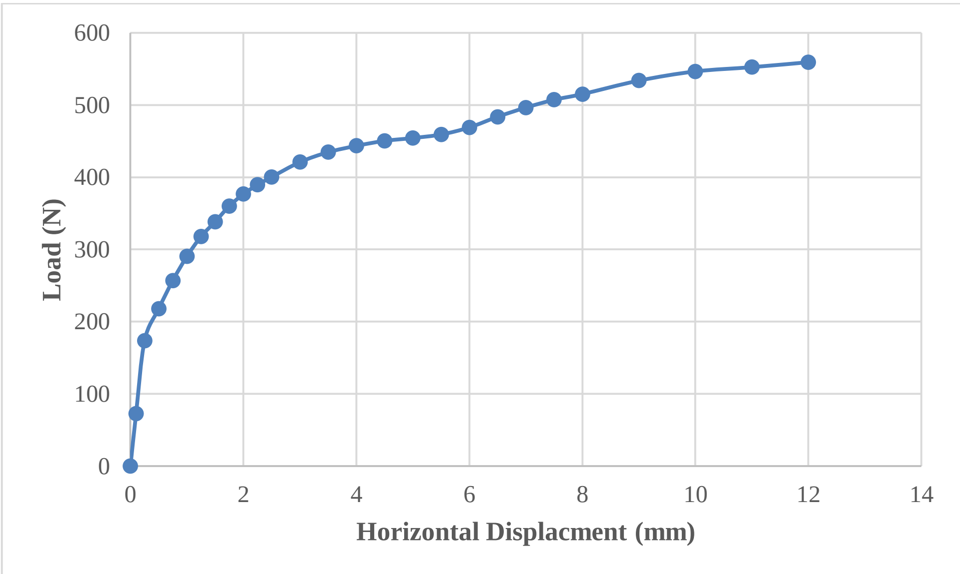


Fig.27: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.2 N/mm^2

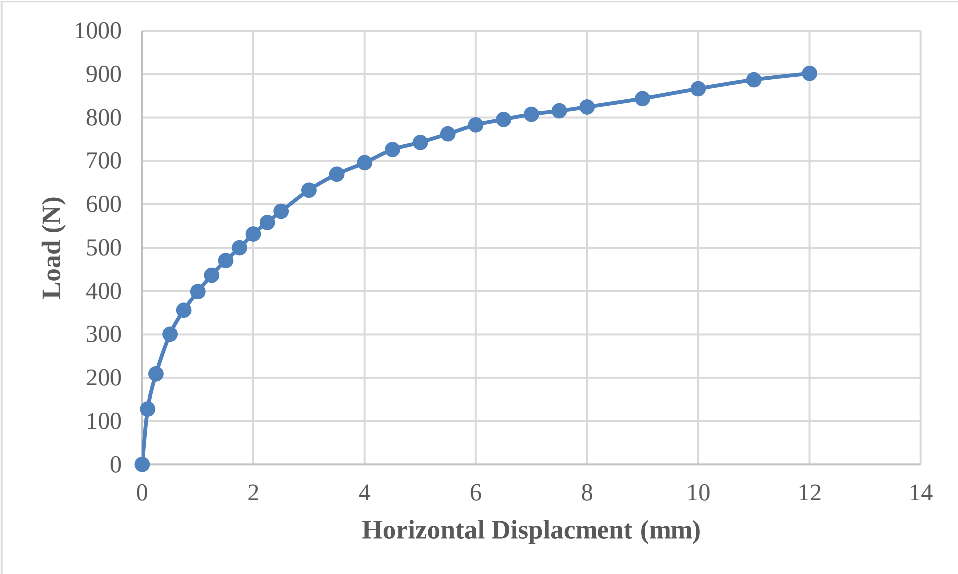


Fig.28: Load-Displacement Response of Reinforced Soil (P_f =0.25%) at Normal Stress = 0.3 N/mm^2

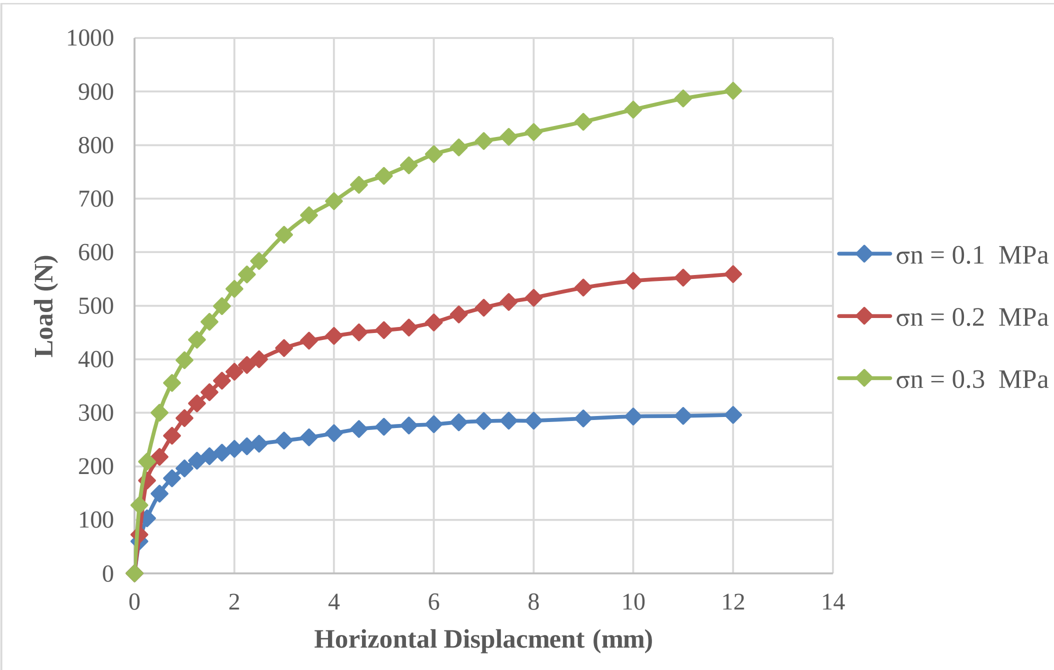


Fig.29: Load-Displacement Response of Reinforced Soil (P_f =0.25%)

Table 14: Load-Displacement Response of Reinforced Soil (P_f =0.50%)

Horizontal Displacment (mm)	**Load (N)**		
	σ_n=0.1N/mm^2	**σ_n=0.2N/mm^2**	**σ_n=0.3N/mm^2**
0	0.00	0.00	0.00
0.1	108.89	88.29	68.67
0.25	142.25	186.39	137.34
0.5	179.52	245.25	232.50
0.75	204.05	274.68	287.43
1	227.59	294.30	336.48
1.25	245.25	323.73	386.51
1.5	257.02	362.97	426.74
1.75	267.81	372.78	461.07
2	277.62	382.59	501.29
2.25	285.47	402.21	522.87
2.5	293.32	412.02	548.38
3	305.09	431.64	587.62
3.5	314.90	451.26	619.01
4	323.73	461.07	642.56
4.5	328.64	470.88	662.18
5	334.52	480.69	686.70
5.5	338.45	490.50	715.15
6	342.37	500.31	747.52
6.5	346.29	510.12	773.03
7	350.22	519.93	791.67
7.5	353.16	529.74	816.19
8	356.10	539.55	838.76
9	362.97	549.36	869.17
10	367.88	559.17	898.60
11	371.80	568.98	926.06
12	374.74	568.98	948.63

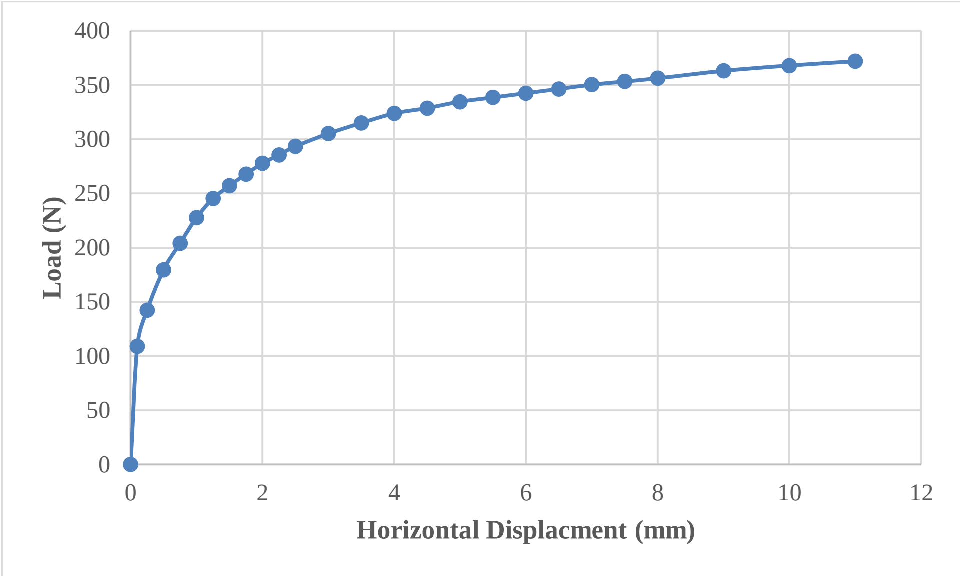


Fig.30: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.1 N/mm^2

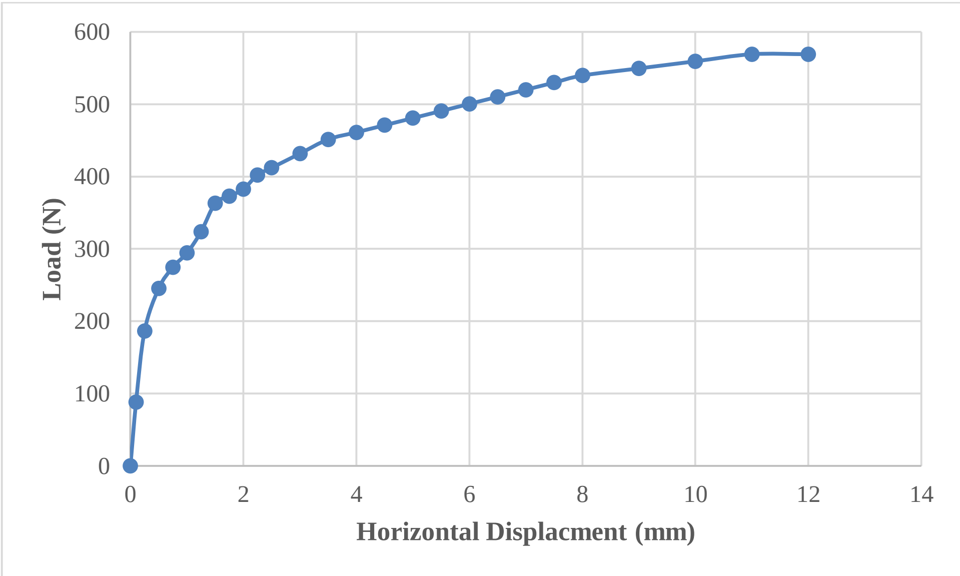


Fig.31: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.2 N/mm^2

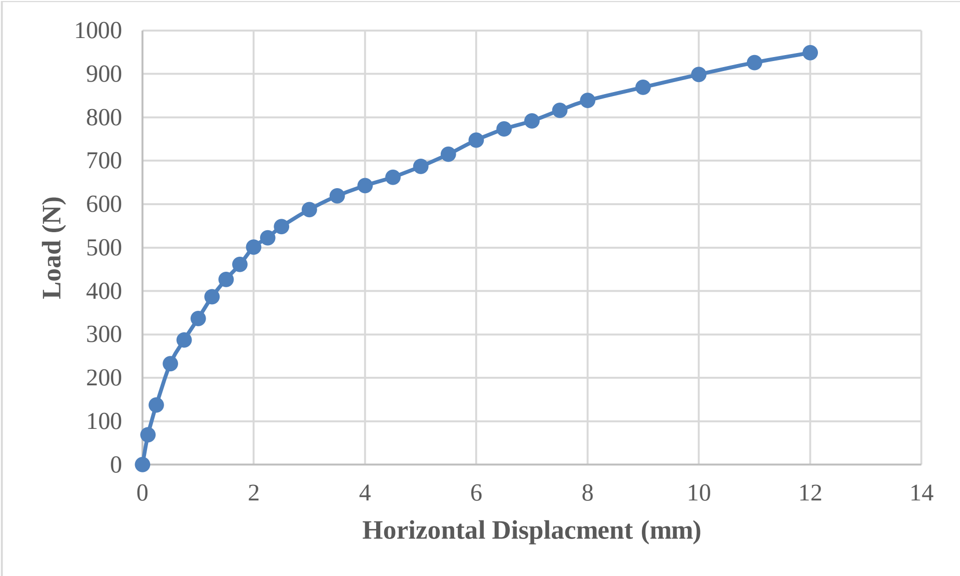


Fig.32: Load-Displacement Response of Reinforced Soil (P_f =0.50%) at Normal Stress = 0.3 N/mm^2

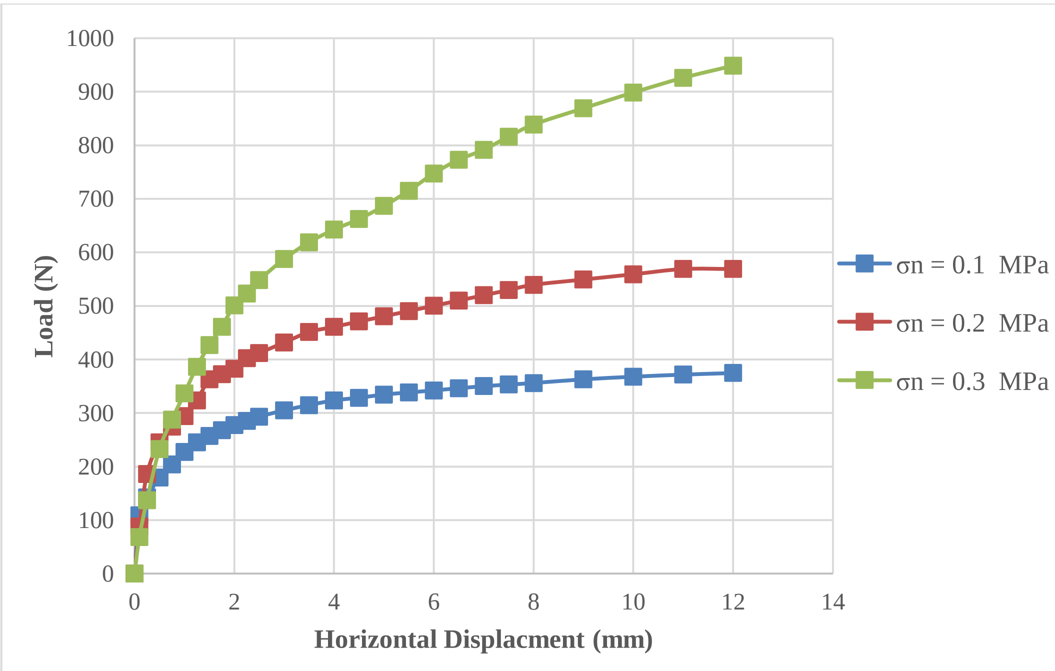


Fig.33: Load-Displacement Response of Reinforced Soil (P_f =0.50%)

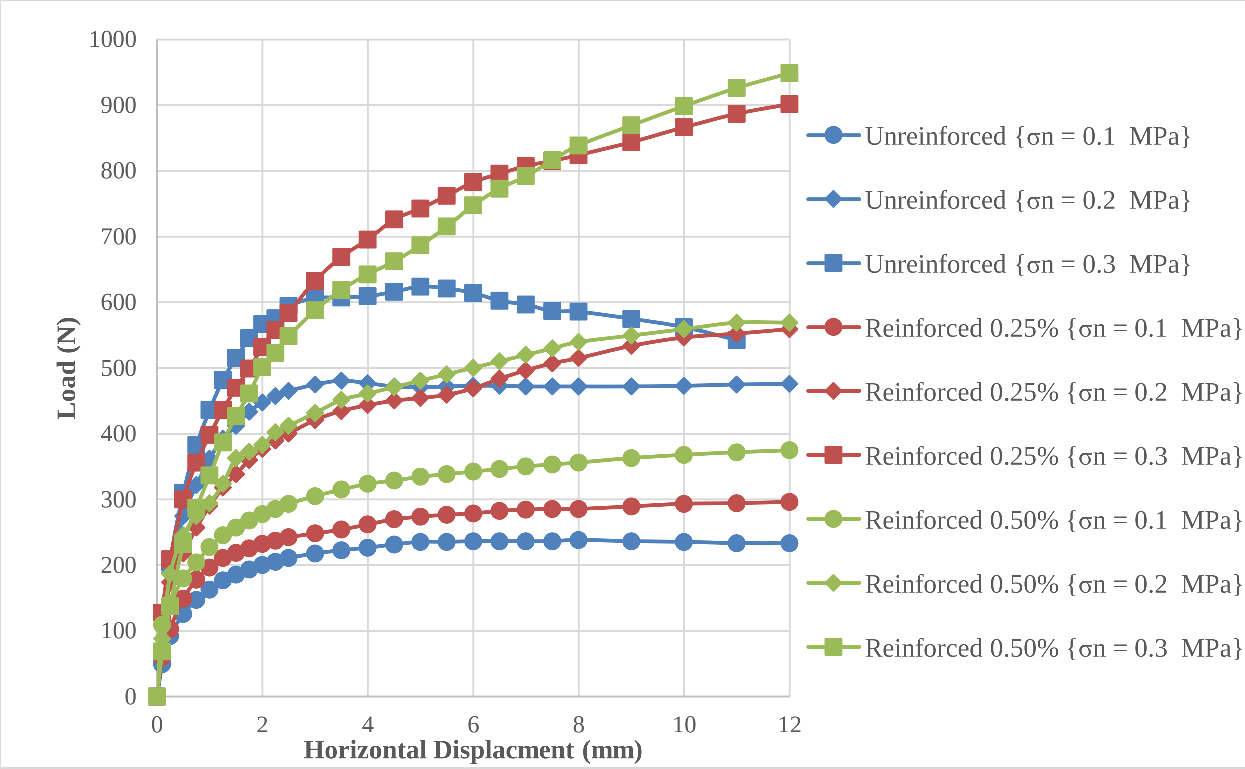


Fig.34: Comparison of Load-Displacement Response with varying fibre content

CHAPTER-5

RESULTS AND ANALYSIS

5.0 INTRODUCTION

In the following chapter, variations in results have been shown of the various tests that have been carried out.

This chapter consists of 3 sub-chapters namely,

- **Chapter 5.1:** Graphs showing variation in Traixial Test results.
- **Chapter 5.2:** Graphs showing variation in Direct Shear Test results.
- **Chapter 5.3:** Comparison between Unreinforced & Reinforced Soil

The effect of fibre reinforcement is shown in the succeeding chapters. The difference in the shear strength parameters due to the addition of fibre is shown and also the difference in the shear strength parameters obtained from the above two tests is indicated.

5.1 Graphs Showing Variation in Triaxial Test Results

Table 15: Variation in Major & Minor Principal Stresses of Unreinforced soil

σ_3(N/mm^2)	**Unreinforced**	
	σ_d(N/mm^2)	**σ_1(N/mm^2)**
0.1	0.463	0.563
0.2	0.594	0.794
0.3	0.828	1.128

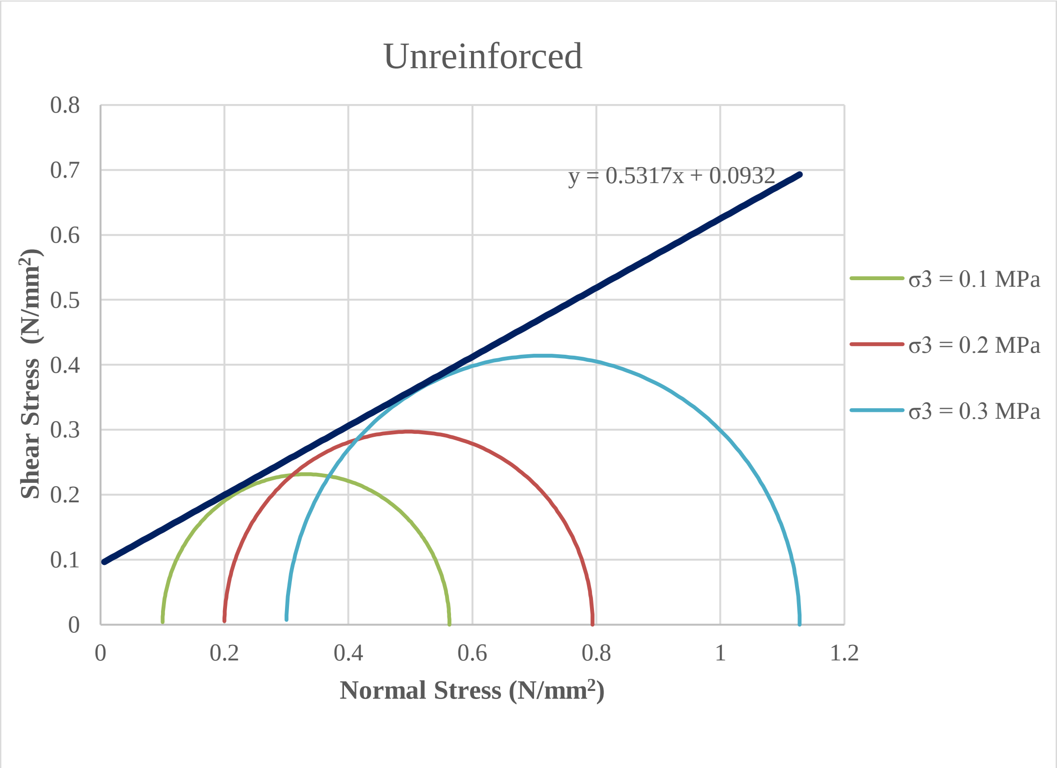


Fig.35: Mohr Circle with respective failure envelope of Unreinforced Soil (P_f =0%)

The angle of internal friction and cohesion of unreinforced soil are 28˚ & 0.0932 N/mm^2 respectively.

Table 16: Variation in Major & Minor Principal Stresses of Reinforced Soil (P_f=0.25%)

σ_3(N/mm^2)	Reinforced 0.25%	
	σ_d(N/mm^2)	σ_1(N/mm^2)
0.1	0.6014	0.7014
0.2	0.83	1.03
0.3	0.899	1.199

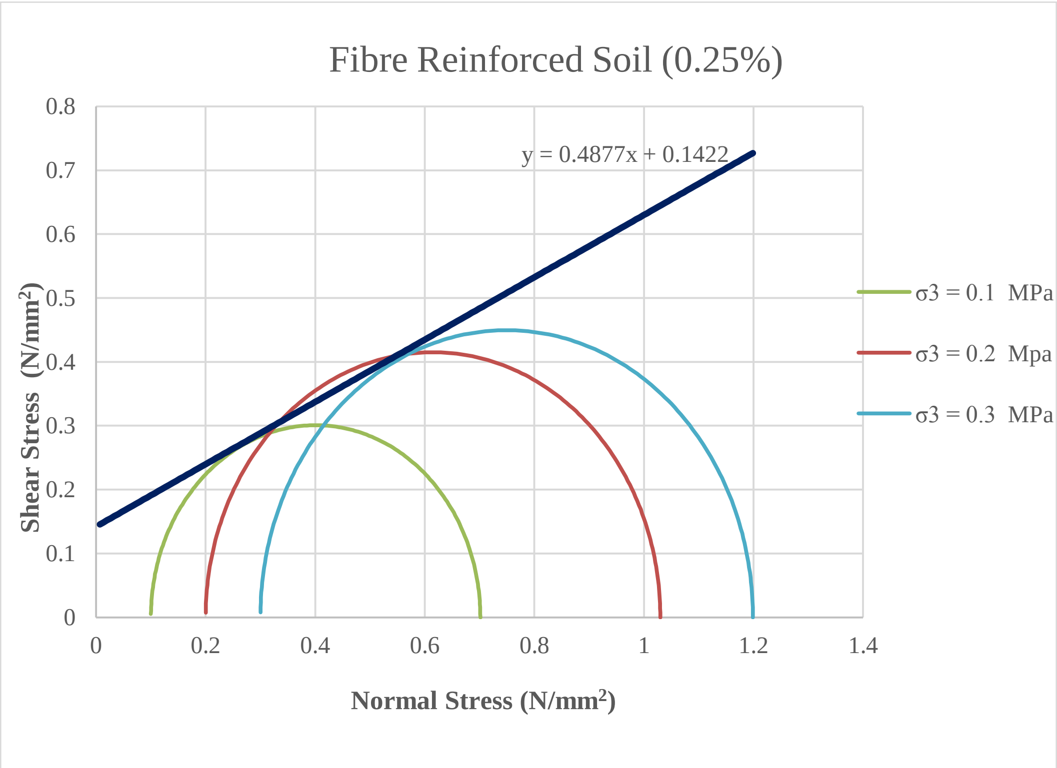


Fig.36: Mohr Circle with respective failure envelope of Reinforced Soil (P_f =0.25%)

The angle of internal friction and cohesion of unreinforced soil are 26˚ & 0.1422 N/mm^2 respectively.

Table 17: Variation in Major & Minor Principal Stresses of Reinforced Soil (P_f=0.50%)

σ_1(N/mm^2)	σ_1(N/mm^2)	
	σ_d(N/mm^2)	σ_1(N/mm^2)
0.1	0.75	0.85
0.2	0.939	1.139
0.3	1.14	1.44

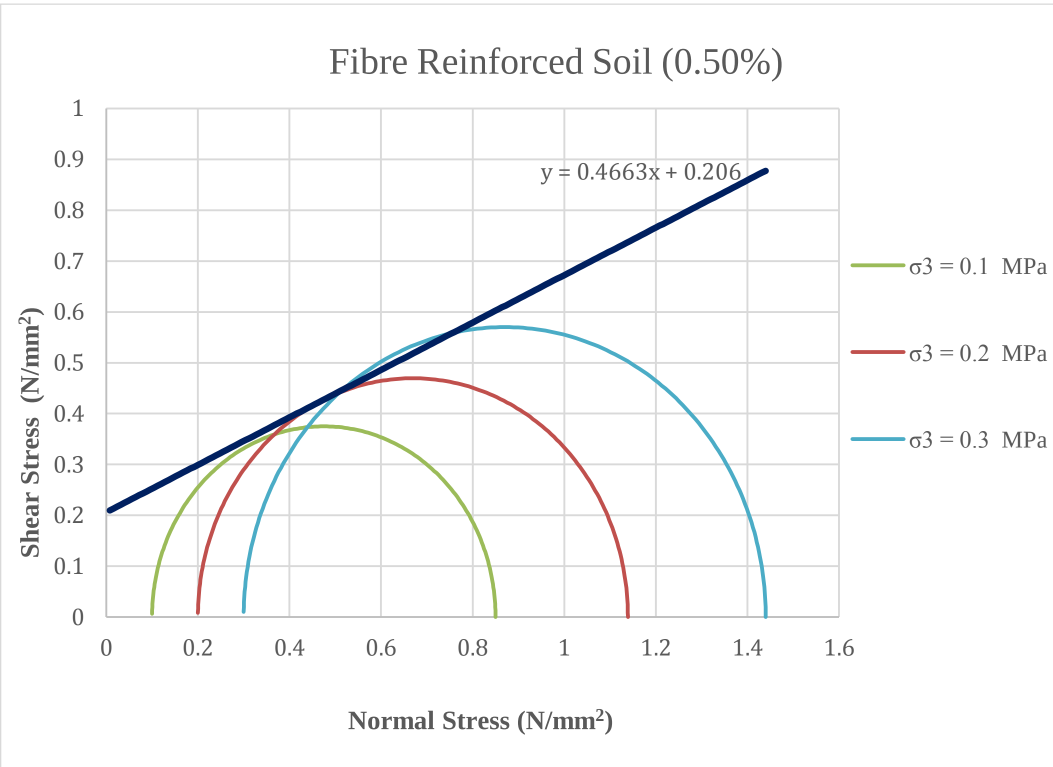


Fig.37: Mohr Circle with respective failure envelope of Reinforced Soil (P_f =0.50%)

The angle of internal friction and cohesion of unreinforced soil are 25˚ & 0.206 N/mm^2 respectively.

Table 18: Variation of Cohesion & Angle of Internal Friction with varying fibre content

P_f	Cohesion (N/mm^2)	ϕ
0	0.0932	28
0.25	0.1422	26
0.5	0.206	25

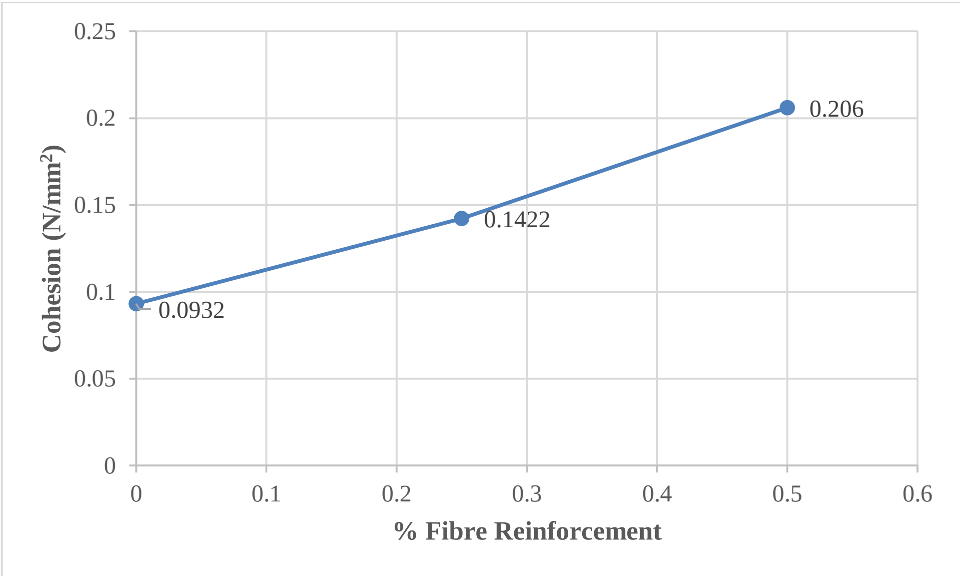


Fig.38: Variation of Cohesion with varying fibre content

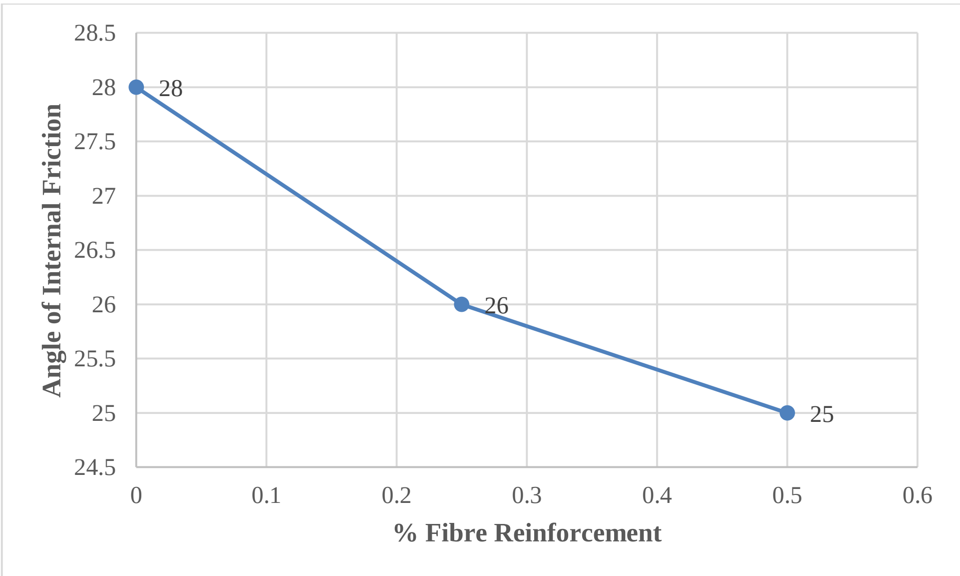


Fig.39: Variation of Angle of Internal Friction with varying fibre content

5.2 Graphs Showing Variation in Direct Shear Test Results

Table 19: Normal v/s Shear Stress for Unreinforced Soil

Normal Stress (N/mm^2)	**Load (N)**	**Shear Stress (N/mm^2)**
0.1	238.38	0.07
0.2	480.69	0.13
0.3	623.92	0.17

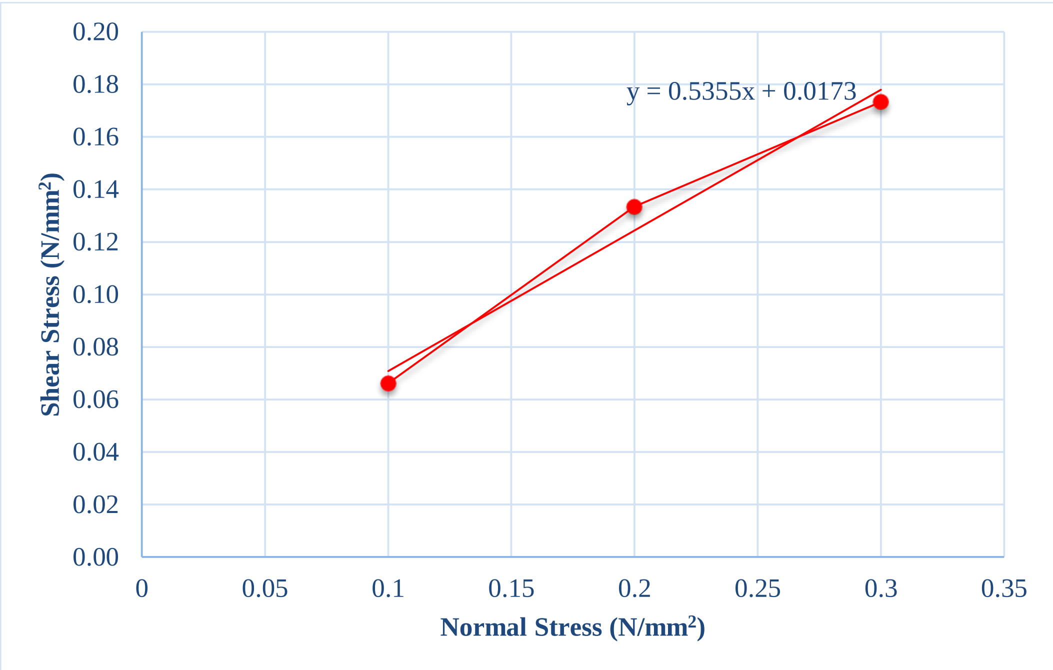


Fig.40: Failure Envelope of Unreinforced Soil

The angle of internal friction and cohesion of unreinforced soil are 28.17˚ & 0.0173 N/mm^2 respectively.

Table 20: Normal v/s. Shear Stress for Reinforced Soil (P_f =0.25%)

Normal Stress (N/mm^2)	**Load (N)**	**Shear Stress (N/mm^2)**
0.1	315.88	0.09
0.2	559.17	0.16
0.3	697.49	0.19

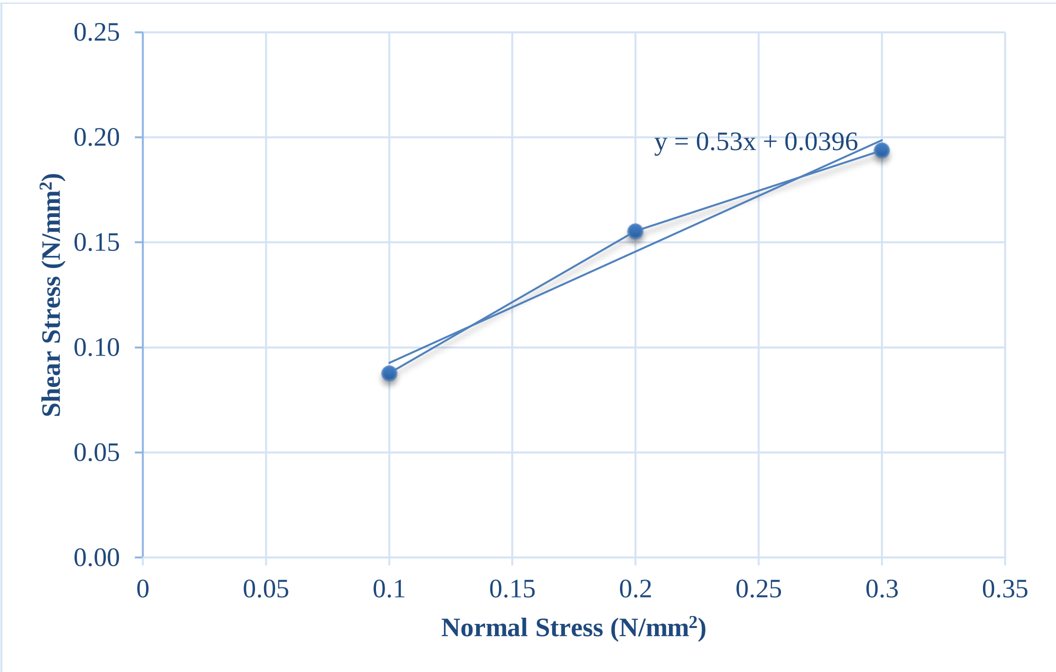


Fig.41: Failure Envelope of Reinforced Soil (P_f =0.25%)

The angle of internal friction and cohesion of unreinforced soil are 27.92˚ & 0.0396 N/mm^2 respectively.

Table 21: Normal v/s Shear Stress for Reinforced Soil (P_f =0.50%)

Normal Stress (N/mm^2)	**Load (N)**	**Shear Stress (N/mm^2)**
0.1	419.87	0.12
0.2	568.98	0.16
0.3	779.90	0.22

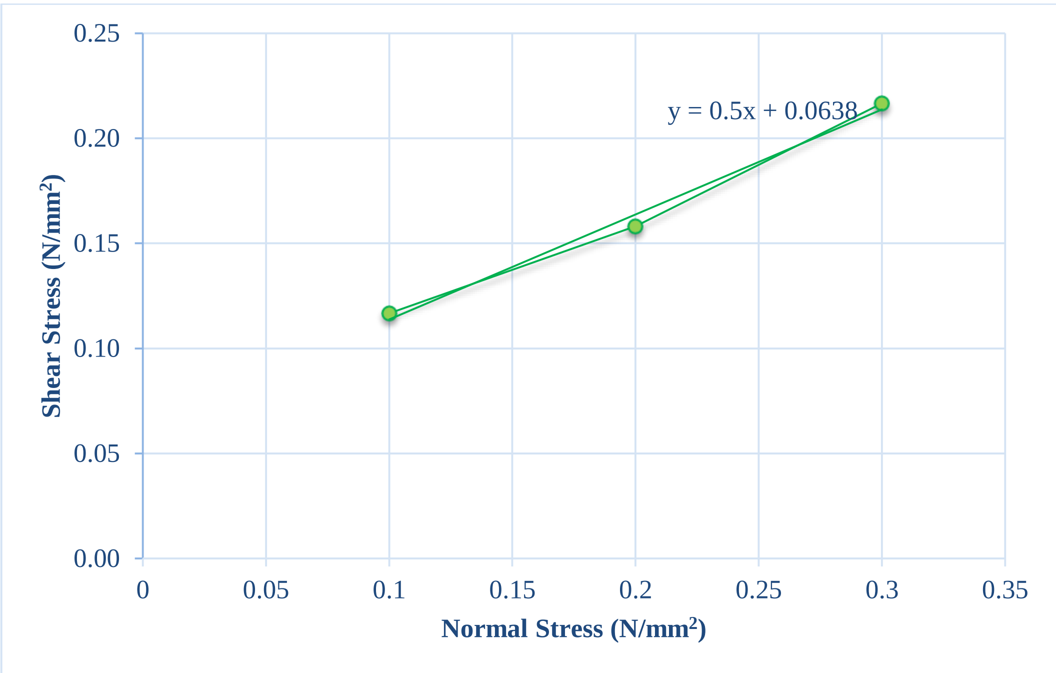


Fig.42: Failure Envelope of Reinforced Soil (P_f =0.50%)

The angle of internal friction and cohesion of unreinforced soil are 26.56˚ & 0.0638 N/mm^2 respectively.

Table 22: Variation in Normal v/s Shear Stress for Unreinforced Soil

Normal Stress (N/mm^2)	Shear Stress (N/mm^2)		
	Unreinforced	**Reinforced 0.25%**	**Reinforced 0.50%**
0.1	0.07	0.09	0.12
0.2	0.13	0.16	0.16
0.3	0.17	0.19	0.22

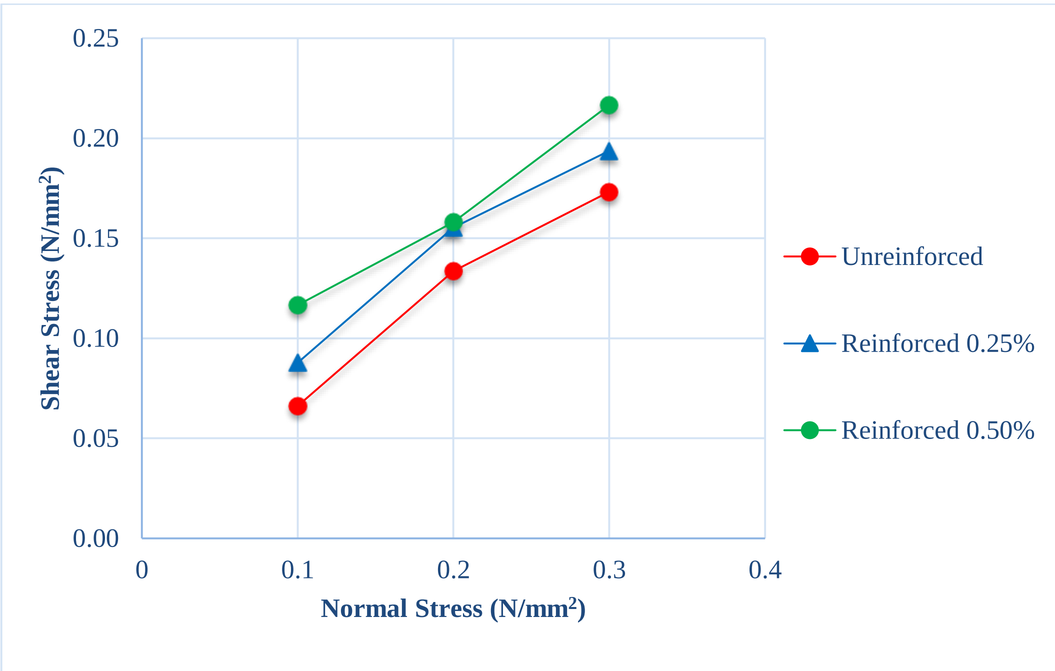


Fig.43: Comparison of Failure Envelopes of Unreinforced & Reinforced Soil

Table 23: Variation of Cohesion & Angle of Internal Friction with varying fibre content

P_f	Cohesion (N/mm^2)	ϕ
0	0.0173	28.17
0.25	0.0396	27.92
0.5	0.0638	26.56

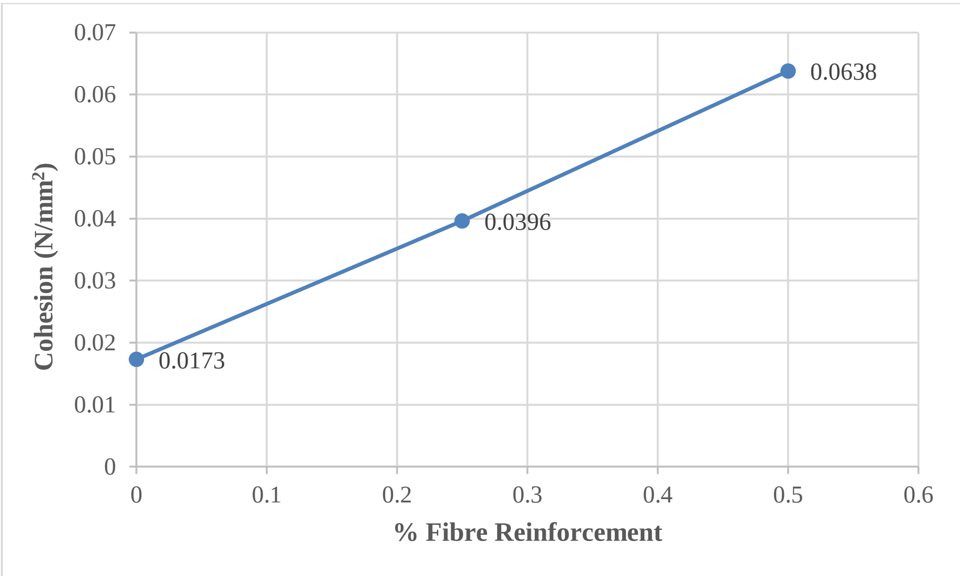


Fig.44: Variation of Cohesion with varying fibre content

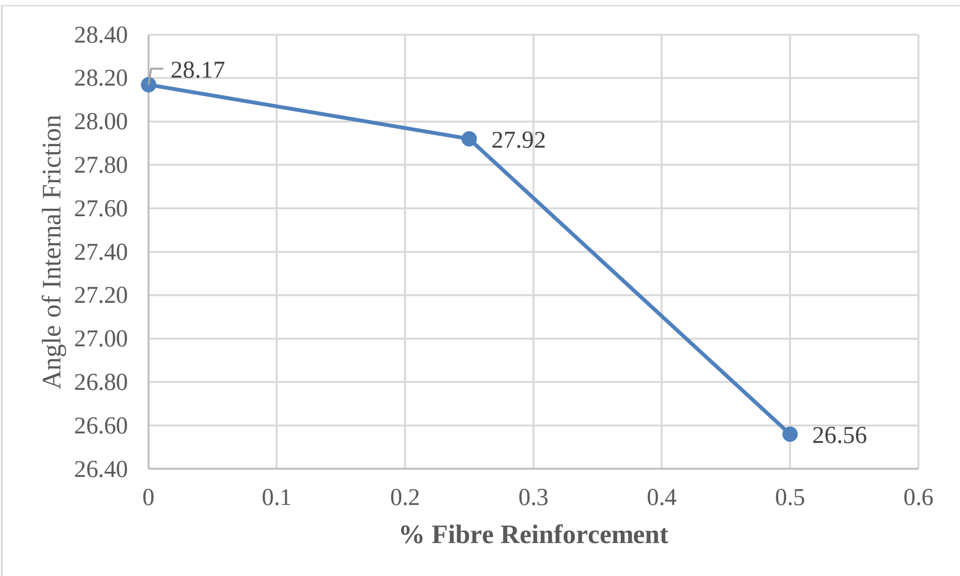


Fig.45: Variation of Angle of Internal Friction with varying fibre content

5.2 Comparison between Unreinforced & Reinforced Soil

a) $P_f = 0\%$ b) $P_f = 0.25\%$ c) $P_f = 0.50\%$

Fig.46: Bulged Samples after conducting UU Tests on Unreinforced & Reinforced Soil

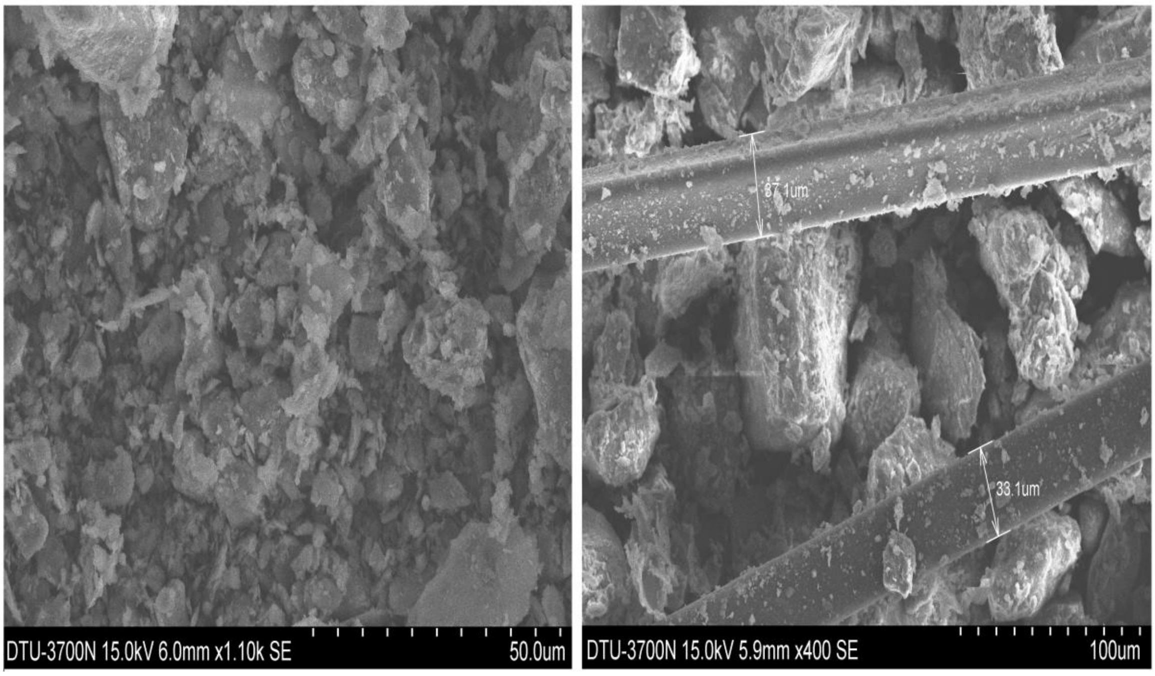


Fig.47) Scanning Electron Micrographs of Unreinforced & Fibre Reinforced Soil

CHAPTER 6

CONCLUSIONS

CONCLUSIONS

1. For Unreinforced soil, the value of cohesion and angle of internal friction are 0.093 N/mm^2 & 28˚ according to Triaxial tests; and according to Direct Shear tests, the values are 0.017 N/mm^2 & 28.17˚ respectively.

2. For Reinforced soil (P_f=0.25%), the value of cohesion and angle of internal friction are 0.1422 N/mm^2 & 26˚ according to Triaxial tests; and according to Direct Shear tests, the values are 0.039 N/mm^2 & 27.92˚ respectively.

3. For Reinforced soil (P_f=0.50%), the value of cohesion and angle of internal friction are 0.206 N/mm^2 & 25˚ according to Triaxial tests; and according to Direct Shear tests, the values are 0.064 N/mm^2 & 26.56˚ respectively.

4. According to the above Triaxial results, there was a 52.6% increase in the cohesion intercept due to the addition of 0.25% fibre into the soil and 121% increase due to the addition of 0.50% fibre. Fig.38. suggests a linear rise in the cohesion due to the addition of fibre.

5. But there was a 7.14% decrease in the angle of internal friction due to the addition of 0.25% fibre into the soil and 10.71% decrease due to the addition of 0.50% fibre. Fig.39. suggests that the graph initially decreases at an increasing rate and then at a decreasing rate.

6. According to the above Direct Shear results, there was a 129% increase in the cohesion intercept due to the addition of 0.25% fibre into the soil and 269% increase due to the addition of 0.50% fibre. Fig.44. suggests a linear rise in the cohesion due to the addition of fibre.

7. There was a 0.9% decrease in the angle of internal friction due to the addition of 0.25% fibre into the soil and 5.7% decrease due to the addition of 0.50% fibre. Fig.45. suggests that the graph initially decreases at a decreasing rate and then at an increasing rate.

8. A bulging failure pattern was observed in the case of Triaxial test (Fig.46). On comparison of samples at the same axial strain it is observed that on the addition of higher fibre content the bulging reduces.

9. There is also a moderate rise in shear strength and compressive strength values of the fibre reinforced soil.

10. The above point may be explained with the fact that on the addition of fibre the total contact area increases between the soil particles and the fibres which in turn increases the compressive strength.

11. The increase in shear strength may be explained by the fact that the friction between fibre and the soil increases due to abrasion of fibre by soil particles. SEM images showing interlocking between soil particles and fibre can be seen in Fig.47. This soil-fibre interaction leads to increased resistance to applied loads, hence greater shear strength. Also better interlocking is achieved due to the triangular shape of the Recron-3S fibre.

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