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PERFORMANCE AND ANALYSIS OF COIR FIBER AS A SOIL REINFORCEMENT

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ABSTRACT

The increasing tempo of construction activity has led to the requirement of good soil whose availability is less hence, there is need of improving the soil condition which can be accomplished through ground improvement methods. Among all the ground improvement techniques, soil reinforcement is emerging as an attractive alternative. The addition of natural fibre to the soil is very good soil reinforcement technique. Coir fibre extracted from the outer shell of the coconut can be effectively used to tackle many short term stability issue in geotechnical engineering.

Coir fibre having high lignin content and less cellulose content than fibres such as flax and cotton, which makes it stronger but less flexible. Coir is bio-degradable product and it takes approximately 20 years to degrade over the ground and with suitable coating takes about 4-5 years to decompose under the burial condition. It is moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant, unaffected by moisture and dampness, tough and durable, resilient, spring back to shape even after constant use and have low thermal conductivity and bulk density.

The present study is focussed on modifying the geotechnical properties of soil by reinforcing it with different percentages of coir fibre in the soil obtained from the Gautam Budh Nagar region of District, Delhi NCR. For this study coir fibre was purchased from the local market of New Delhi. The study is conducted in two phases. In the first phase, the geotechnical properties of soil were studied by conducting laboratory tests. In the second phase, soil mixed with four different percentages of coir fibre i.e., 0.25 %, 0.50%, 0.75%, and 1% were subjected to various tests.

CHAPTER 1 INTRODUCTION

General

For growth of country along with the technological advancements, development in infrastructure field is also required and with the rapid rate of urbanization in our country it is becoming difficult to find the proper quality of soil for engineering applications. Hence, it is a challenging task for a geotechnical engineer to come up with the ideas which would allow us to work on the even poor quality of soil with any risk of failure of the structure. With a diversification of many types of soil in our country a major category of soil which isof many problems to engineers is expansive soil which creates a lot of problems to structure formed on them. This study focusses on the expansive soils and how various geotechnical parameters can be enhanced by the use of coir fibre.

A Review on Expansive Soils

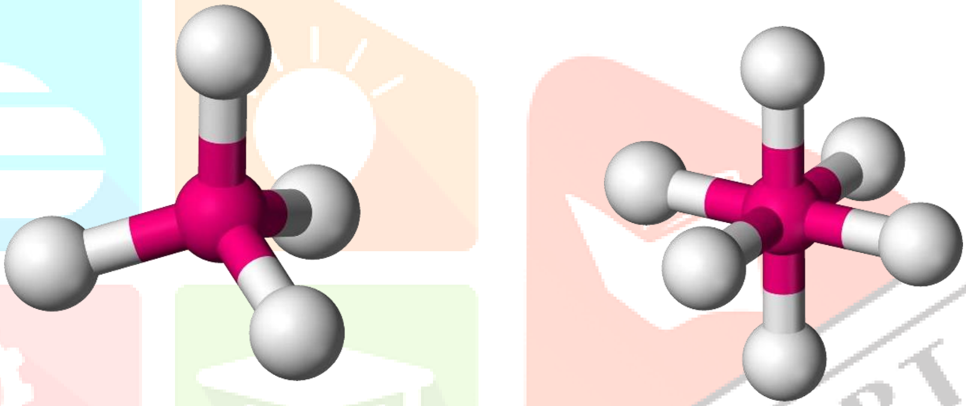
Expansive or swelling soils, as their name implies, are soils that swell when subjectedto moisture. These swelling soils typically contain clay minerals that attract and absorb water. Covering about 15 to 20% of the total land area of the country these dark colour soils show a large change in volume with water content. The dark colour is due to the presence of the compound of iron and aluminum, accumulated humus and colloidal hydrated double ionand aluminum silicate. Prior to building the structure, a soil test of the site should be performed to ensure that the soils are stable and to determine the approximate effect that the soil will have on the structure. With the breakdown of igneous rock through the weathering action leads to the formation of clay, weathering allows to recrystallize the atoms of soil hence changing their behaviour than the parent rock, with the recrystallization SilicaTetrahedron sheet and Aluminium octahedral sheets are formed. It is only the mode of stacking of these sheets, the nature of bonding force and the different metallic ion in the crystal lattice that go to make different clay mineral.

Tetrahedral Sheets

It has four oxygen or hydroxyls having the configuration of a tetrahedron enclose a silicon atom. The tetrahedra are combined in a sheet structure so the oxygens of the bases of all the tetrahedra are in a common plane, and each oxygen belongs to two tetrahedra. The silica tetrahedral sheet alone may be reviewed as a layer of silicon atom between a layer of oxygens and a layer of hydroxyls.

Octahedral Sheets

It has six hydroxyl ions at the corners of an octahedron enclosing an aluminium or magnesium or some other metallic ion. The rows of hydroxyl ion divide its -1 charge with two other units, leaving a total of two negative charges 1/3 X 6 per unit. Thus, the net charge of an octahedral unit with the aluminium ion at the centre is +1. If the atom at the centre is aluminium, the resulting sheet is called gibbsite and if magnesium is the central atom, then the sheet is called brucite sheet.



Tetrahedral Sheet Octahedral Sheet

Fig 1.1: Basic Structure of Tetrahedral and Octahedral Sheets

Clay soils are normally associated with water and their properties are greatly influenced by the presence of water. Montmorillonite is the smallest clay mineral and is more active than any other clay mineral. Activity values of minerals are shown in the following section.

Table 1.1: Activity Values of Different Minerals

Mineral	Activity No.
Na-montmorillonite	4-7
Ca-montmorillonite	1.5
Illite	0.5-1.3
Kaolinite	0.3-0.5
Halloysite (hydrated)	0.1
Calcite	0.2
Quartz	0

It can be seen from the above table that the soil which contains montmorillonite in it have too high tendency to show swelling characteristic when in presence of moisture and this mineral is the reason which causes the expansive soils to swell.

Structure of Montmorillonite

Montmorillonite is formed from weathering of volcanic ash under poor drainage conditions or in marine waters. The basic structural unit consists of an alumina sheet sandwiched between two silica sheets. Successive structural units are stacked one over another. The thickness of each structural unit is about 10 Å.

The two consecutive structural units are fused together by a link between oxygen ions of the two silica sheets. The link is due to the natural attraction for the cations in the intervening space and due to Van der Waals forces. The negatively charged surfaces of the silica sheets attract water in the space between two structural units. This results in an expansion of the mineral. The soil containing a large amount of the mineral montmorillonite exhibits high shrinkage and high swelling characteristics. The water in the intervening space can be removed by heating at 200^{o} to 300^{o} C.

This property of expansive soil to swell by large volume may seriously endanger the stability of the overlying structure and road pavement. So, we are in need of the ways which would allow us to work on these type of soil also. Various methods like soil nailing, grouting, soil stabilization through various additives and Vibro-compaction have been developed and are widely used to enhance the geotechnical properties of soil and among this one of thetechnique to improve the soil is through the process of soil reinforcement.

Soil Reinforcement

The concept and principle of soil reinforcement were first developed by Vidal demonstrating the introduction of reinforcement agents in order to improve the shearresistance in soil. Reinforcing the soil is a technique in which tensile elements are used within the soil for improving stability and to control deformation. In order to make reinforcement effective, it must intersect with potential failure surfaces present in the soil mass. Strains occurring in the soil mass will produce strains in the reinforcement, which in turn will generate tensile loads in the reinforcements these tensile loads keep the soil movements under control and therefore giving additional shear strength. This outcome in the composite soil/reinforcement system having altogether more prominent shear strength thanthe soil mass alone.

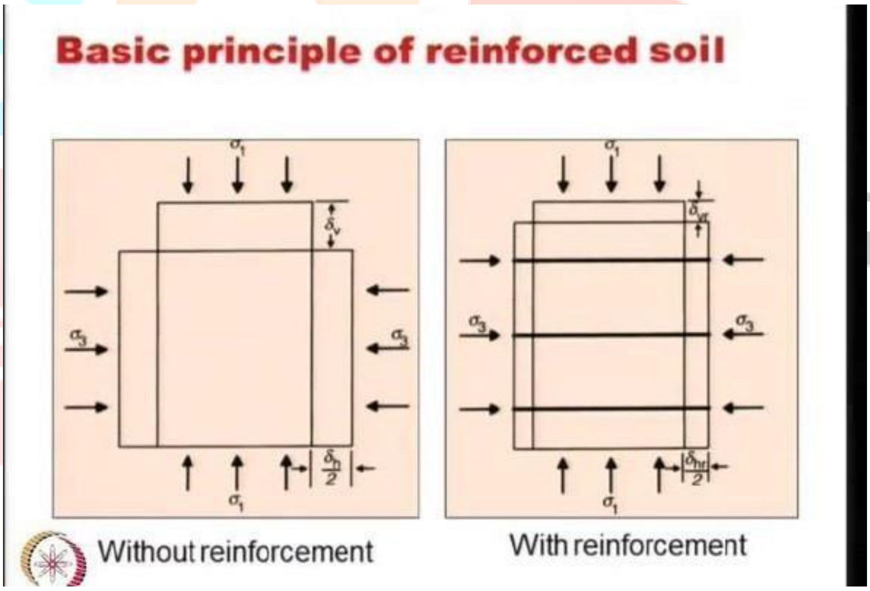


Fig 1.2: Principle of Soil Reinforcement

Reinforced soil is a very cost-effective technique compared to other construction techniques. The significant advantages of strengthened soil are:

•Reinforcement in the soil enhances the shear resistance of the soil therebyimproving its structural capability

• The inclusion of reinforcement enables us to use poor quality soils as the structural components

• Reduce the compressibility of soil

•More durable as material is non-biodegradable

• Improves strength, toughness, ductility and stiffness of soil

•Soil piping resistance improves

• Increase soil resistance against liquefaction under dynamic loading conditions

• Less expensive compared to other reinforcing materials

• Construction time can be diminished with the use of reinforcement technique.

Methods for Soil Reinforcement

Reinforcement in the soil can be done by various methods. Following charts showsvarious methods which can be used for the same:

Soil reinforcement methods
- 1) Physical: vibration, thermo-electrical, freeze and thaw
- 2) Mechanical
  - 1) Geosynthetic
    - a) Geogrid
    - b) Geotextile
    - c) Geocomposite
    - d) Geonet
    - e) Geocell
  - a) Using fibrous material
    - 2) Randomly Distributed
      - a) Natural
      - b) Man Made
  - a) Compaction e.g. surcharge
- 3) Chemical
  - a) Conventional Materials (e.g. cement, lime).
  - b) Enzymes (e.g. PZ-22X)
  - c) Polymeric Resins (e.g. Polyvinyl Alcohol)

At the present time, there is a greater awareness that landfills are filling up, resourcesare being used up, the planet is being polluted and that non-renewable assets won't keep going forever. Thus, there is a need to work on environmentally friendly materials. That is the reason there have been numerous experimental investigations and a great deal of interest has been created worldwide on potential applications of natural fibres for soil reinforcement in recent years. The term ‘‘eco-composite’’ demonstrates the significant role of natural fibres in the modern industry. Mainly, what portion of the plant the fibre originated from, the age of the plant; and how the fibre was isolated, are some of the factors which influence the execution of natural fibres in a natural fibre reinforced soil.

Soil reinforcement techniques can be divided into two major categories:-

1. In-situ (soil reinforcement)
2. Constructed (soil reinforcement

As described above reinforcement can be done through various agents, so in thisstudy, a naturally occurring coir fibre was used as the reinforcement.

Coir Fibre

Coir fibre is extracted from the outer shell of a coconut. The common name, scientific name and plant family of coconut fibre are Coir, Cocos nucifera and Arecaceae (Palm), respectively. Two types of coir fibre found are brown and white in colour. Brown coir whichis harvested from fully ripened coconuts is thick, strong and has high abrasion resistance. Matured brown coir fibre have high lignin content and less cellulose content than fibres suchas flax and cotton, which makes it stronger but less flexible. White coir fibres are harvested from coconuts before they are ripe and are white or light brown in colour, are smoother andfiner, but also weaker. Coir is bio-degradable product and it takes approximately 20 years todegrade over the ground, a few experiment performed by Rao and Balan (2000) suggested that the fibre will last 2-3 years in the burial condition. Studies have shown that coating the fibre with a protective layer could increase its durability. Coir fibres measure up to 3-5 cm in length with a diameter of about 0.5 mm. A coconut harvest occurs once in 45 days. From1000 coconuts it would be possible to extract 10 kgs of coir. Among vegetable fibres, coir has one of the highest concentrations of lignin, making it stronger There are many general advantages of coconut fibres, e.g., they are moth-proof, resistant to fungi and rot, provide excellent insulation against temperature and sound, not easily combustible, flame-retardant,unaffected by moisture and dampness, tough and durable, resilient, springs back to shape even after constant use.. Coconut coir has low thermal conductivity and bulk density.

The components of natural fibres are cellulose, hemicellulose, lignin, pectin, waxes and water-soluble substances. The cellulose, hemicellulose and lignin are the basic components of natural fibres.

- **Cellulose:** Cellulose is the fundamental basic part of all plant fibres. Cellulose has a positive connection with the tensile strength, specific strength, specific Young's modulus, density, diameter, and length of fibres. It has a strong effect on their density and tensile strength.
- **Lignin:** Lignin has a negative connection with the tensile strength, specific strength, specific Young's modulus, density, diameter and length. It strongly affects the tensile strength, specific strength, length, and specific Young's modulus.
- **Hemicellulose:** Hemicellulose is comprised of chains of sugars. They contain a gathering of polysaccharides (barring pectin) fortified together in moderately short, fanning chains and remains related with the cellulose after lignin has been expelled. Hemicelluloses have a positive connection with Young's modulus, specific strength, diameter, and moisture gain. With increment in the content of hemicelluloses, thesequalities of characteristic fibre do increases.
- **Pectin:** Pectin is the basic structural component of all plant fibres. The outer cell wall is porous and consists also of pectin and other non-structural carbohydrates. The pores of the outer skin are the prime diffusion paths of water through the material.

Manufacturing of Coir Fibre

The conventional creation of filaments from the husks is a relentless and tedious process. In the wake of isolating of the nut, the husks are handled by different retting procedures for the most part in lakes of salty waters (for three to six months) or in backwaters or tidal ponds. This requires 10-12 months of anaerobic (bacterial) ageing.

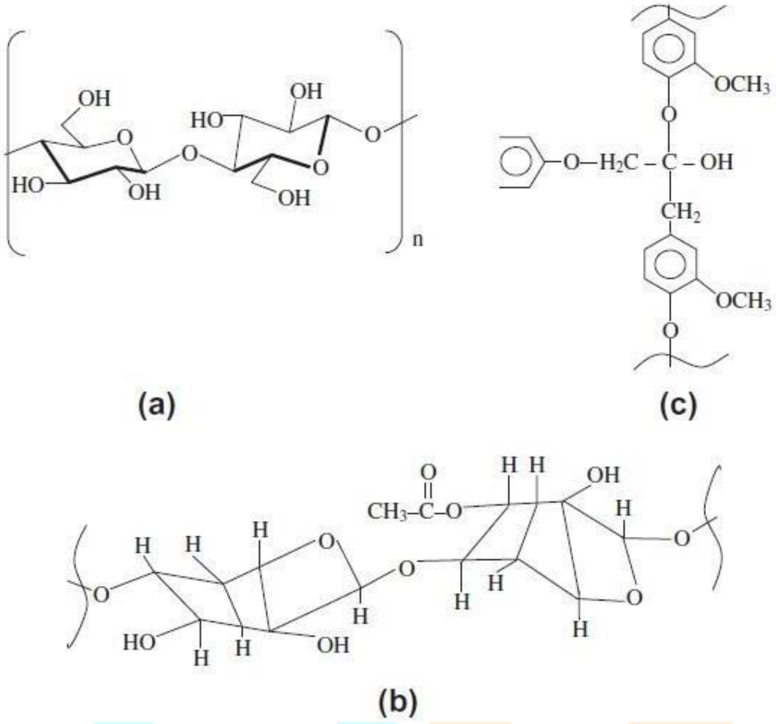


Fig 1.3: Chemical Structure of (a) Cellulose (b) Hemicellulose and (c) Lignin

Table 1.2: Properties of Coir Fibres (After Banerjee et al., 2002)

Property	Fibres < 100 mm in Length
Breaking load, N	217.8
Tenacity (cN/tex)	11.5
Modulus (Initial) (cN/tex)	85.9
Modulus offset) (cN/tex)	9.5
Breaking extension, %	41.7
Energy to break (Joules) \	0.0062
Thickness in 1/100th mm	13.57
Linear density (tex)	18.9

By retting, the husks are mollified and can be decorticated and the fibre is separated bybeating, which is normally done by hand. In the wake of hackling, washing and drying (inthe shade) the strands are slackened physically and cleaned. Alternatively, in mechanicalprocesses by the use of either defibreing or decorticating equipment process the husks afterjust five days of submersion in water tanks. Crushing the husk in a breaker opens the fibres.By the use of revolving drums, the coarse long strands are isolated from the short woodyparts and the substance. The stronger fibres are washed, cleaned, dried, hackled and combed.This fibrous material is usually thrown out or is used as fuel. Hence, it can be used extensively in noncritical civil engineering applications and thereby the cost of civilengineering construction can be brought down to a great extent. It is in this context that use of natural materials like coir for ground improvement becomes significant.

Objectives of the Study

1. To study the various geotechnical properties of soil such as maximum dry density, optimum moisture content, California bearing ratio, unconfined compressive strength and shear strength parameters by mixing soil with different percentages of coir fibre.

2. To suggest an optimum content of coir fibre to be mixed in the soil for strength improvement in the soil.

Organisation of the Thesis

This thesis comprises of 5 chapters. Chapter 1 provides a general overview of Expansive soil, the method of soil reinforcement and coir fibre. Chapter 2 presents a comprehensive literature review on the modification of soil properties by coir fibre. Chapter 3 provides the description of materials and experimental procedures. The experimental results obtained from this work are presented and discussed in Chapter 4. Chapter 5 summarizes the conclusions emanating from the results presented in chapter 4. The suggestions for future work on this topic are included in Chapter 5.

CHAPTER 2 REVIEW OF LITERATURE

General

The study is based on the use of coir fibre as a reinforcement in the soil so in order to conduct the experimental programme, various research literature was studied which helped in the understanding of the behaviour of coir fibre with soil. This chapter describes the previous study which has been done and a brief review of that study has been done.

Previous Studies on Coir Fibre

Rao *et al.* (2005) conducted the triaxial tests to calculate the strength of sand which was reinforced with coir fibre. The percentage of coir varied was 0.5% and 1%. It was seen that longer fibres were stiffer than the shorter ones. To study the stiffness of fibre the fibre having a length between 150-199 mm was designated as type A1 and with fibre length less than 100 mm they were designated as type A2, later the fibre was cut into a length of 25 mm for further experimental work. It was found that deviator stress at the time of failure increases with increase in the fibre content confirming the ability of coir fibre in improving the strength of sand, at the lower value of confining pressures, A2 type coir fibre exhibits higher increase in value of deviator stress at the time of failure than A1 type of fibre. At fibre content of 0.5% coir content A2 type shows higher strength than A1 type and at fibre content of 1% both A1 and A2 type shows near about similar strength when coir fibre was randomly distributed.

Babu and Vasudevan (2008) studied the influence of coir fibre on strength and stiffness behaviour of soil, a series of the triaxial tests were conducted at various fibre content and at different fibre lengths, diameter and different confining pressure, it was concluded from the study that stress-strain behaviour has improved by the use of coir fibre and the value of deviator stress increased up to 3.5 times with inclusion of fibre in soil, the deviator stress in case of reinforced soil increases with the diameter of fibre and the maximum value of this stress was found when fibre used was of length in between 15-25 mm and was also observed that stiffness behaviour of soil has increased and immediate settlement of soil can be minimized by the use of coir fibre in the soil.

Chauhan *et al.* (2008) studied the effect of coir fibre and polypropylene fibre in the silty sand mixed with fly ash. Fly ash was mixed at 10%, 20%, 30% and 40% of the dry weight of the soil and 30% fly ash was found to be optimum. Both the fibres at 0.5%, 1%, 1.5% and 2% by dry weight were used in the study. UCS values in case of coir fibre increased up to 0.75% making it as an optimum value and for polypropylene fibre optimum dose was found out to be 1%, finding from the triaxial tests resulted that the coir fibre exhibit more improvement in shear strength of soil than the synthetic fibre, for coir fibre improvement was by 47.50% and in synthetic fibre it was by 40%.

Subaida *et al.* (2009) reinforced the unpaved road with woven coir geotextile. It was concluded that bearing capacity increased with use of coir geotextile, significant rise in value of ultimate bearing capacity was obtained when geotextile was placed at mid- depth of base course, woven geotextile also decreased the permanent vertical deformation over the loaded area of pavement under repeated loading by restraining the lateral spreading of base material. It was concluded that coir geotextile should be placed with sufficient fill above the geotextile layer in order to mobilize frictional resistance and this would also help to decreasethe damage caused to the geotextile due to traffic.

Dasaka and Sumesh (2011) reinforced the soil with the coir fibre at various fibre content and found that with the fibre length of 15 mm, unconfined compressive strength increases with the increase in the fibre content and the soil shows a ductile behaviour with the addition of the fibre. It was found that peak compressive strength increased up to the fibre content of 1.5% and after that, the compressive strength does not increase considerably.From the study, it can be stated that with the increase in the fibre content the failure would take place slowly and samples behave like ductile material and well-defined failure surface could not be seen due to increased ductile behaviour. When triaxial tests were conducted in the Unconsolidated Undrained (UU) condition under the various confining pressure it was observed that peak deviator stress increases with increase in fibre content which clearly indicates that the fibre-soil composite is more ductile compared to unreinforced soil and ductility increases with increase in the fibre dosage and also the cohesion and friction angle was increased significantly and attains a peak value at the optimum fibre content of 1.5%.

Dutta *et al.* (2012) studied the effect of inclusion of coir fibre (15 mm in length) in the unconfined compressive strength of the soil. Dry fibre, sodium hydroxide and carbon tetrachloride treated coir fibres were taken for the study. The specimen for the unconfined compressive tests were prepared from unreinforced and reinforced dry/treated fibre with the fibre content of 0.4%, 0.8% and 1.6%. An increase in axial stress from 63.98 kPa to 79.67 kPa was observed when the clay specimen was reinforced with 0.4% dry fibresand with reinforcing it with 1.6% dry fibres this value increased to 114.77 kPa. Similarly, for the NaOH treated fibre the peak stress of clay with 0.4% fibres was 81.47 kPa which on increasing the fibre content to 1.6% elevated to 130.03 kPa. Further, when the soil mix was reinforced with 0.4% CCl_4 treated fibres, the peak stress observed was 70.69 kPa, which again increased to 245.78 kPa when the fibre content was increased to 1.6%.

Nithin and Sayida (2012) studied the result on silty sand mixed with fly ash and reinforced with coir fibre and analysed that randomly distributed coir fibre are useful in improving the bearing capacity of the soil. The silty sand was mixed with varying content of fly ash from 5% to 20% and coir fibre was added in the range of 0.5% to 5% with different aspect ratio. In the unconfined compression tests the optimum result produced by fly ash was at proportion of 15% fly ash and 85% silty sand and in this proportion, the coir fibre with varying content was mixed in the admixture. It was seen that with the increase in the content of coir fibre the strength value does increases but only up to an optimum value, when we increase beyond the optimum value fibres starts to accumulate together within the samples which cause coir fibre to slip on each other which in turn decreases the unconfined strength of the mix. The optimum fibre content of coir for the aspect ratio of 40 came out to be 3%, for the aspect ratio of 80 it was 4% and was 2% for the aspect ratio of 120 and 160.

Kirar *et al.* (2012) conducted the triaxial test on the reinforced and unreinforced sand. Coir fibre used for reinforcement was of random diameter varying from 0.1 mm to 0.3 mm with an average length of fibre as 20 mm. It was observed from the study that fibre is more effective at higher shear strain where it increases the shear modulus significantly.

Maliakal and Thiyyakkandi (2013) studied the effect of randomly distributed coir fibre on the shear strength of clay, for this series of consolidated undrained test were performed with varying fibre content having an aspect ratio of 50, 100 and 150 and fibre content of 0.5, 1 and 2% was taken for study. For all percentages of coir fibre maximum improvement in strength was obtained at the fibre content of 2% and improvement in strength was 1.7 times in comparison to the unreinforced soil. For the aspect ratio, the maximum improvement was reported at the aspect ratio of 150 and the length of fibre at thisaspect ratio was 36 mm.

Sreekumar and Nair (2013) focussed on the investigation for improving the properties of stabilized lateritic block with help of coir cutting waste utilized from coir industry as a reinforced material. The use of lateritic soil was done in the study which showshigh clay content and was pre-stabilized with sand and cement, after this pre-stabilized block were prepared with further stabilizing with waste coir fibre and was tested for strength and durability. In his study he stabilized the soil with sand and cement, by making the block in the block making machine with varying percentages of sand and cement and curing them for 28 days, it was found that optimum results were obtained when the sand was 25% and the cement used was 8%. So, this was the reference used for the addition of coir fibre. The coir fibre content was varied in 0.5%, 1% and 1.50%. Now the block of soil-sand-cement-coir was made and tested for the optimum result in the laboratory. Various tests were conducted,it was seen that bulk density decreases on increasing the coir fibre as there was a replacement of dense material by the lighter coir fibre resulted in the increase of the total volume of mix. For the compressive strength, with coir waste at the rate of 0.50% showed improvement of 19% over reference block, but on increasing the fibre content this value starts decreasing andhence for compressive strength the fibre content should restrict to 0.5% to the dry weight of soil. Also in the case of tensile strength, the fibre content of 0.5% showed 9% increase in the tensile strength which starts decreasing beyond the content of 0.5%. The study was also conducted to determine the effect of water absorption by the coir fibre and was found that at 0.5% coir fibre combination showed comparatively low water absorption than other combination and found to be within the limit as by Indian standards.

Singh (2013) used randomly distributed coir fibre varied as 0%, 0.25%,0.50% and 1% by dry weight of soil and were mixed in the soil which would lead to homogenous soil mass and helps in maintaining isotropy in strength. Coir fibre in length from 50 mm to 150 mm were used for the study with the average diameter of 1mm, from the various CBR tests conducted, it was observed that in case of unsoaked CBR the value has increased by 205% with application of coir fibre over the plain soil and for the soaked CBR this increase was noted to be 200% and for both the cases the coir fibrecontent used was 1%.

Chaple and Dhatrak (2013) studied effect of coir fibre on bearing capacity and settlement of footing, with 0.25%, 0.50%, 0.75% and 1% of coir fibre using the laboratory model test on square footing which were supported on compressible clayey soil reinforced with coir fibre which were randomly distributed in soil. It was observed that there is an increase in bearing capacity of soil by coir fibre. The ultimate bearing capacity for reinforced soil with 0.50% coir for 100 mm, 50 mm and 25 mm depth were 425 kN/m^2, 495 kN/m^2 and665 kN/m^2 respectively which were quite higher than unreinforced soil having a value of 250 kN/m^2. The bearing capacity increases only up to a fibre content of 0.50% and there after start decreasing with the further addition of coir fibre in it.

Naveen and Yasaswi (2013) described the development of a set of natural fibre based polyester composite which consists of coir as a reinforcement and epoxy resin. Coir composites were developed and mechanical properties were evaluated at varying fraction and length of coir fibre. From the experiments performed it was found that mechanical properties depend upon the volume of fibres in composite and 5% coir fibre showed significant strength than higher fibre content and it was concluded from the study that coir fibre matrix is suitable for structural and non-structural work.

Singh and Mittal (2014) investigated the clayey soil with varying the percentages of coir fibre as 0.25%, 0.50%, 0.75% and 1% by weight. A series of unconfined compressiontest (UCS) and California bearing ratio (CBR) test were conducted in his study. From the study, it was found that there is considerable improvement in compressive strength of the soil reinforced with the coir fibre. Soil with no reinforcement had an unconfined strength of

2.75 kg/cm^2 which then on adding of fibre increased to a value of 6.33 kg/cm^2 for coir content of 1% by weight of soil, this increase in value could be because of increase in the shear parameters, it was found difficult to prepare the identical sample beyond 1% of fibre content so, only up to 1% of coir fibre was used in his study. From the CBR tests also it canbe stated that the value for both the unsoaked as well as the soaked test has considerably increased on increasing the fibre content in the soil sample, it was noted that the soaked value of CBR has improved to a value of 9.22% from that of 4.75% when 1% coir fibre wasincluded in the soil and also for the unsoaked condition the value has increased from

8.22% to 13.55%. It could be concluded from his study that coir fibre can be utilized successfully in sub base for flexible pavement and also for the rigid pavement.

Kar *et al.* (2014) used the coir fibre of length of 15 mm, 20 mm and 25 mm with the aspect ratio (length\diameter) being 75, 100 and 125 respectively and conducted a series of direct shear test with unreinforced and reinforced soil with different values of normal stresses. The fibre content here was varied from 0.2% to 1.0% at an increment of 0.2%, also the CBR test was also conducted in the same aspect ratio but the fibre content was varied from 0.2 to 1.6% with the increment of the 0.2%. From the direct shear tests it can be inferredthat with increase in normal stresses, peak and residual strength of the reinforced soil increases and this increase was seen up to 0.8% coir content, if the fibre content was increased beyond 0.8%, the value of both peak and residual strength start decreasing irrespective of aspect ratio. The maximum increase in the peak and residual strength was found at 20 mm fibre length. From the CBR tests it was found that up to the fibre content of1.4% the CBR value increases for all the aspect ratio, and after the fibre content of 1.4% theCBR value starts decreasing, the cause for decrease in the CBR values beyond this fibre content could be because that at higher fibre content the bond between fibre and soil could not be developed properly which causes balling effect and also lead to poor mixing.

Kumar and Vikranth (2014) studied the effect of inclusion of coir fibre in the blackcotton soil and made an attempt to find out the improvement in strength of soil with differentpercentages of coir fibre and fly ash through a series of unconfined compression test (UCS)and California bearing ratio (CBR) test. Fly ash at 0%, 5%, 10%, 15% and 20% with coir fibre in 0% 0.25%, 0.50%, 0.75% and 1% was used in study. From the analysis of CBR testsconducted by him, it could be said that there is a huge amount of improvement of strength when coir fibre along with fly ash is mixed in the soil. The maximum value was found at flyash content of 20% and coir fibre content of 1%. The increase in CBR value was found to be 285% more than that of unreinforced soil. It was also seen that with only fly ash contentin the soil the CBR value does increase about 83%.In the UCS analysis also huge amount ofimprovement in strength was seen, again the combination of 20% fly ash and 1% coir fibre was found to be the optimum, by this combination the amount of increase in the strength of reinforced soil as compared to unreinforced soil was about 120% and with only fly ash at 20% the UCS value increases by 66%. So from above study, it could be concluded that flyash can be used for black cotton soil for its improvement but when it is mixed with coir fibre there is a vast increase in the strength of the soil.

Ramasubbaroa (2014) focussed on the investigation of strength behaviour related to expansive soil reinforced with coir fibres which were coated with kerosene and were randomly distributed. The coir fibres used was in the varied as 0%, 0.5%, 1% and 1.5% by dry weight of soil. Water absorption tests were carried out on treated and simple coir fibre which were soaked in water for 1, 2 and 3 days. The other tests carried out were compaction test, unconfined compression test and tensile strength test. In order to determine the water adsorption capacity of coir fibre, uncoated coir weighing about 10g were immersed in water for 1 day and weight was checked which came out to be 63.7g, resulting in water adsorption of about 537%, if same coir fibre treated with kerosene was used water absorption capacity was reduced to 364%. Similarly, tests were done for 2 and 3 days and it was found that 2 days immersion of coir fibre in kerosene is sufficient which reduced water absorption capacity from 537 to 223%. From the compaction tests conducted, it was seen that maximum dry density decreases and OMC increases by the addition of fibre from 0 to 1.5% due to the replacement of lighter fibre with the heavy soil. By the results of UCS tests, we came to know that soil reinforced with 1% coir fibre gives the maximum value of UCS and this strength value decreases with increase in fibre content due to the dominance of fibre to fibre interaction in place of soil fibre. Tensile strength was determined from splitting test and it was studied that tensile strength was increased from 64 kPa to 96 kPa increasing by 50% when soil was reinforced with treated coir fibre at 1% fibre content.

Anggraini *et al.* (2015) performed the experiment to know the effects of coir fibre in the tensile and flexural strength of soft marine clay. Coir fibre ranging from 0.5% to 1% was used in the study. The optimum dose of coir fibre for sample cured till 28 days for the compressive strength test was reported to be 1% and an increase in strength of about 2.6 times was reported as compared to unreinforced soil. The tensile strength of reinforced soil came out to be maximum at fibre content of 1.5%, after this fibre content it was studied that interlocking and friction mobility of the samples gets reduced.

Soundara and Senthil (2015) compared the inclusion of coir fibre and polypropylene fibre in the clay soil. The fibres were varied as 0.5%, 1% and 1.5% for both coir and polypropylene. From the standard proctor tests in case of coir fibre, it was observed that MDD decreases with increase in the coir fibre due to the low specific gravity of coir fibre than that of soil and the value of OMC has increased and increment noted was too high, so, the use of coated fibre was recommended. The same trend was also seen in polypropylene fibre, the CBR value for the unsoaked case increased by 64.6% and 80% forcoir fibre and polypropylene fibre respectively and for soaked, the value increased by 84% and 106.5% when compared to the unreinforced soil in case of coir fibre and polypropylenefibre respectively.

Gaikwad and Sharma (2015) studied two different types of coir fibre- white coir and brown coir and performed the series of CBR test in the clayey soil sample at the maximum dry density and corresponding optimum moisture content. The percentages of white and brown coir used were 0.25%, 0.50%, 0.75% and 1% and comparison in the CBRstrength of both the coir fibre was done. For both the fibres the value of MDD decreases andof OMC increases. Unsoaked CBR test was done on both the coir and was observed that maximum value was obtained at 1% fibre content in case of brown coir fibre where the value increased from 9.50(plain soil) to 16.12% and for white coir maximum value of CBR was found at 0.75% of fibre content in this case the value increased from 9.50 to 14.60.

Abhijith (2015) studied the effect of coir fibre to determine CBR strength of soil, coir fibre with varying length from 0.5 to 3 cm and with the different percentage from 2 to 8% of the weight of the soil was taken for the study. The study was conducted to improve CBR strength, to determine the optimum fibre content and also to locate the perfect position of geotextile in the soil subgrade. After the tests, results inferred that the optimum fibre content is 5% of total weight of the soil with the optimum fibre length of 1.5 cm, ideal position of coir geotextile in the subgrade was found to be at the top of subgrade and conclusion was made from the study that geotextile does increase the strength of the pavement.

Shukla *et al.* (2015) investigated the application of coir fibre to improve thegeotechnical properties of the expansive soils, the percentage of fibres used for the study were 0.25%, 0.50%, 0.75% and 1%. CBR tests were conducted in both soaked and unsoakedcondition, an increase in both the type of CBR values was found with the increase in the fibre content. For soaked CBR, value rises from 3.9% to 8.6%, whereas for the case of unsoaked it increased to 13.2% from a value of 8.1% with the fibre content of 1% in both the cases and resulted that thickness of pavement can be reduced with use of coir fibre, with result obtained it can be stated that coir reduces the cost of pavement and economical construction can be achieved with the improvement in strength.

John and Patel (2015) utilized coir fibre and also coir pith along with fly ash and cement in order to improve the nature of swelling soil. Fibre used were cut into 20 mm, 40 mm and 60 mm in length, in the percentages 0.5, 1, 2, 3 and 4% were randomly distributed in the soil. It was concluded after the comparison of coir pith and coir fibre that, coir pith isless effective in strengthening than the coir fibre, optimum dose of coir fibre and coir pith toimprove CBR and UCS value was 3% and 2% & 2% and 1.5% respectively.

Jayasree *et al.* (2015) used coir waste which consists of coir pith and short coir fibresto study the change in the behaviour of soil. For the experimental study, six different percentages of coir pith ranging from 0.5 to 3% were used and short fibre ranged from 0.2 to 1%. After the various tests, it was concluded that swell index reduced by 95% and 92% with the addition of coir pith and coir fibre respectively also the compression index was reduced by 68 and 94% respectively. It was also seen that the rate of consolidation gets accelerated by the use of coir waste, it was reported that 2% coir pith and 0.6% coir fire is optimum for use and use of coir waste as reinforcing material to mitigate the volume changesin case of expansive soil was recommended.

Peter *et al.* (2016) investigated the behaviour of soil which was stabilized with coir fibre and also the use of Coir pith was done in the study. Coir fibre was varied in content of0.2%, 0.4%, 0.6%, 0.8% and 1% whereas the coir pith was varied from 0% to 3%. It was observed that with the inclusion of both coir pith and coir pith, the maximum dry density decreases and for OMC in the case of coir fibre was found decreasing initially which couldbe due to flocculation of clay particle when coir was added to them and again there was increase in an OMC with the further addition of coir fibre. CBR tests were conducted for both coir fibre and coir pith and 2% coir pith was found to be optimum for use and 0.6% coirfibre was noted to be an optimum where the CBR value increased about 4 times as comparedto that of the plain soil.

Das *et al.* (2016) studied about the shear strength parameters of the unreinforced andreinforced soil with coir fibre. A series of direct shear test were conducted at the normal stress of 0.5 kg/cm^2, 1.0 kg/cm^2 and 1.5 kg/cm^2. The coir fibre was added to the value of 1%, 2% and 3% by weight of soil. It was observed that the application of coir fibre on sandresult in an increase in the shear strength parameters. The main cause for the improved shearstrength is that in the absence of reinforcement the soil shows brittle failure but after the reinforcement, the soil starts showing the ductile failure as the friction has now been developed between the soil and the reinforced material. It was also seen that increase of the shear strength parameters was only up to the optimum value of fibre content which here comes out to be 2.1%, beyond this the reduction in the internal friction angle is obtained andhence in the shear strength of the soil.

Yadav and Tiwari (2016) investigated clay soil mixed with pond ash, cement and treated coir fibre through the various tests. Through the experiments, it was found that withthe addition of cement content and coir fibre to the clay pond ash mixture, it has decreased the maximum dry unit weight and has led to increase in OMC because of the flocculation process and lubricating effect of absorbed water by coir fibre. The unconfined strength of clay pond mixture reinforced with 1% coir fibre and stabilized with 2% cement is found to be 2.55 times more than that of clay alone, if cement content increased to 4% with 1% coir fibre the value comes out to be 4.84 times more than of clay alone and was also observed that the addition of fibre suppress the crack remarkably. At fibre content greater than 1%, there is a reduction in strength which could possibly as a result of the decrease in the interaction between fibre to the particle of composite and dominance of fibre to fibre interaction as the volume occupied by coir fibre has increased.

Anggraini *et al.* (2016) studied the effect of Nano-modified coir fibre with ferric hydroxide and aluminium hydroxide on the shear strength of marine clay treated with lime. Two type of soil mixtures one with additive and other without additive were used at their optimum moisture content. Mixing of soil with 1% of modified and unmodified coir fibres was done manually and 5% of lime was added. It was observed that coir fibre increased the tensile strength by 33% and 66% in fibres when they were treated with ferric hydroxide and aluminium hydroxide respectively, with the addition of coir fibre ductility of the soil increased. The angle of internal friction increased from 40^0 in limed soil reinforced with unmodified fibre to 42^{o} in limed soil reinforced with modified fibre, also the cohesion value does increase from 40 kPa to 60 kPa when modified coir fibre was used.

Ayininuola and Oladotun (2016) investigated the geotechnical properties of soil when mixed with coir fibre. Coir with the percentages varying from 0.1 to 1.5% was used and three different soil samples were used to carry out the experimental work. Cohesion values of soil samples increased up to the fibre content of 1.2% and after this fibre content it starts decreasing and the angle of internal friction also increased up to the same fibre content, for the CBR tests on all three soil samples the strength increased up to 1.2% of coirfibre after this value it starts decreasing so making 1.2% of coir fibre as the optimum dose to be mixed in soil.

2.3 Concluding Remarks

This chapter has shed some light on the previous studies on the marble dust soil mixture. It showed the variation of different geotechnical properties of soil mixed with marble dust as reported by many researchers.

CHAPTER 3 MATERIALS AND METHODS

General

The main objective of this study is to investigate the change in the behaviour of soil when coir fibre at varying percentages was mixed in clayey soil through the various geotechnical tests conducted in the laboratory.

Materials Used

Coir Fibre

Coir fibre was purchased from local market in Haldwani, District Nainital (Uttarakhand). Coir used for the study was cut into 30 mm length. Fig. 3.1 shows the coir fibre used for the study.

Fig. 3.1: Coir Fibre Soil

The soil used in the study was taken from Sitarganj region of District Udhamsingh Nagar (Uttarakhand). As per IS: 1498-1970 the soil is classified as CL. Soil used for the study is shown in Fig. 3.2.

Fig. 3.2: Disturbed Soil Specimen

Methodology

The clayey soil was mixed with four different content of coir fibres which were 0.25%, 0.50%, 0.75% and 1% in order to prepare various samples.

In order to investigate the various geotechnical properties of soil tests were conducted in soil and soil mixed with the various percentages of coir fibre, the various testsconducted are listed as:

- Grain size distribution
- Consistency limits
- Specific gravity
- Compaction test
- Unconfined compression test
- California bearing ratio test
- Triaxial shear test.

A brief discussion about these tests is presented in the following sections.

Determination of Grain Size Distribution

In order to determine the content of coarse grain soil and fine grain soil this test wasconducted in two steps:

- Sieve analysis
- Sedimentation analysis

Sieving was done to determine the coarser content of the soil which determines graveland sand proportion in the soil sample. This was done by using various sieves ranging from40 mm sieve size to .075 mm and hydrometer test was conducted to determine the content of silt and clay in the soil as per IS: 2720 (Part IV) -1985.

Determination of Consistency Limits

To determine the Liquid limit, Plastic limit and Shrinkage limit of soil tests was conducted with reference to IS: 2720 (Part V)-1985.

Liquid limit is the minimum water content at which soil has a tendency to flow and all soil possess negligible shear strength at the liquid limit, it is performed with the help ofCasagrande's apparatus in the lab. Plastic limit refers to that water content at which soil sample would just begin to crumble when rolled into a thread of approximately of 3 mm in diameter. Shrinkage limit is the smallest value of water content at which soil mass is completely saturated. Plasticity index is the range of moisture content over which a soil exhibits plasticity. It is equal to the difference of liquid limit and plastic limit.

Specific Gravity Determination

Specific Gravity was determined by soil fraction passing through 4.75 mm IS sieve with the help of Pycnometer as per instruction of IS: 2720 (Part III) 1980. It is defined as theratio of the weight of a given volume of solids to the weight of the equivalent volume of water at 4ºC.

Procedure for Standard Proctor Compaction Test

To analyse the geotechnical properties of soil like unconfined compressive strength, CBR value of soil, we need to find out the water content at which with the help of compactive effort we can find the maximum value of dry density, referring this water content to be as optimum moisture content (OMC) and dry density as maximum dry density (MDD) and in order to determine these values standard proctor tests were conducted in the lab with a help Cylindrical mould of 1000 cc capacity with 100 mm of diameter and 127.3 mm height fitted with detachable base and collar with 50 mm height wasused. The soil was compacted in 3 layers each receiving 25 number of blows from a rammerof weight 2.6 kg falling from a height of 310 mm. Fig. 3.3 shows the sample of mould in which compaction is done.

Fig. 3.3: Standard Proctor Test Mould

Procedure for California Bearing Ratio Test

It is the ratio of test load with standard load represented in percentage for a given penetration of plunger with a combination of load penetration and empirical chart this method allow us to determine the thickness of pavement.

To investigate the effect of coir fibre in enhancing the CBR value of soil California bearing ratio test in unsoaked and soaked condition was conducted in accordance with IS 2720 (Part XVI)-1987 on a soil compacted to their MDD at OMC in a mould of diameter 150mm and height of 175 mm provided with a 50 mm height collar and a displace disc of 50 mm deep to keep in mould during penetration, a surcharge is also kept to stimulate the effect of overlying pavement. Penetration of plunger of 50 mm in diameter is allowed with a rate of 1.25 mm\min and load reading at various interval are noted down. CBR values arecalculated for penetration of 2.5

mm and 5 mm for unsoaked CBR result are produced immediately and in order to stimulate the worst possible condition of moisture in field sample is kept submerged in water for 96 hours before soaked CBR values are calculated. Fig. 3.4 shows the CBR machine used in the study.

Fig. 3.4: CBR Testing Machine

Procedure for Unconfined Compressive Strength Test

In order to determine the shear strength of soil, it is one of the fastest and easy to perform test which widely used for cohesive soil. To study the effects of coir fibre in strength behaviour of soil unconfined compression test were performed in accordance with IS: 2720 (Part X) – 1991.

The cylindrical test specimens were prepared from a mould of size 50 mm (diameter) X 100 mm (height). For strength determination samples were put in compression testing machine and a load was applied on it with a strain rate of 1.25 mmper minute until either the sample fails by cracking or strain in the sample is more than20% of the length of the sample. To analyze the effect of curing of sample, tests were conducted at 0, 7, 14 and 28 days. The unconfined compressive strength of specimens was determined from stress versus strain curves. Fig. 3.5 represent the UCS testing machine.

Fig. 3.5: Digital UCS Testing Machine

Procedure for Triaxial Shear Test

The Unconsolidated Undrained (UU) Triaxial tests were conducted on soil mixed with coir fibre. The cylindrical specimens were prepared at their corresponding

MDD and OMC according to IS: 2720 (Part – XI) 1993. The confining pressures usedin this study are 0.5, 1 and 2.0 kg/cm^2.

The specimen prepared is placed centrally on the pedestal of the triaxial cell. The cell is assembled with the loading ram and the cell containing specimen is placed in the loading machine. The operating fluid is admitted to the cell and the pressure is raised to the desired value. A rate of axial compression will be selected such that failure is produced within a period of approximately 5 to 15 minutes. A sufficient number of readings of the load and compression measuring gauges being taken to determine the stress-strain curve. Fig. 3.6 shows the triaxial shear test apparatus.

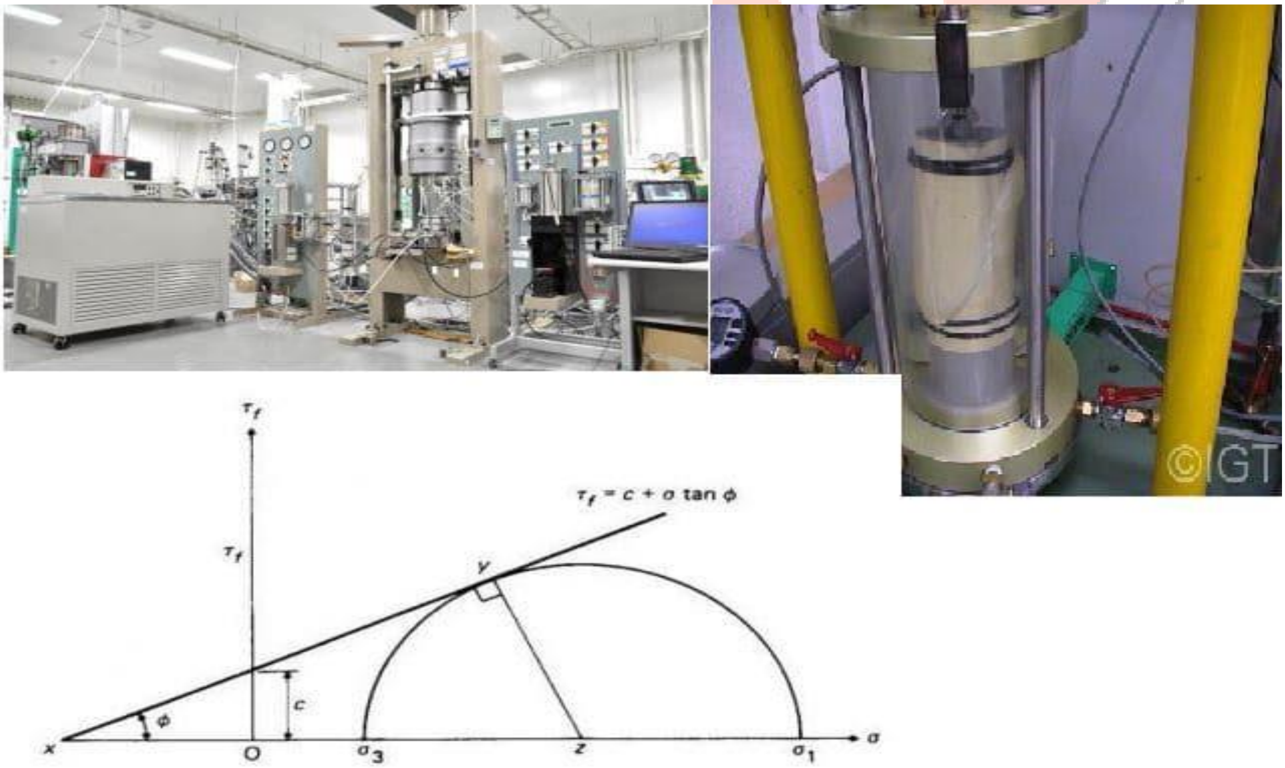


Fig. 3.6: Triaxial Shear Testing Machine and Specimen after Failure

Table 3.1: Experimental Programme

S. No.	Soil mix	Tests	No. of Samples
1.	Soil + 0% CF	Specific Gravity Particle Size Distribution Consistency Limits Light Compaction Test UCS Tests (0,7,14 & 28 Days) CBR Tests (Unsoaked & Soaked) Triaxial Shear Tests	3 1 1 1 12 2 3
2.	Soil + 0.25% CF	Light Compaction Test UCS Tests (0,7,14 & 28 Days) CBR Tests (Unsoaked & Soaked) Triaxial Shear Tests	1 12 2 3
3.	Soil + 0.50% CF	Light Compaction Test UCS Tests (0,7,14 & 28 Days) CBR Tests (Unsoaked & Soaked) Triaxial Shear Tests	1 12 2 3
4.	Soil + 0.75% CF	Light Compaction Test UCS Tests (0,7,14 & 28 Days) CBR Tests (Unsoaked & Soaked) Triaxial Shear Tests	1 12 2 3
5.	Soil + 1% CF	Light Compaction Test UCS Tests (0,7,14 & 28 Days) CBR Tests (Unsoaked & Soaked) Triaxial Shear Tests	1 12 2 3
		Total No. of Tests Performed	95

Concluding Remarks

The experimental programme, as discussed in this chapter is carried out in view of the objectives of the study. The results obtained by conducting different types of tests on the soil and soil mixed with different percentages of coir fibre are presented and analysed in the next chapter.

CHAPTER 4 RESULTS AND DISCUSSION

General

A series of conventional laboratory tests including standard compaction tests, California bearing ratio tests, unconfined compressive strength tests and Triaxial shear testswere carried out on the soil mixed with different percentages of coir fibre. The tests results and discussion are presented in this chapter.

Index Properties

Specific Gravity

Specific Gravity is one of the vital properties required for geotechnical and different applications of soil. The specific gravity of soil was determined according to IS: 2720 (Part III/Sec II) 1980. An average of three sample is accounted. The Specific gravity of the soil sample is found to be 2.53.

Grain Size Analysis

IS: 2720 (Part IV) 1985 was used to determine the grain size analysis. The particle size of soil ranges from coarse sand to silt size as shown in Fig. 4.1. The percentage of particles passing through the 75 μ sieve was found to be 92.44%.

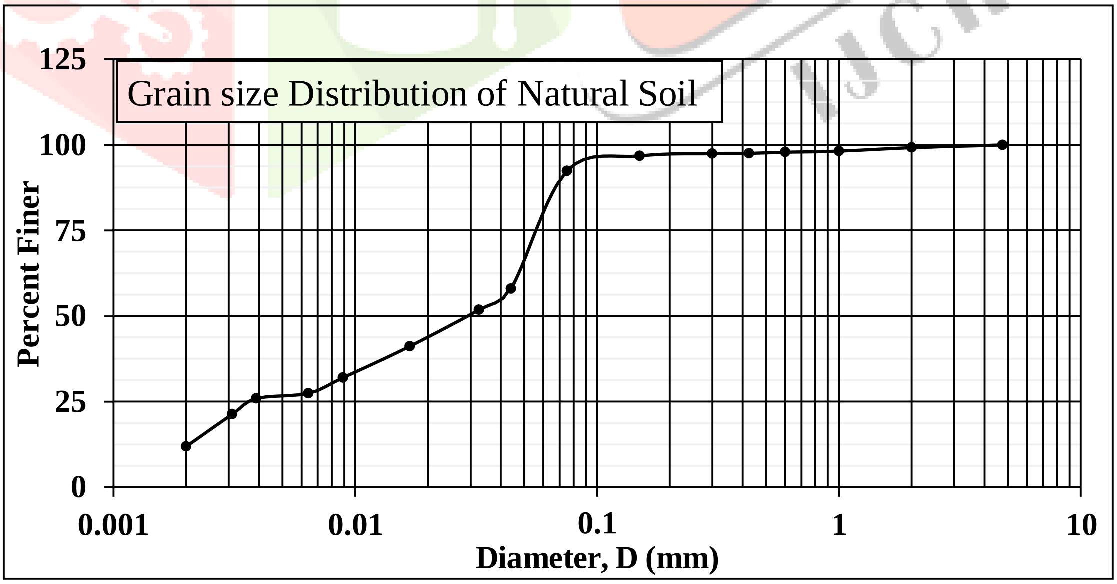


Fig. 4.1: Grain Size Distribution Curve of the Soil

Consistency Limits

The tests for consistency limits were conducted as per IS: 2720 (Part V) 1985. From the Fig. 4.2, the liquid limit of soil was observed as 27.06%. Plastic limit of the soil sample was 11.76%. So, plasticity index (PI) of soil was 15.30.

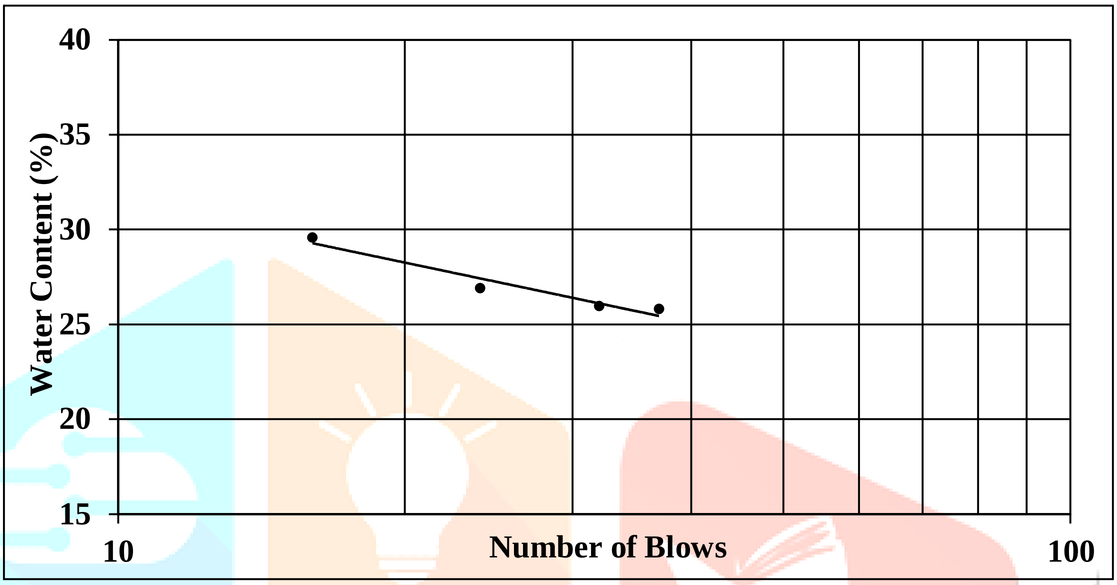


Fig. 4.2: Flow Index Curve of the Soil

The physical properties of soil used in the study are presented in Tables 4.1.

Table 4.1: Physical Properties of Soil

Parameter	Value
Specific gravity (G)	2.53
Dry Density, kN/m^3	17.71
Liquid Limit	27.06
Plastic Limit	11.76
Plasticity Index	15.30
Optimum moisture content (OMC), %	13
Grain size distribution Sand size fraction (%) Silt size fraction (%) Clay fraction (%)	 7.56 80.52 11.92
Soil type as per IS: 1498-1970	CL

Results:-

Results of Standard Proctor Compaction Tests

The compaction tests were done on soil without coir fibre and with the varyingcontent of coir fibre, the results of the various tests conducted are shown in Figs. 4.3 to 4.7.

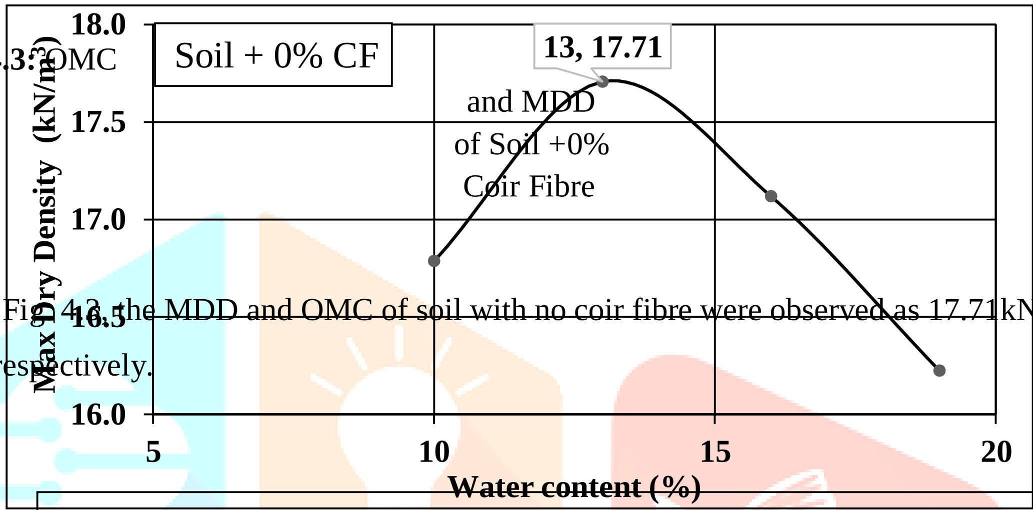


Fig. 4.3: OMC and MDD of Soil +0% Coir Fibre

From Fig 4.3, the MDD and OMC of soil with no coir fibre were observed as 17.71kN/m^3 and 13% respectively.

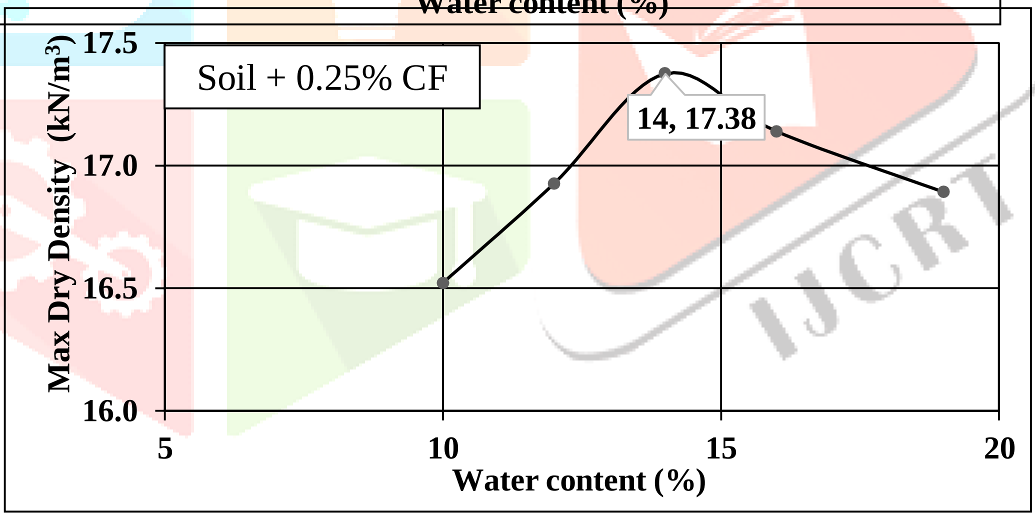


Fig. 4.4: OMC and MDD of Soil + 0.25% Coir Fibre

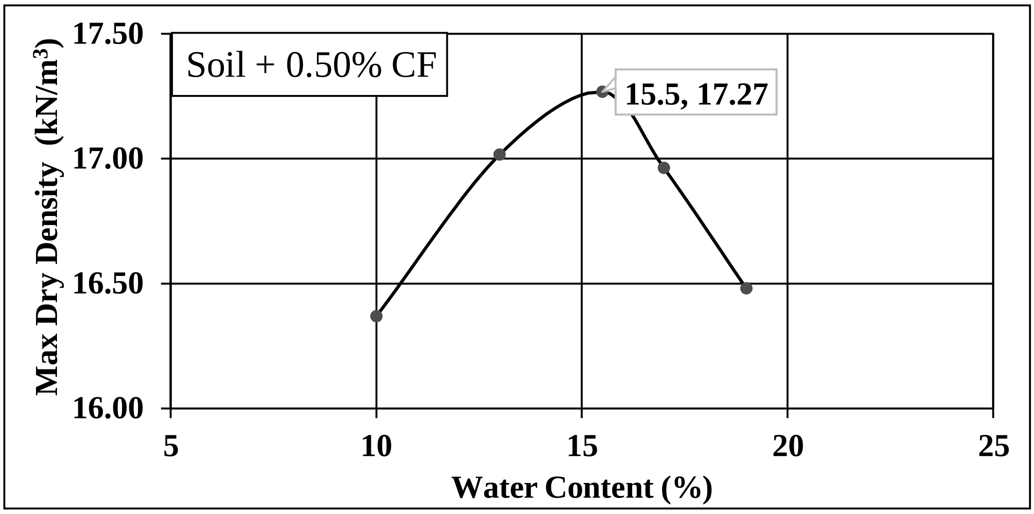


Fig. 4.5: OMC and MDD of Soil + 0.50% Coir Fibre

Similarly, from Figs. 4.4 and 4.5, the MDD and OMC of soil with 0.25% and 0.50%coir fibre were found to be 17.38 kN/m^3 and 14% and 17.27 kN/m^3 and 15.5% respectively.

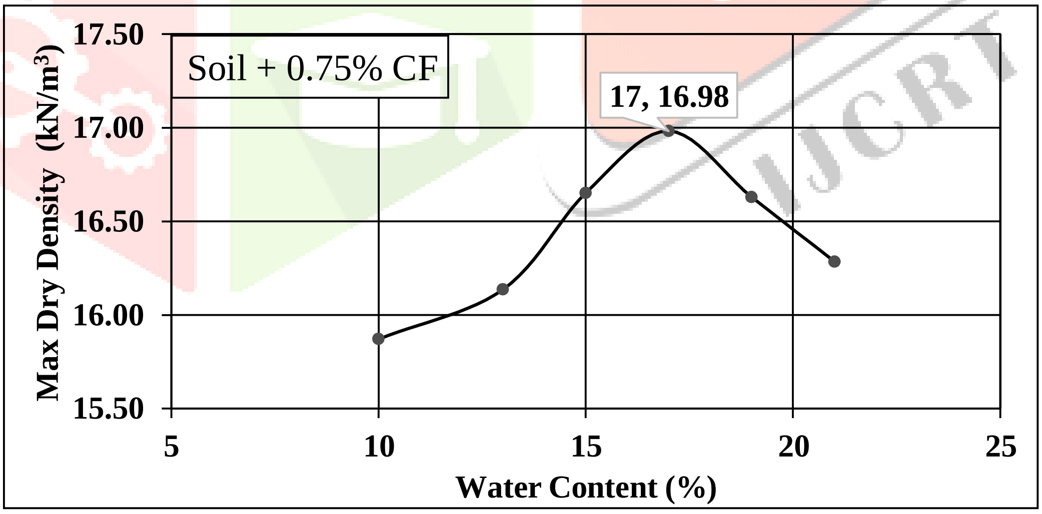


Fig. 4.6: OMC and MDD of Soil + 0.75% Coir Fibre

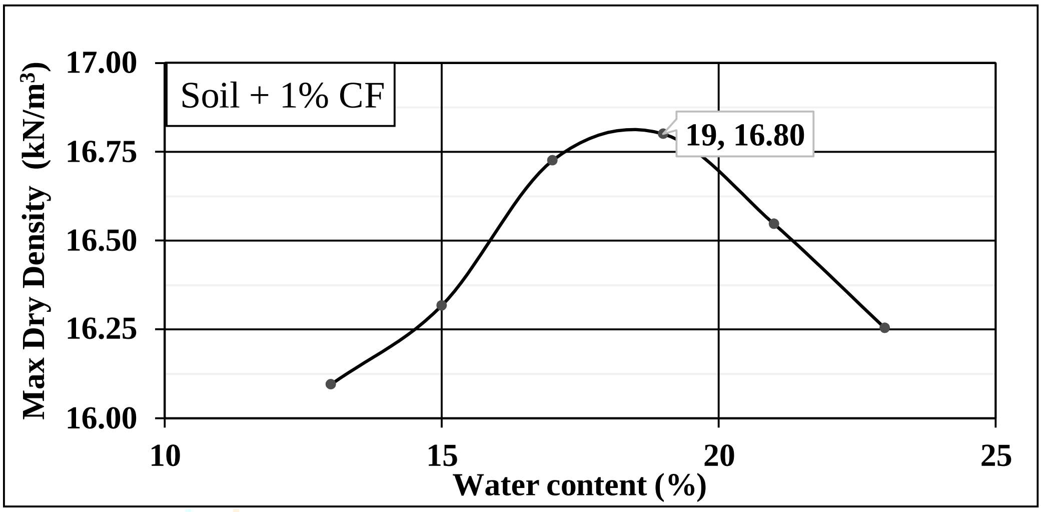


Fig. 4.7: OMC and MDD of Soil + 1% Coir Fibre

Figs. 4.6 and 4.7 show the MDD and OMC of soil with 0.75% and 1% coir fibre andwere found to be 16.98kN/m^3 and 17% and 16.80kN/m^3 and 19% respectively.

Summary of Results

The compaction tests were performed using soil with varying proportion of coir fibre. The results obtained for each mix are summarized in Table 4.2.

Table 4.2: OMC and MDD of Soil with Coir Fibre

S.No.	Material	OMC (%)	MDD (kN/m^3)
1	Soil + 0.00% Coir Fibre	13.00	17.71
2	Soil + 0.25% Coir Fibre	14.00	17.38
3	Soil + 0.50% Coir Fibre	15.50	17.27
4	Soil + 0.75% Coir Fibre	17.00	16.98
5	Soil + 1% Coir Fibre	19.00	16.80

Results of California Bearing Ratio Tests

CBR value represents the strength of soil, widely used in the design of base and subbase materials for pavement. The results under unsoaked condition show CBR values ranging from 6.67 to 11.32%. The result under soaked condition shows CBR value ranging from 2.16 to 4.45%. The value obtained under the soaked condition is found to be less in comparison to unsoaked CBR value which may be due to the destruction of capillary forces under soaked condition.

The results obtained after CBR test in both unsoaked and soaked condition are shown in Figs. 4.8 to 4.17.

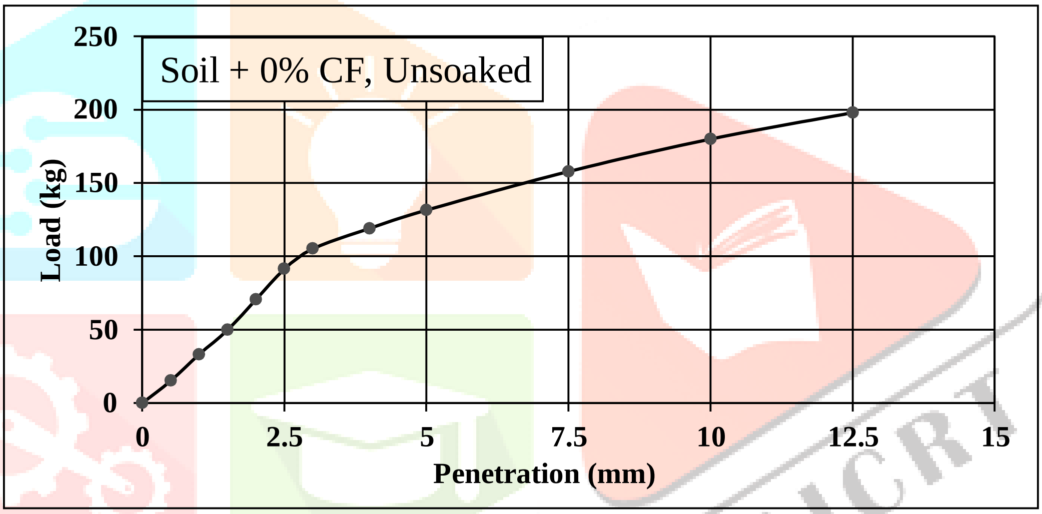


Fig. 4.8: CBR Curve of Soil and Soil + 0% Coir Fibre in Unsoaked Condition

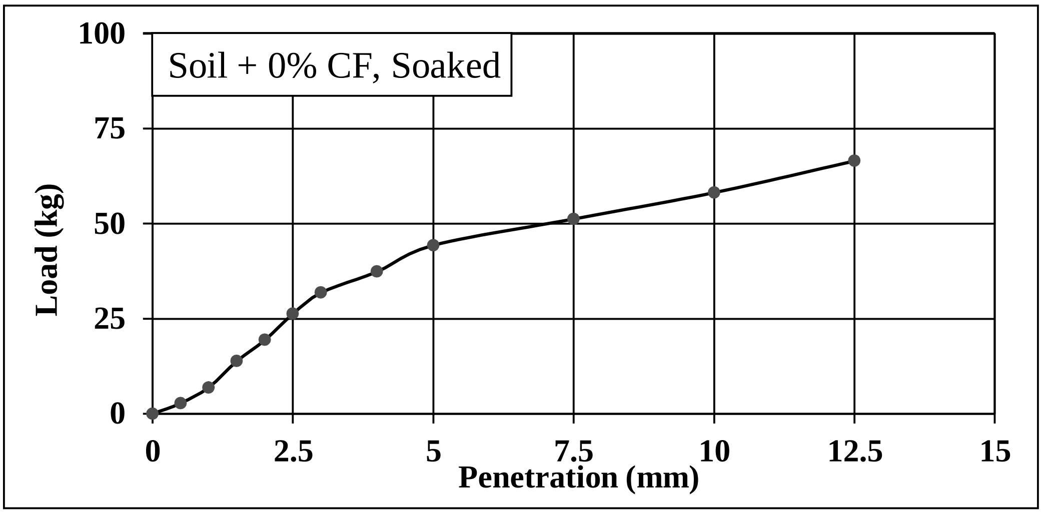


Fig. 4.9: CBR Curve of Soil and Soil + 0% Coir Fibre in Soaked Condition

From figs. 4.8 and 4.9, the CBR values in unsoaked and soaked condition with nofibre content were obtained as 6.67% and 2.16% respectively.

Figs. 4.10 and 4.11 show the CBR tests (unsoaked and soaked) for soil mix with0.25% coir fibre.

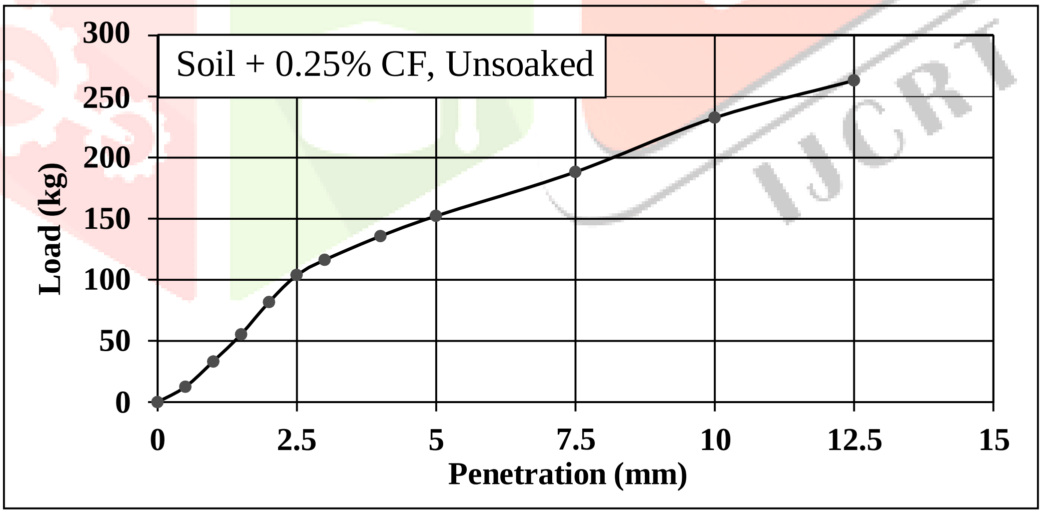


Fig. 4.10: CBR Curve of Soil and Soil + 0.25% Coir Fibre in Unsoaked Condition

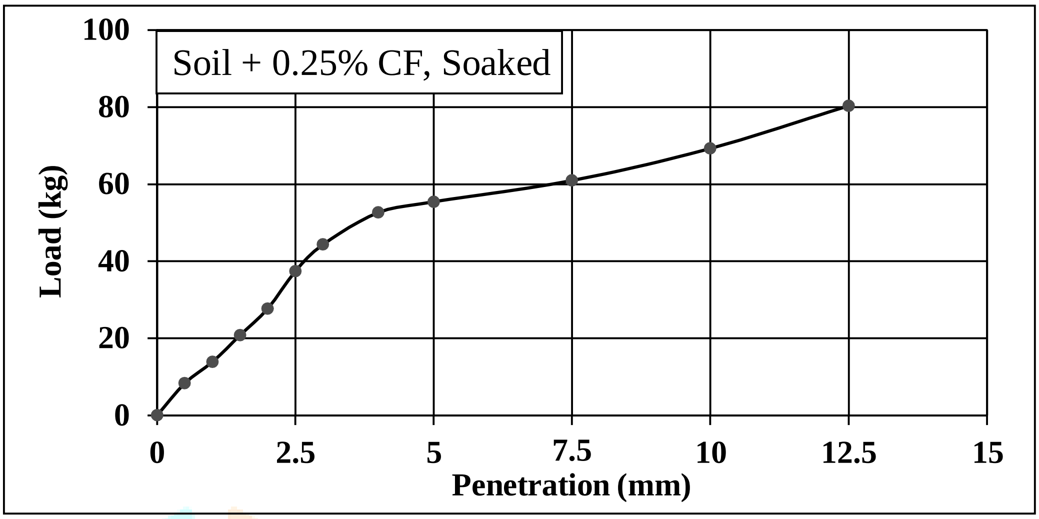


Fig. 4.11: CBR Curve of Soil and Soil + 0.25% Coir Fibre in Soaked Condition

Figs. 4.10 and 4.11 show the CBR values in unsoaked and soaked condition and wereobtained as 7.54% and 2.79% respectively.

Figs. 4.12 and 4.13 show the CBR values in unsoaked and soaked condition for soilmixed with 0.50% coir fibre and the values obtained were 8.29% and 3.03% respectively.

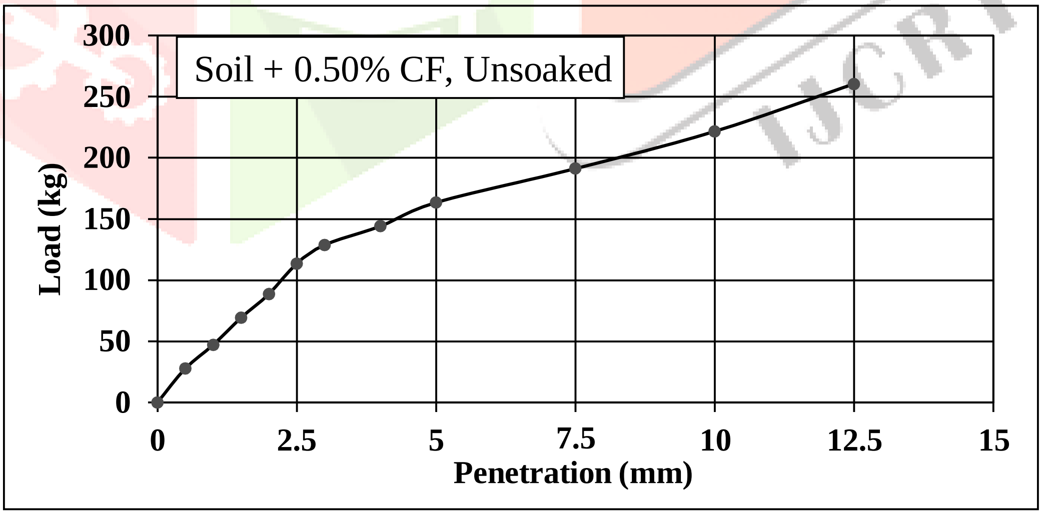


Fig. 4.12: CBR Curve of Soil and Soil + 0.50% Coir Fibre in Unsoaked Condition

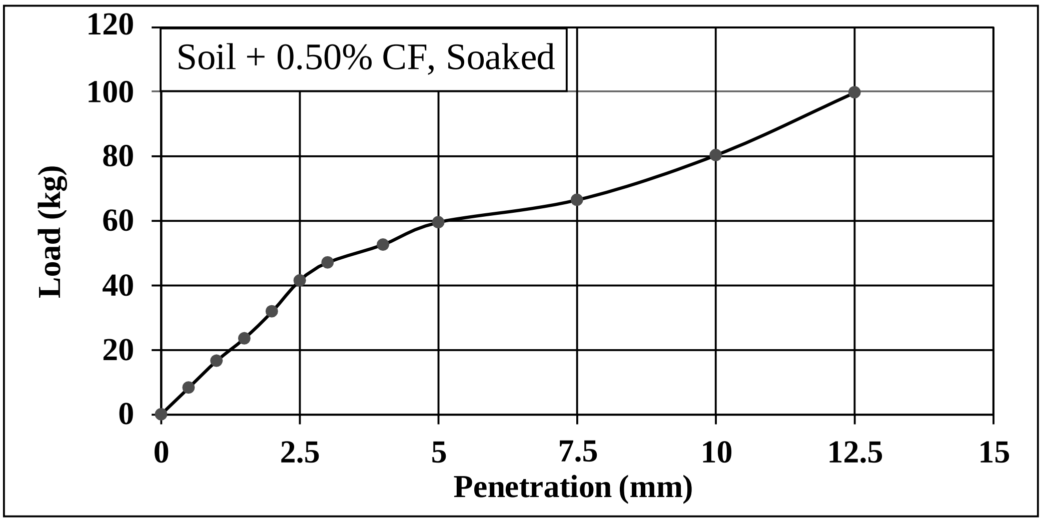


Fig. 4.13: CBR Curve of Soil and Soil + 0.50% Coir Fibre in Soaked Condition

Figs. 4.14 and 4.15 show the CBR values in unsoaked and soaked condition for soilmixed with 0.75% coir fibre.

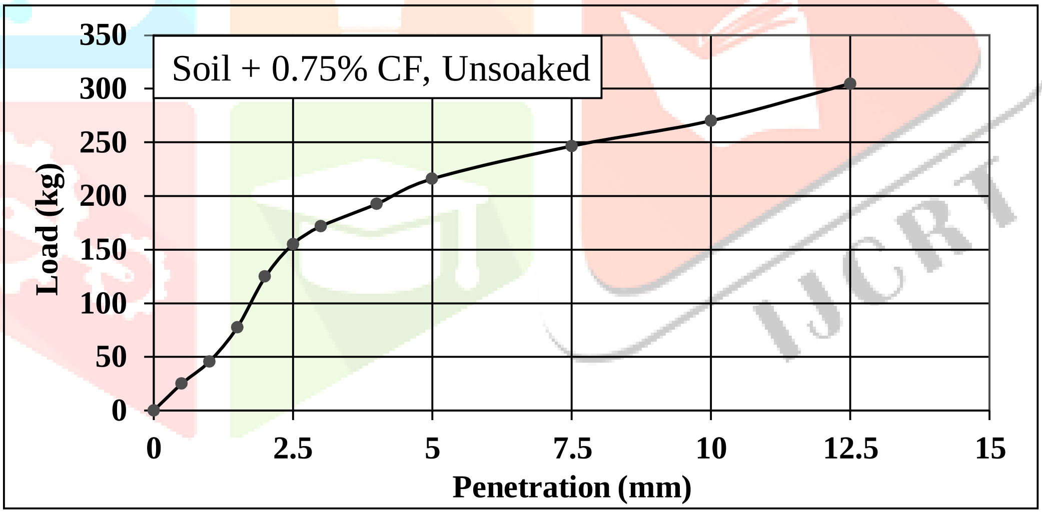


Fig. 4.14: CBR Curve of Soil and Soil + 0.75% Coir Fibre in Unsoaked Condition

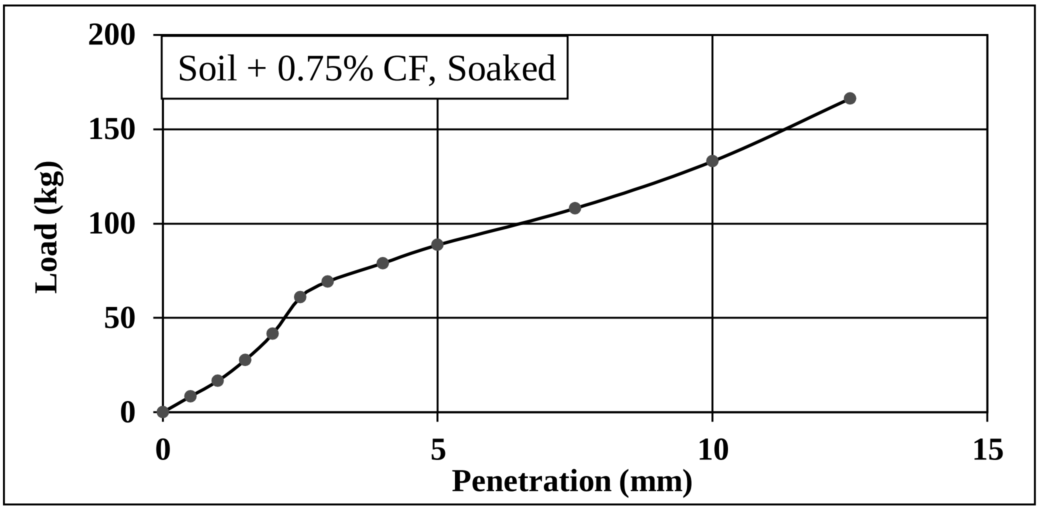


Fig. 4.15: CBR Curve of Soil and Soil + 0.75% Coir Fibre in Soaked Condition

The CBR values for the case of soil mixed with 0.75% coir fibre obtained were11.32% and 4.45% for the case of unsoaked and soaked condition respectively.

Figs. 4.16 and 4.17 show the CBR values in unsoaked and soaked condition for soilmixed with 1% coir fibre and values were 9.78% and 3.46% respectively.

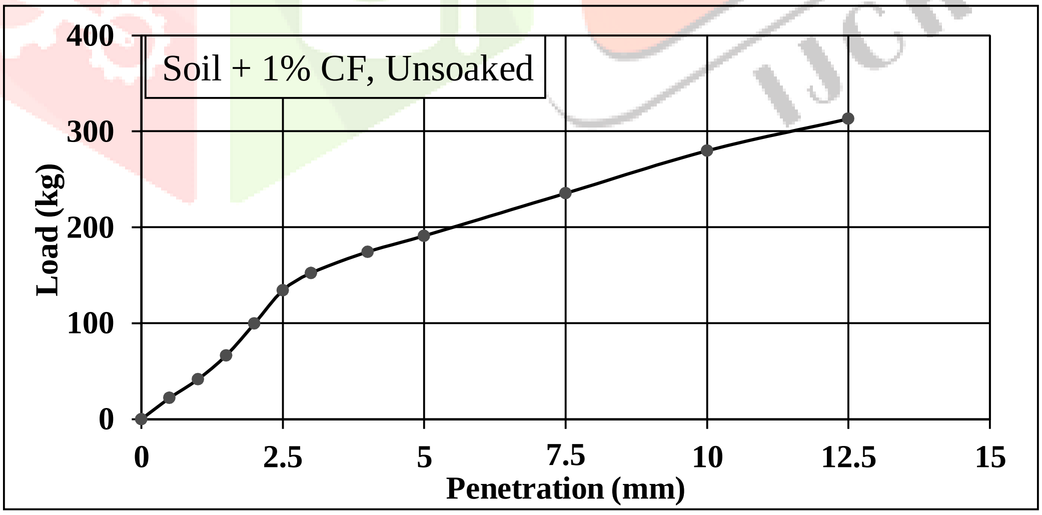


Fig. 4.16: CBR Curve of Soil and Soil + 1% Coir Fibre in Unsoaked Condition

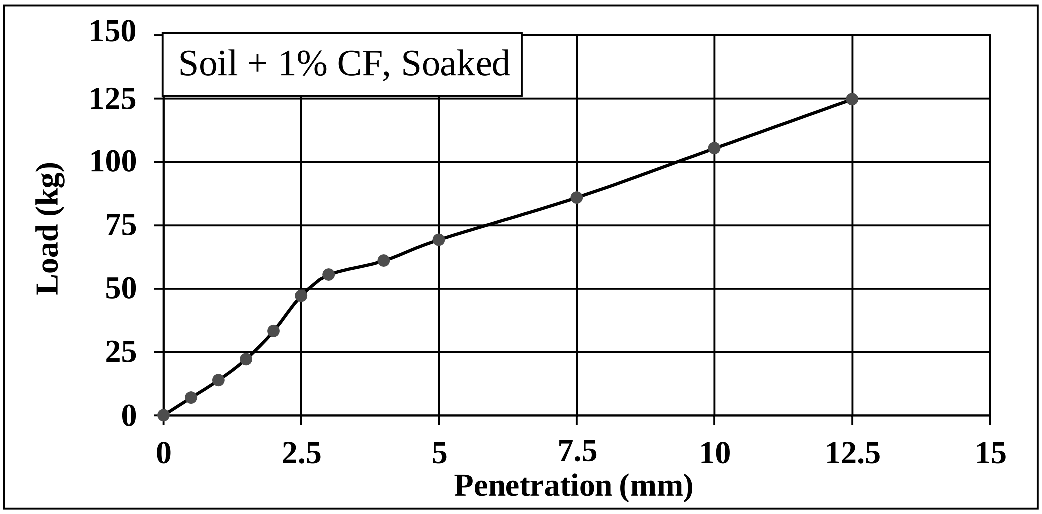


Fig. 4.17: CBR Curve of Soil and Soil + 1% Coir Fibre in Soaked Condition

Summary of Results

CBR tests were performed using soil with varying proportion of coir fibre. The results obtained for each mix are summarized in Table 4.3.

Table 4.3: CBR Values of Soil Mix for Unsoaked and Soaked Conditions

S.No.	Material	CBR Values (%)	
		Unsoaked	Soaked
1	Soil + 0.00% Coir Fibre	6.67	2.16
2	Soil + 0.25% Coir Fibre	7.54	2.79
3	Soil + 0.50% Coir Fibre	8.29	3.03
4	Soil + 0.75% Coir Fibre	11.32	4.45
5	Soil + 1% Coir Fibre	9.78	3.46

Results of Unconfined Compressive Strength Tests

The unconfined compressive strength tests were performed on soil and soil reinforced with coir fibre. The stress–strain behaviour obtained during the unconfined compression tests are shown in the upcoming plots.

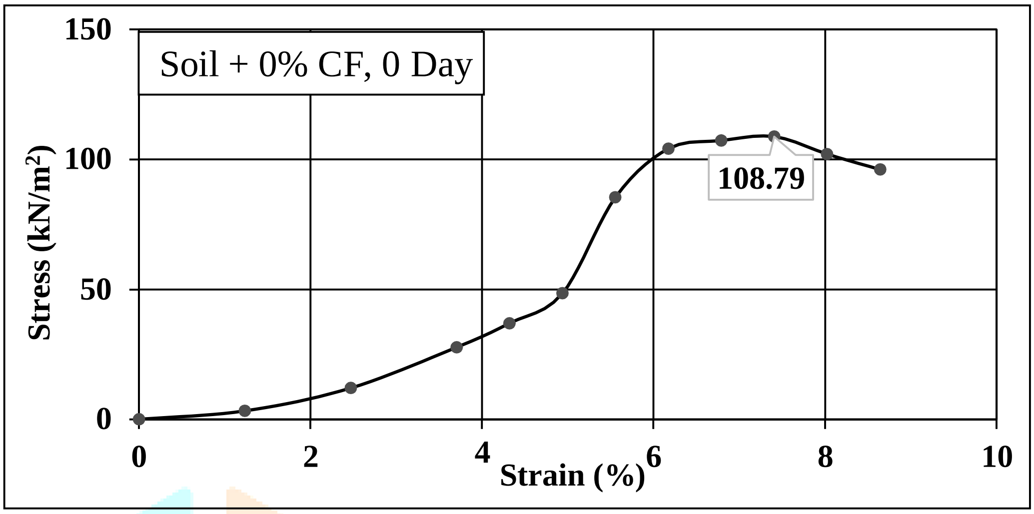


Fig. 4.18: Stress-Strain Curve for Soil with 0% Coir Fibre at 0 Day

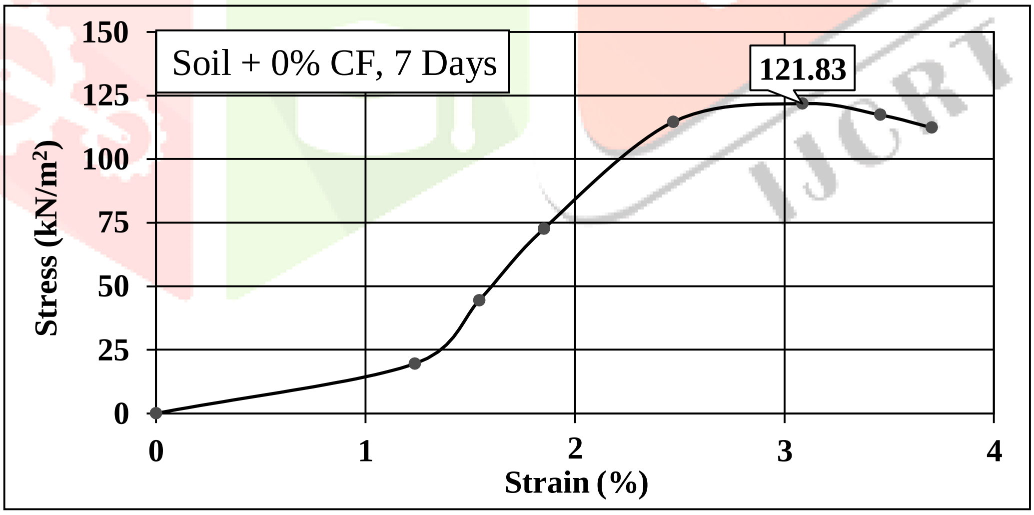


Fig. 4.19: Stress-Strain Curve For Soil with 0% Coir fibre at 7 Days

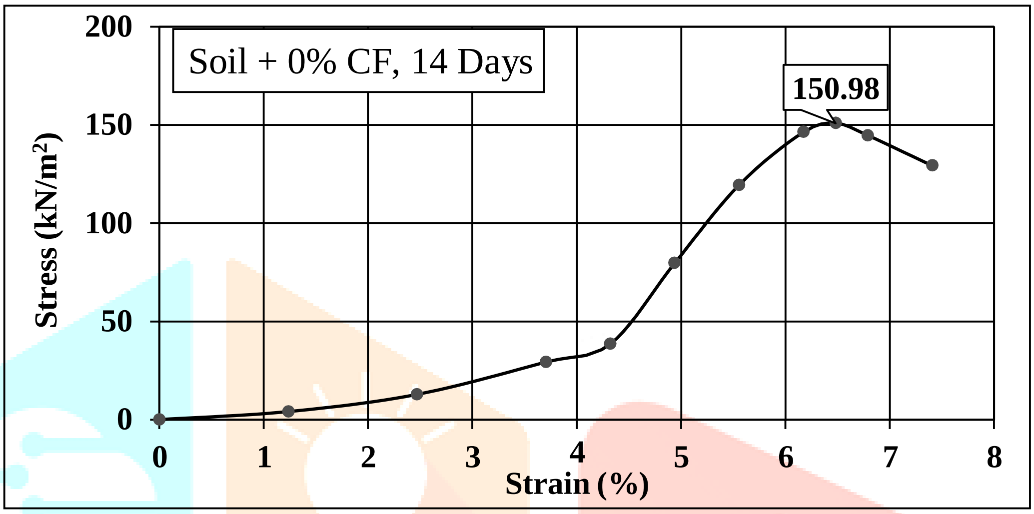


Fig. 4.20: Stress-Strain Curve For Soil with 0% Coir fibre at 14 Days

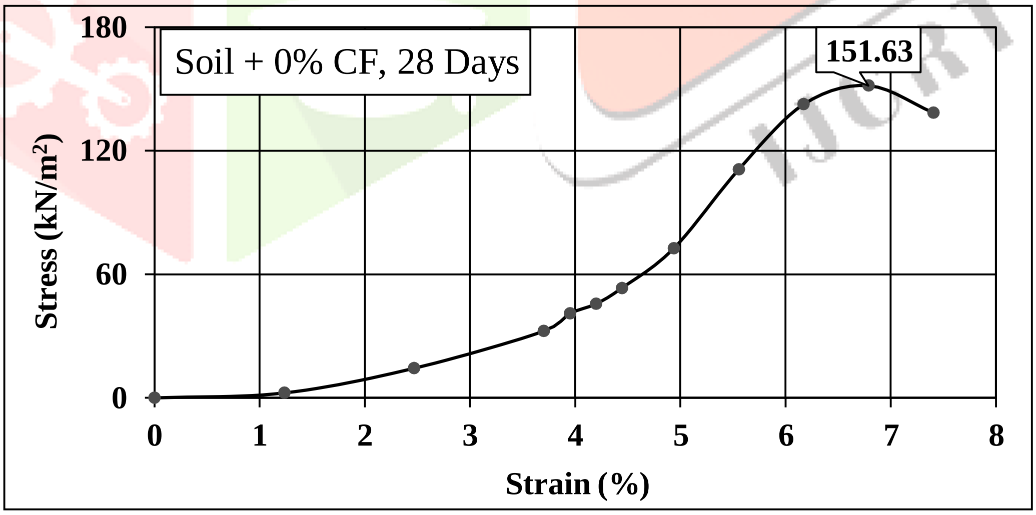


Fig. 4.21: Stress-Strain Curve For Soil with 0% Coir fibre at 28 Days

From Figs. 4.18 to 4.21, it was observed that the UCS of soil without coir fibre for0, 7, 14, and 28 days was found to be 108.79, 121.83, 150.98 and 151.63 kN/m^2 respectively.

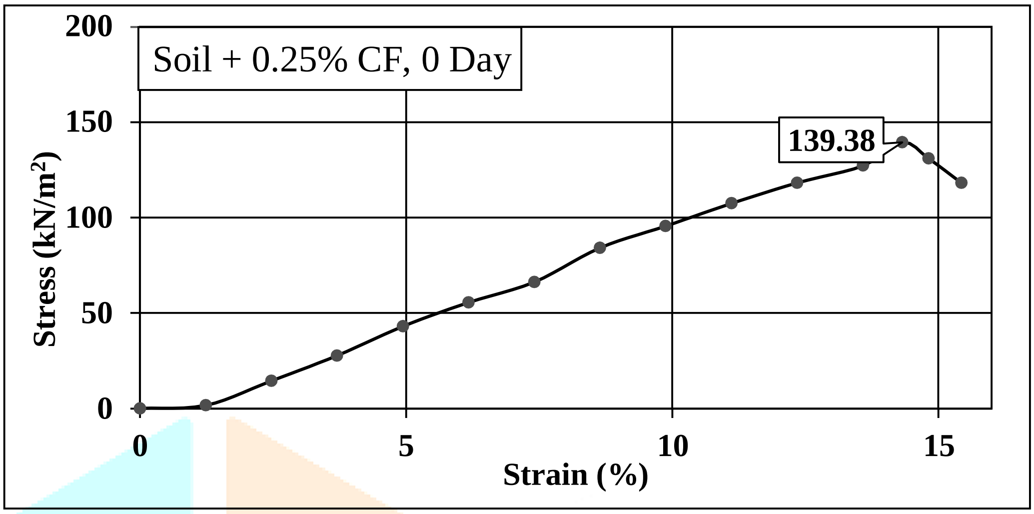


Fig. 4.22: Stress-Strain Curve for Soil with 0.25% Coir Fibre at 0 Day

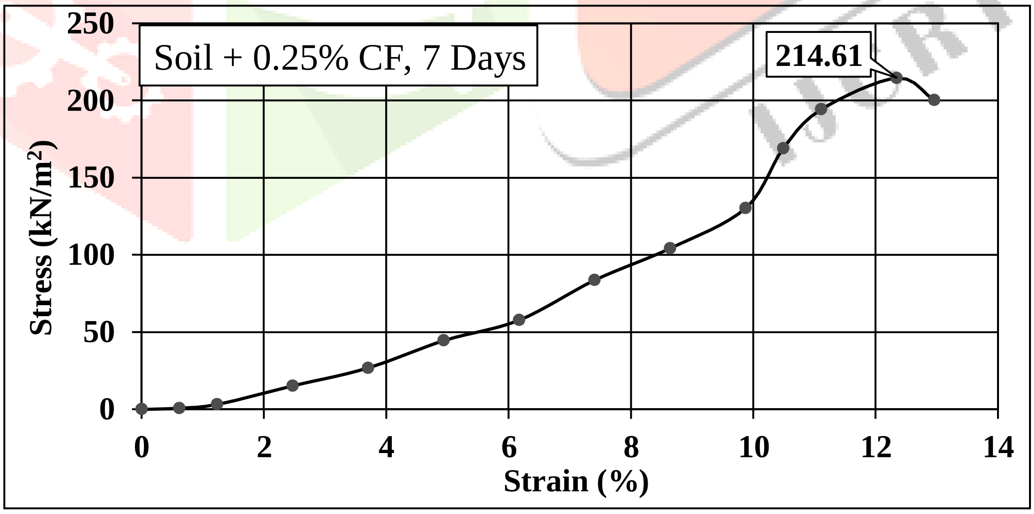


Fig. 4.23: Stress-Strain Curve for Soil with 0.25% Coir Fibre at 7 Days

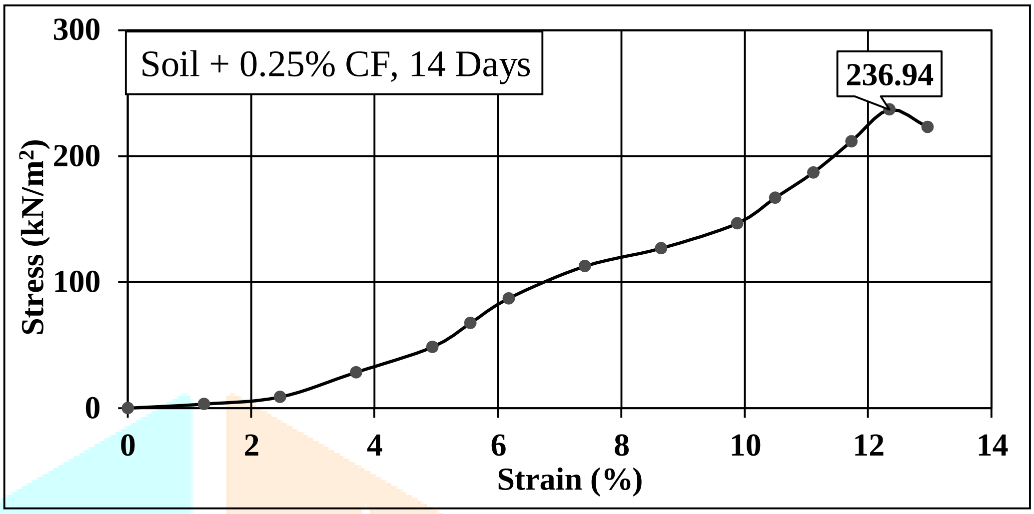


Fig. 4.24: Stress-Strain Curve for Soil with 0.25% Coir Fibre at 14 Days

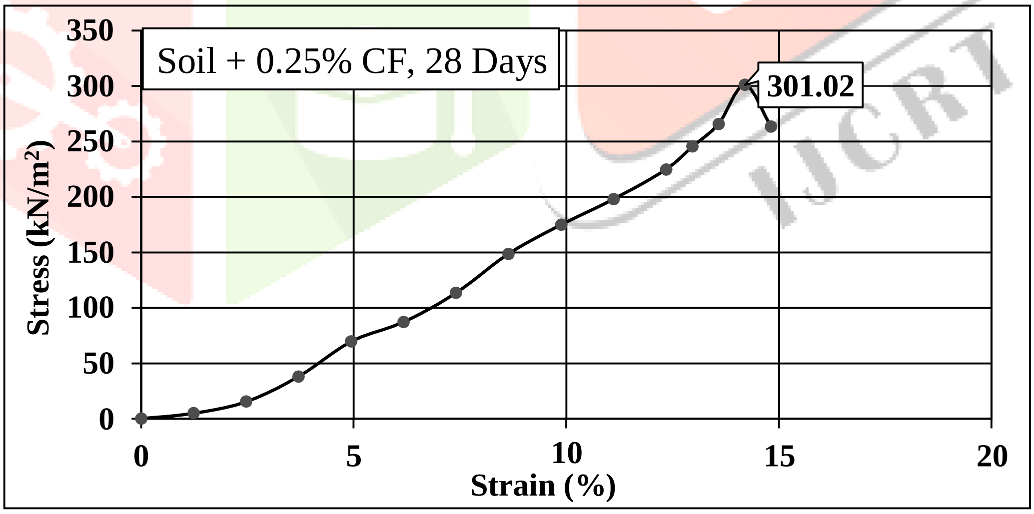


Fig. 4.25: Stress-Strain Curve for Soil with 0.25% Coir Fibre at 28 Days

From Figs. 4.22 to 4.25, it was observed that on increasing the fibre content to 0.25%, the unconfined compressive strength recorded on 0, 7, 14, and 28 days was found to be 139.38, 214.61, 236.94 and 301.02 kN/m^2 respectively.

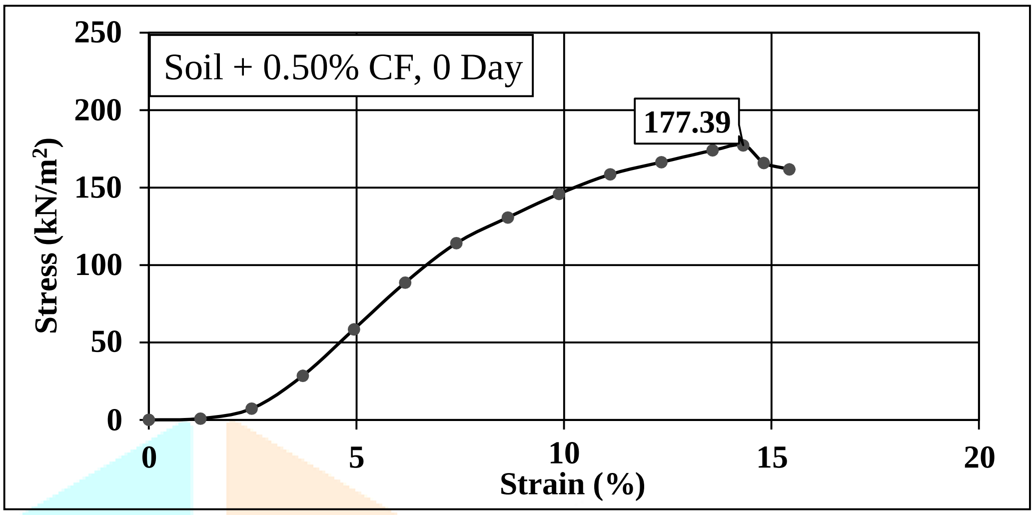


Fig. 4.26: Stress-Strain Curve for Soil with 0.50% Coir Fibre at 0 Day

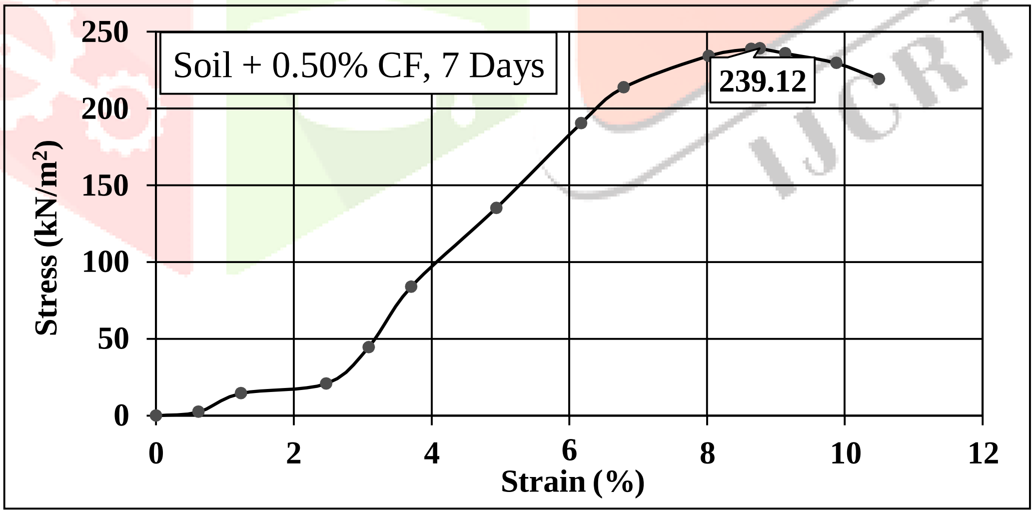


Fig. 4.27: Stress-Strain Curve for Soil with 0.50% Coir Fibre at 7 Days

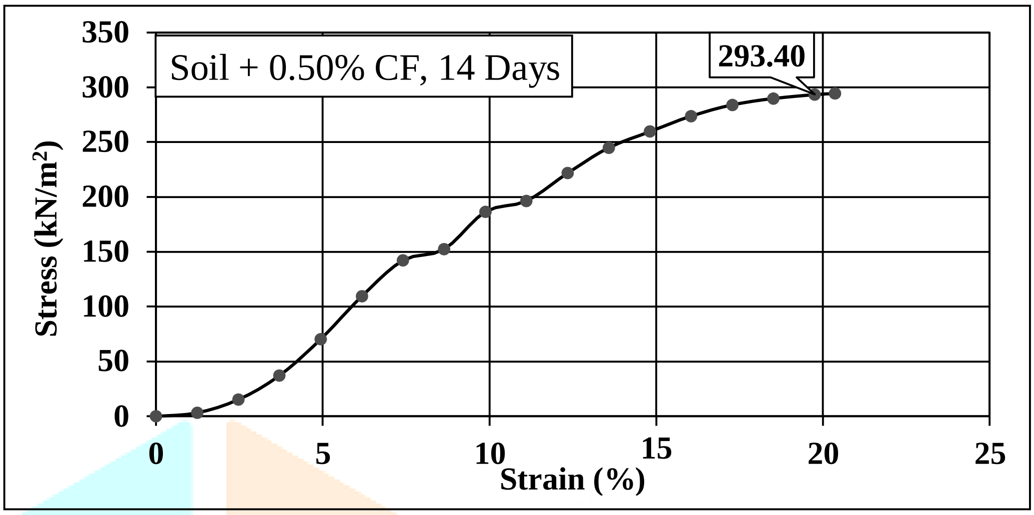


Fig. 4.28: Stress-Strain Curve for Soil with 0.50% Coir Fibre at 14 Days

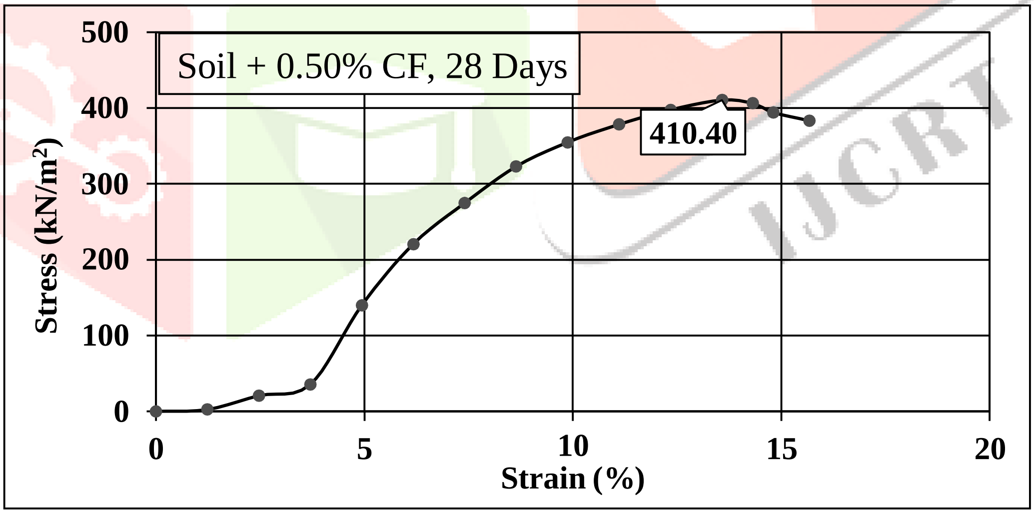


Fig. 4.29: Stress-Strain Curve for Soil with 0.50% Coir Fibre at 28 Days

From Figs. 4.25 to 4.29, it can be revealed with an increase in fibre content to 0.50%, the UCS of soil increased to 177.39, 239.12, 293.40 and 410.40 kN/m^2 for 0, 7, 14 and 28 days respectively.

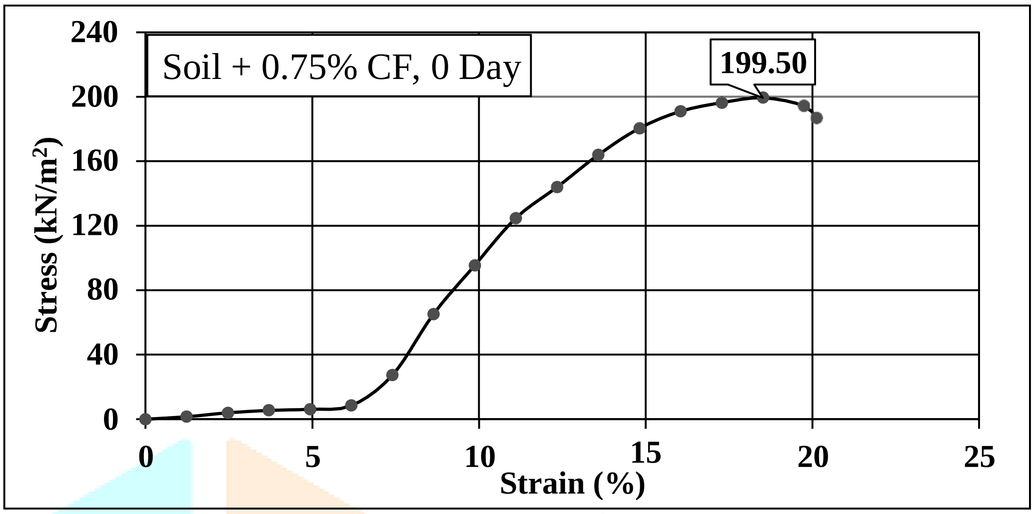


Fig. 4.30: Stress-Strain Curve for Soil with 0.75% Coir Fibre at 0 Day

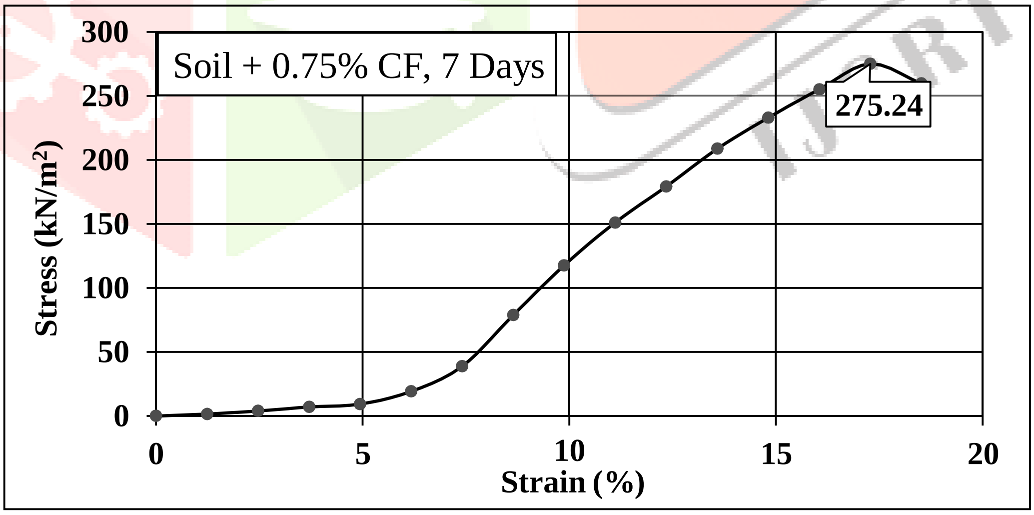


Fig. 4.31: Stress-Strain Curve for Soil with 0.75% Coir Fibre at 7 Days

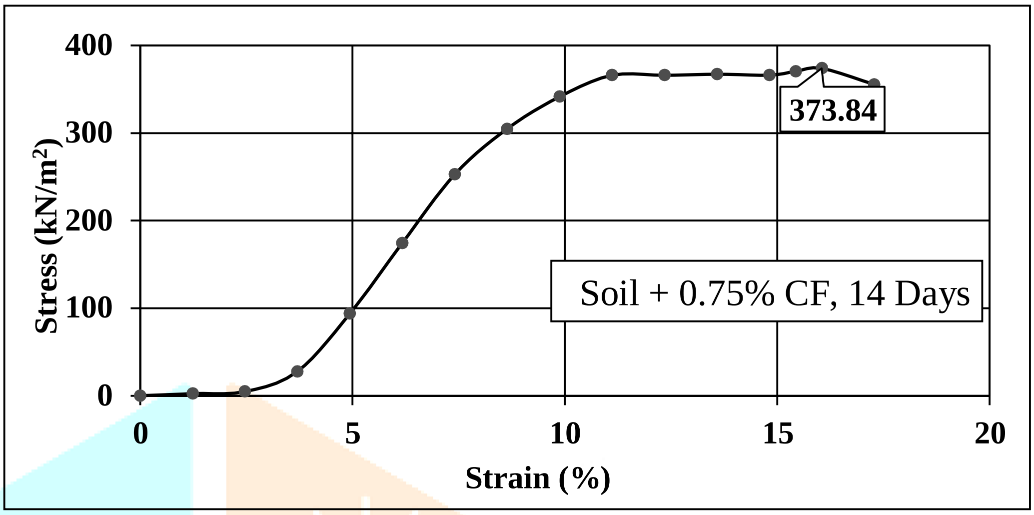


Fig. 4.32: Stress-Strain Curve for Soil with 0.75% Coir Fibre at 14 Days

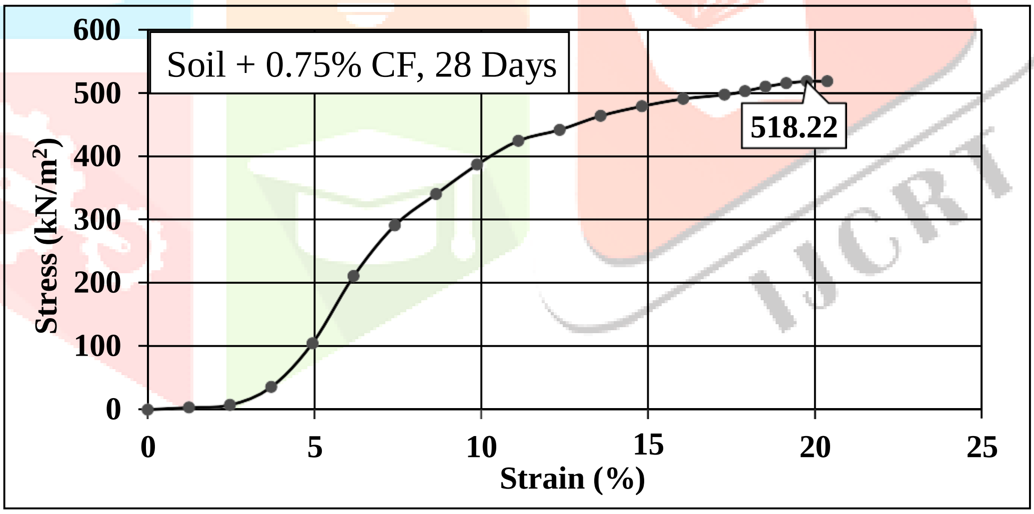


Fig. 4.33: Stress-Strain Curve for Soil with 0.75% Coir Fibre at 28 Days

From Figs. 4.30 to 4.33, it is indicated that on further increasing the coir fibre contentto 0.75%, the UCS value of soil mix increased to 199.50, 275.24, 373.84 and 518.22 kN/m^2 for 0, 7, 14, and 28 days respectively.

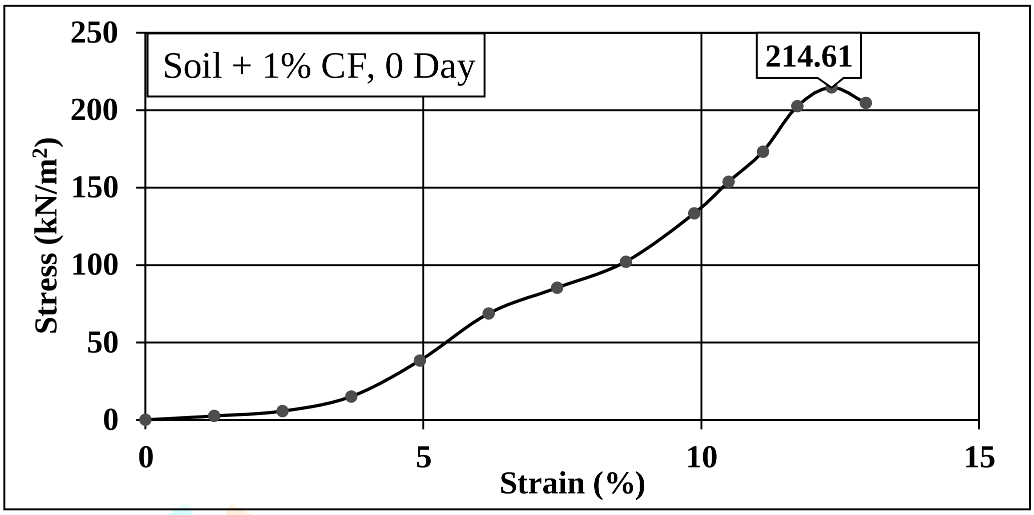


Fig. 4.34: Stress-Strain Curve for Soil with 1% Coir Fibre at 0 Day

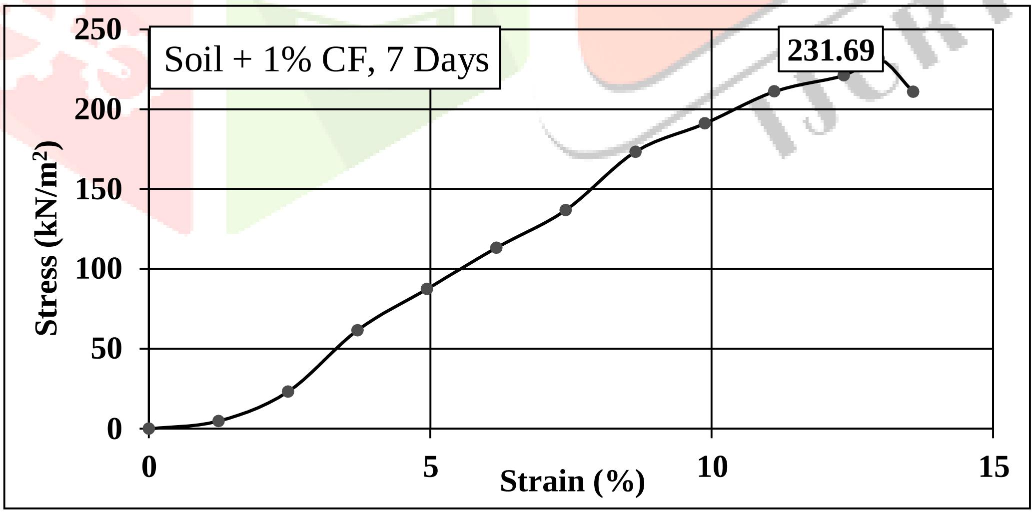


Fig. 4.35: Stress-Strain Curve for Soil with 1% Coir Fibre at 7 Days

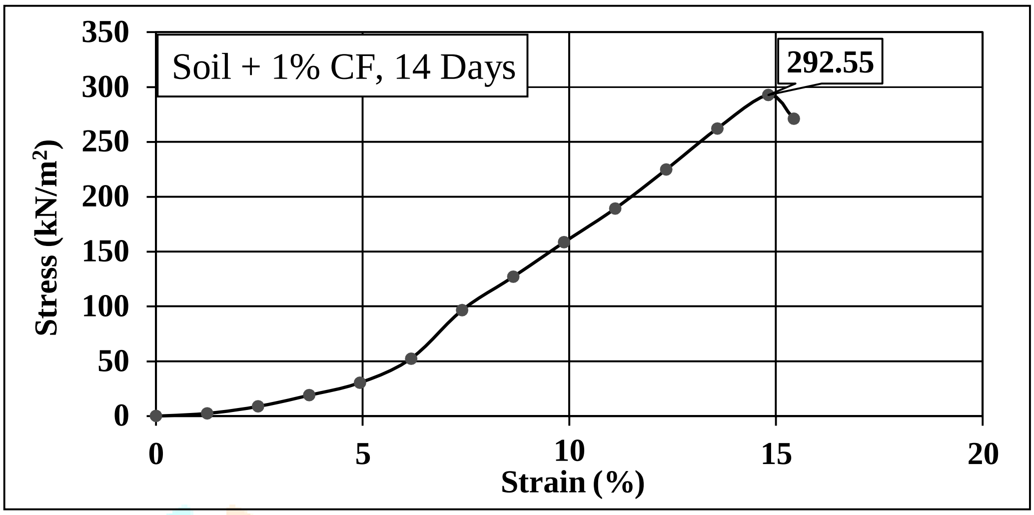


Fig. 4.36: Stress-Strain Curve for Soil with 1% Coir Fibre at 14 Days

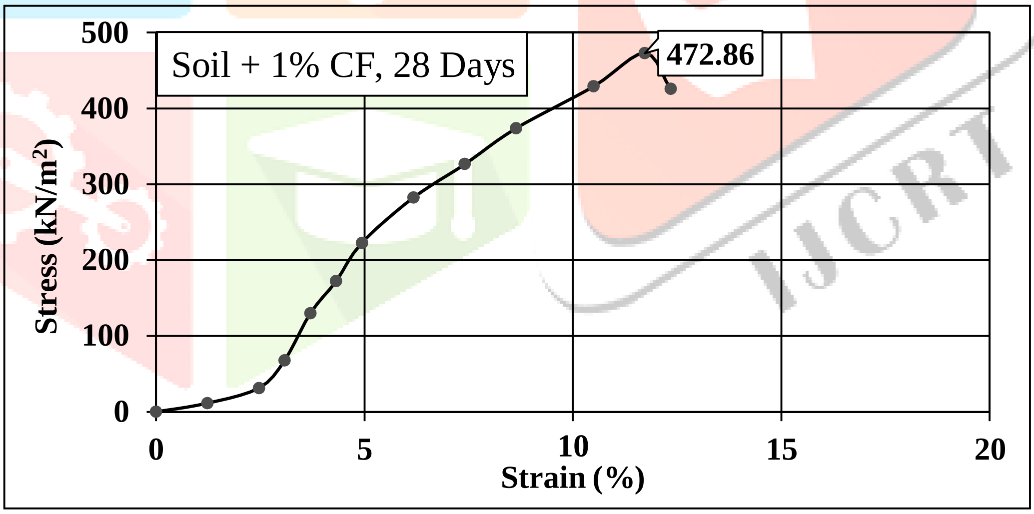


Fig. 4.37: Stress-Strain Curve for Soil with 1% Coir Fibre at 28 Days

The UCS values of soil samples mixed with 1% coir fibre are presented in Figs. 4.34 to 4.37. The UCS value determined on 0, 7, 14 and 28 days with this percentage of coir fibre were obtained as 214.61, 231.69, 292.55 and 472.86 kN/m^2 for 0, 7, 14, and 28 days respectively.

Summary of Results

UCS tests were performed using soil with varying proportion of coir fibre. The results obtained for different mixes are summarized in Table 4.4.

Table 4.4: Variation of UCS with Percentages of Coir Fibre.

Coir fibre (%)	Strength (kN/m^2)			
	0 Day	**7 Days**	**14 Days**	**28 Days**
0.00	108.79	121.83	150.98	151.63
0.25	139.38	214.61	236.94	301.02
0.50	177.39	239.12	293.40	410.40
0.75	199.50	275.24	373.84	518.22
1.0	214.61	231.69	292.55	472.86

Results of Triaxial Shear Tests

Unconsolidated-Undrained (UU) triaxial tests were also carried out on soil sample at cell pressures 0.5, 1.0, and 2.0 kg/cm^2. The results obtained after the UU tests conducted on varying percentages of coir fibre added to the soil are plotted and shown in Figs. 4.38 to 4.42.

The modified failure envelope for the unreinforced soil, i.e., the soil in natural condition without any coir fibre is shown in Fig. 4.38, the values of cohesion (c) and the angle of internal friction (ϕ) are found to be 19.82 kPa and 16.99^o respectively.

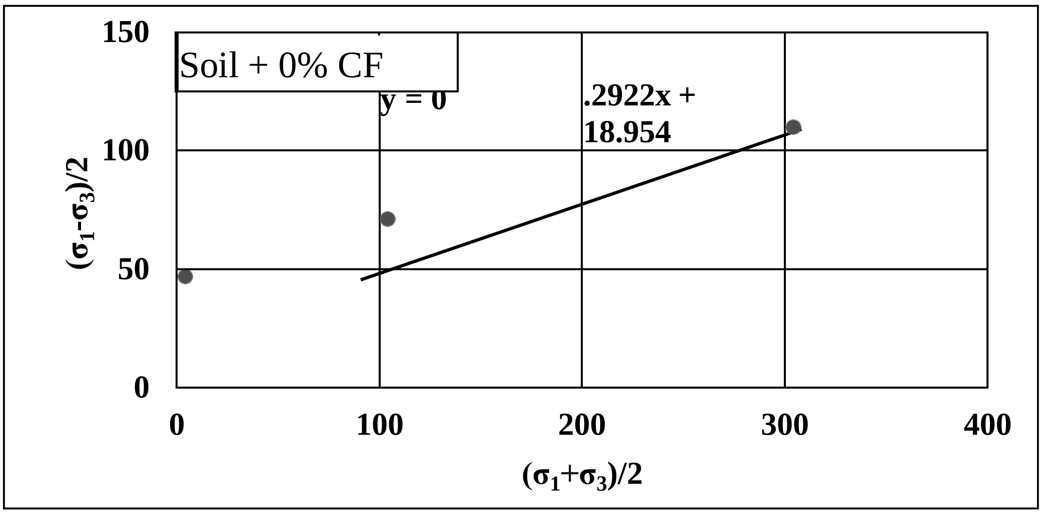


Fig. 4.38: Failure Envelope of Soil with 0% Coir Fibre

Fig. 4.39 shows the failure envelope for the soil mix with 0.25% coir fibre, the values of cohesion (c) and the angle of internal friction (ϕ) were found to be 23.55 kPa and 20.21^{o} respectively.

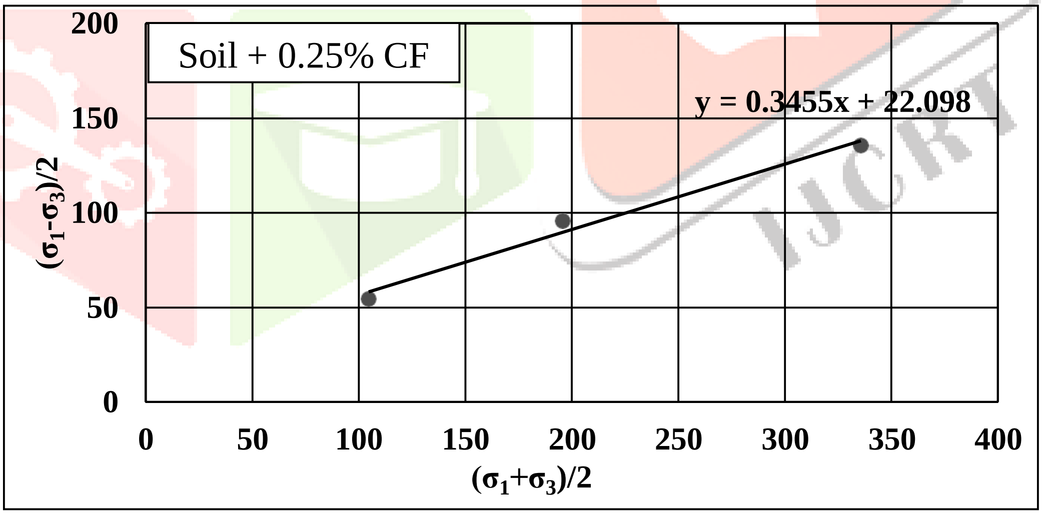


Fig. 4.39: Failure Envelope of Soil with 0.25% Coir Fibre

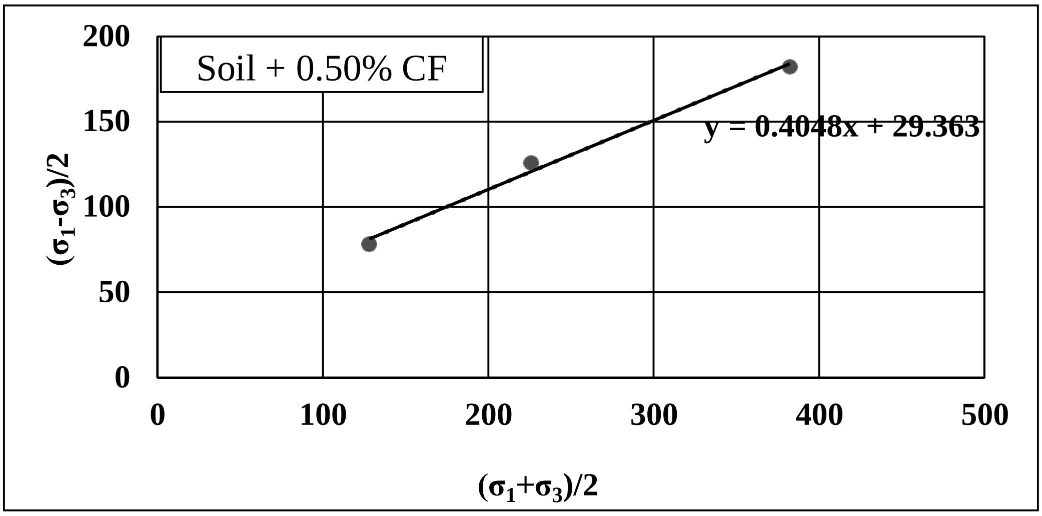


Fig. 4.40: Failure Envelope of Soil with 0.50% Coir Fibre

Fig. 4.40 shows the failure envelope for the soil mix with 0.50% coir fibre, the values of cohesion (c) and the angle of internal friction (ϕ) were found out to be 32.11 kPa and 23.88° respectively.

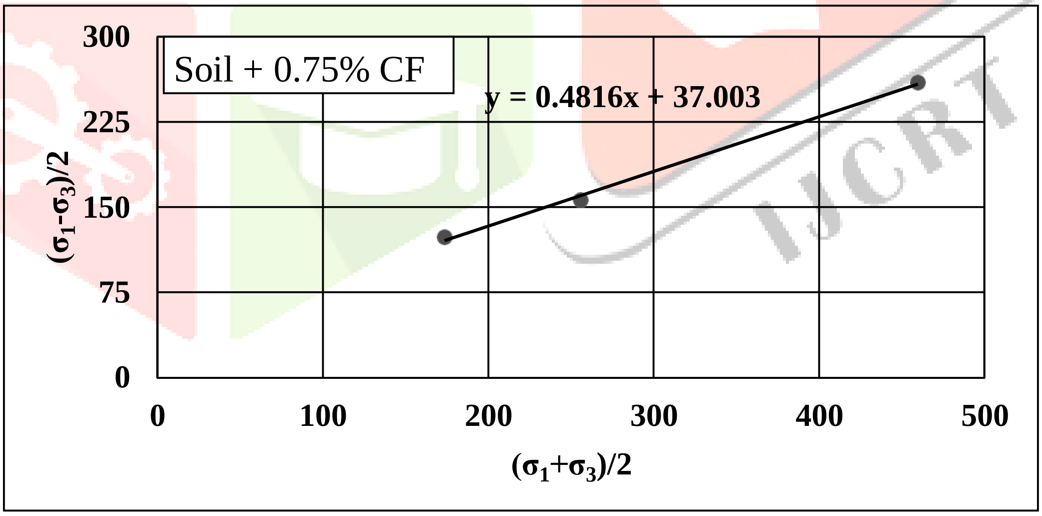


Fig. 4.41: Failure Envelope of Soil with 0.75% Coir Fibre

Fig. 4.41 exhibits the failure envelope for the soil mix with 0.75% coir fibre. The values of cohesion (c) and the angle of internal friction (ϕ) were found to be 42.22 kPa and 28.79° respectively.

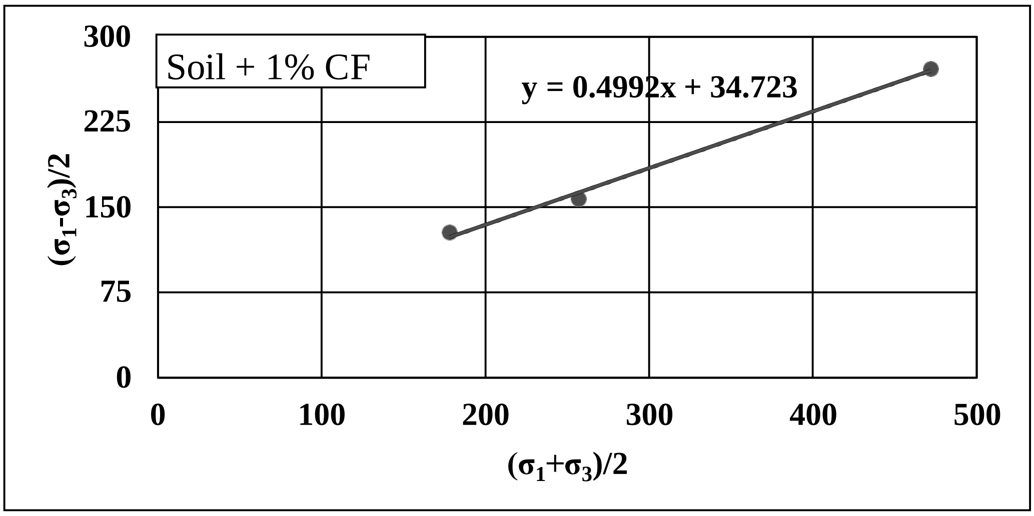


Fig. 4.42: Failure Envelope of Soil with 1% Coir Fibre

Fig. 4.42 shows the failure envelope for the soil mix with 1% coir fibre. The values of cohesion (c) and angle of internal friction (ϕ) were obtained as 40.07 kPa and 29.95° respectively.

Summary of Results

Summary of the results obtained after the Triaxial Tests are presented in Table 4.5

Table 4.5: Shear Strength Parameters for Soil-Coir Fibre Mixes

S.No.	Materials	Shear Strength Parameters	
		c (kPa)	**ϕ (degree)**
1.	Soil+0.00% CF	19.82	16.99
2.	Soil+0.25% CF	23.55	20.21
3.	Soil+0.50% CF	32.11	23.88
4.	Soil+0.75% CF	42.22	28.79
5.	Soil+1.0% CF	40.07	29.95

Concluding Remarks

The results obtained by conducting different types of tests on the soil and soil mixed with different percentages of coir fibre are discussed in this chapter. The conclusions drawn from the results as discussed above are presented in the next chapter.

CHAPTER 5 SUMMARY AND CONCLUSIONS

General

The study was undertaken to investigate the influence of coir fibre in the soil. Tests were performed to evaluate MDD and OMC relationships, shear strength parameters, UCS and CBR values of soil with different proportions of coir fibre. The results of the tests conducted are presented and discussed in the previous chapter. The results obtained are summarized in Table 5.1.

Conclusions

The following conclusions are drawn from the results summarized in Table 5.1.

- **Proctor Test Results**

a) Maximum Dry Density is decreasing with increase in percentages of Coir fibre. The value has decreased from 17.71 KN/m^3 to 16.80 KN/m^3.

b) The percentage of Coir fibre ranging from 0.25 % to 1 % mixed to the soil is responsible for the decrement of Maximum Dry Density.

c) Optimum Moisture Content increased from 13 % to 19 % with increase in the percentage of coir fibre to the soil.

- **California Bearing Ratio Test Results**

a) Unsoaked and soaked values of CBR showed an increasing trend with increasing percentages of Coir fibre till 0.75 % fibre content and after this, the value showeda decreasing trend.

b) The maximum value of CBR for the unsoaked and soaked condition are found to be 11.32 % and 4.45 % respectively

Table 5.1: Test Results of Soil and Soil Mixed with Different Percentages of Coir Fibre

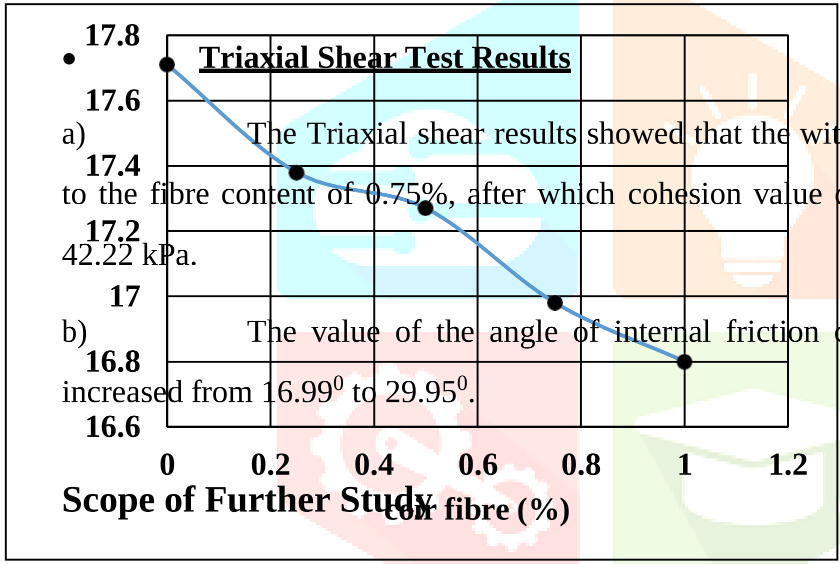
S. No.	Soil-Mix	Parameters Studied													
		LL (%)	PL (%)	PI (%)	G	OMC (%)	MDD (kN/m^3)	CBR (%)		UCS(kN/m^2)				Triaxial Shear Parameters	
								Unsoaked	Soaked	0 day	7 days	14 days	28 days	c (kPa)	ϕ (Degree)
1.	Soil+0% CF	27.06	11.76	15.30	2.53	13	17.71	6.67	2.16	108.79	121.83	150.98	151.63	19.82	16.99
2.	Soil+0.25% CF	-	-	-	-	14	17.38	7.54	2.79	139.38	214.61	236.94	301.02	23.55	20.21
3.	Soil+0.50% CF	-	-	-	-	15.5	17.27	8.29	3.03	177.39	239.12	293.40	410.40	32.11	23.88
4.	Soil+0.75% CF	-	-	-	-	17	16.98	11.32	4.45	199.50	275.24	373.84	518.22	42.22	28.79
5.	Soil+1% CF	-	-	-	-	19	16.80	9.78	3.46	214.61	231.69	292.55	472.86	40.07	29.95

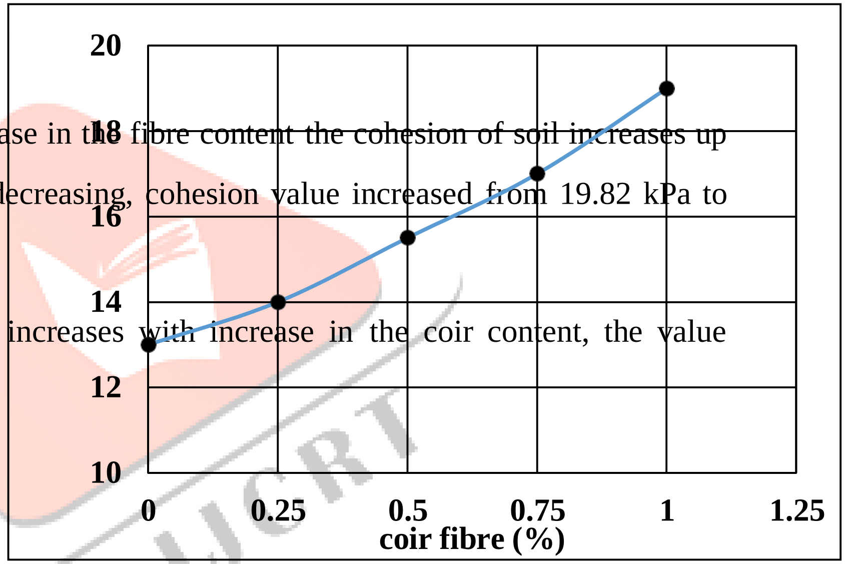
Unconfined Compressive Strength Test Results

a) Unconfined compression strength test conducted at 0, 7, 14 and 28 days of soil sample mixed with Coir fibre.

b) As the percentage of Coir fibre increases to the soil, the unconfined compression strength increased up to coir content of 0.75%, after which strength start decreasing.

c) The Optimum percentage of Coir fibre mixed to soil was found 0.75 % after conducting a series of a laboratory test.





- **Triaxial Shear Test Results**

a) The Triaxial shear results showed that the with the increase in the fibre content the cohesion of soil increases up to the fibre content of 0.75%, after which cohesion value does start decreasing, cohesion value increased from 19.82 kPa to 42.22 kPa.

b) The value of the angle of internal friction continuous increases with increase in the coir content, the value increased from 16.99^0 to 29.95^0.

Scope of Further Study

- Coir fibre is the waste material obtained from the husk of coconut fruit and can beused for civil engineering constructions.
- Stone dust, fly ash and rice husk etc. other additives can be used in mix with Coirfibre to improve strength of soil.
- Coating of coir fibre can be done to increase the life of fibre.

APPENDICES

Appendix A

Moisture-Density Relationship

Max Dry Density(kN\m3)

Fig. A1: Variation of MDD with Percentages of Coir Fibre

Optimum Moisture content (%)

Fig. A2: Variation of OMC with Percentages of Coir Fibre

Appendix B

Moisture-Density Relationship

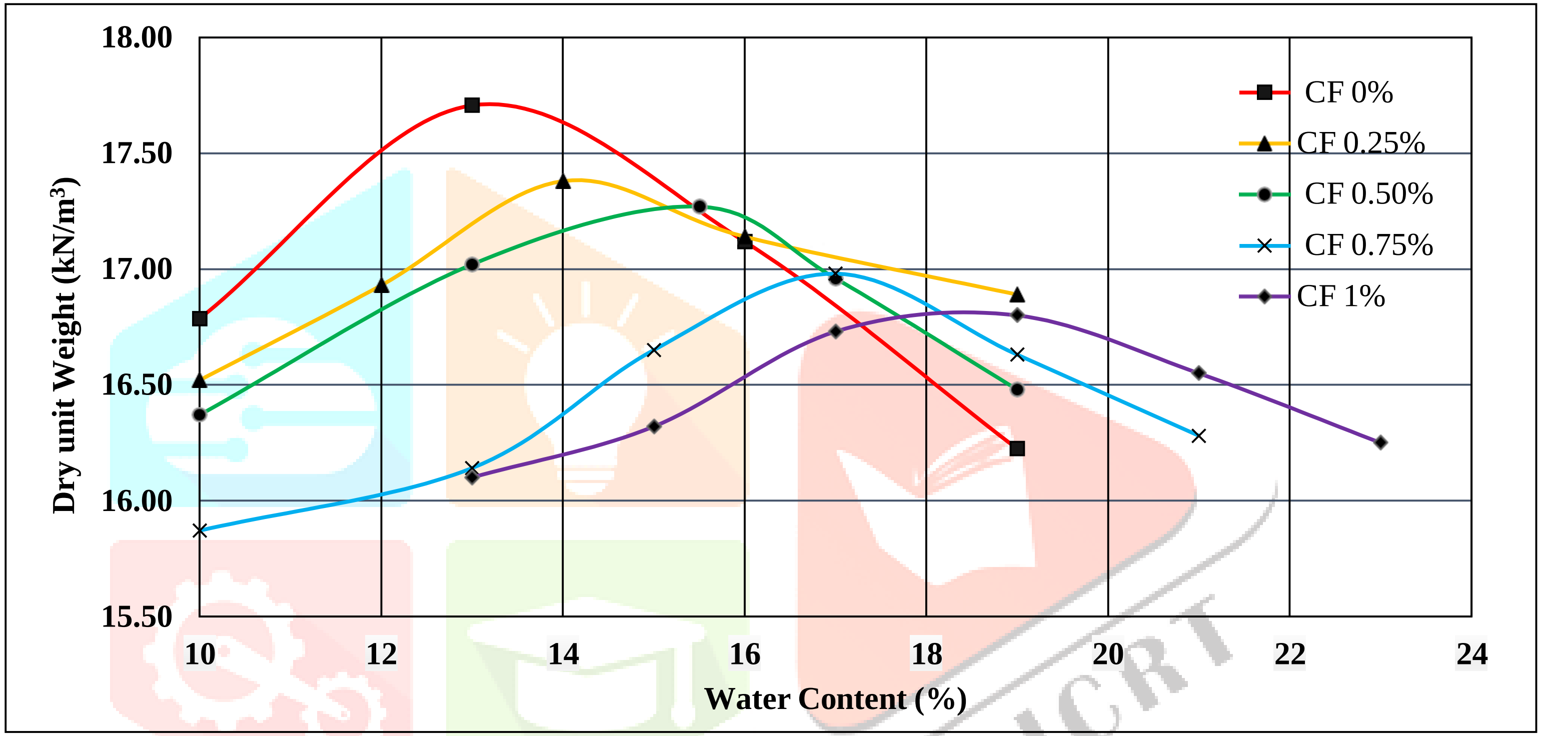


Fig. B1: Variation of Dry Unit Weight and Water Content at Different Coir Fibre Percentages.

Appendix C

California Bearing Ratio

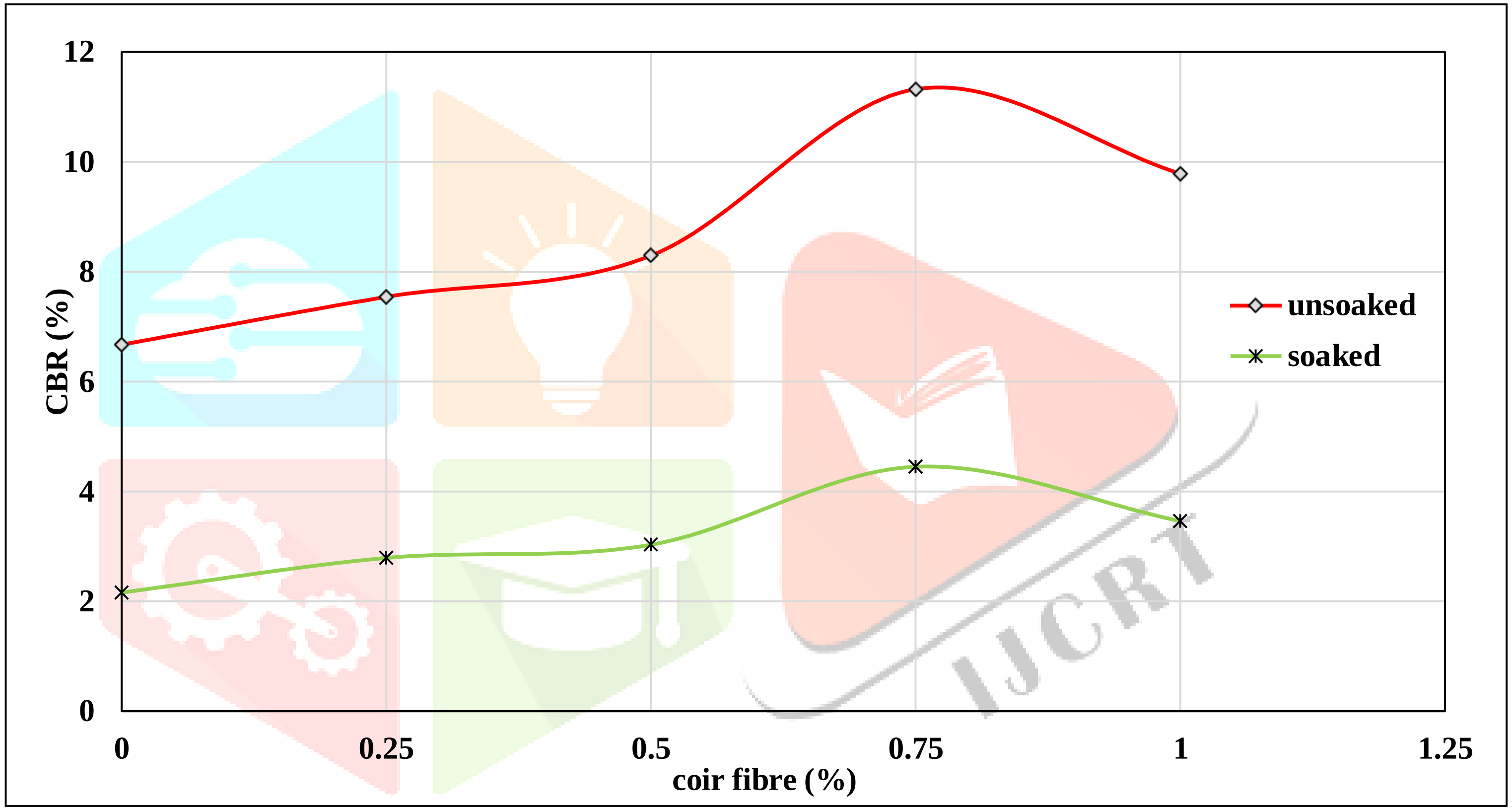


Fig. C1: Variation of CBR with Percentages of Coir Fibre

Appendix D

Unconfined Compressive Strength

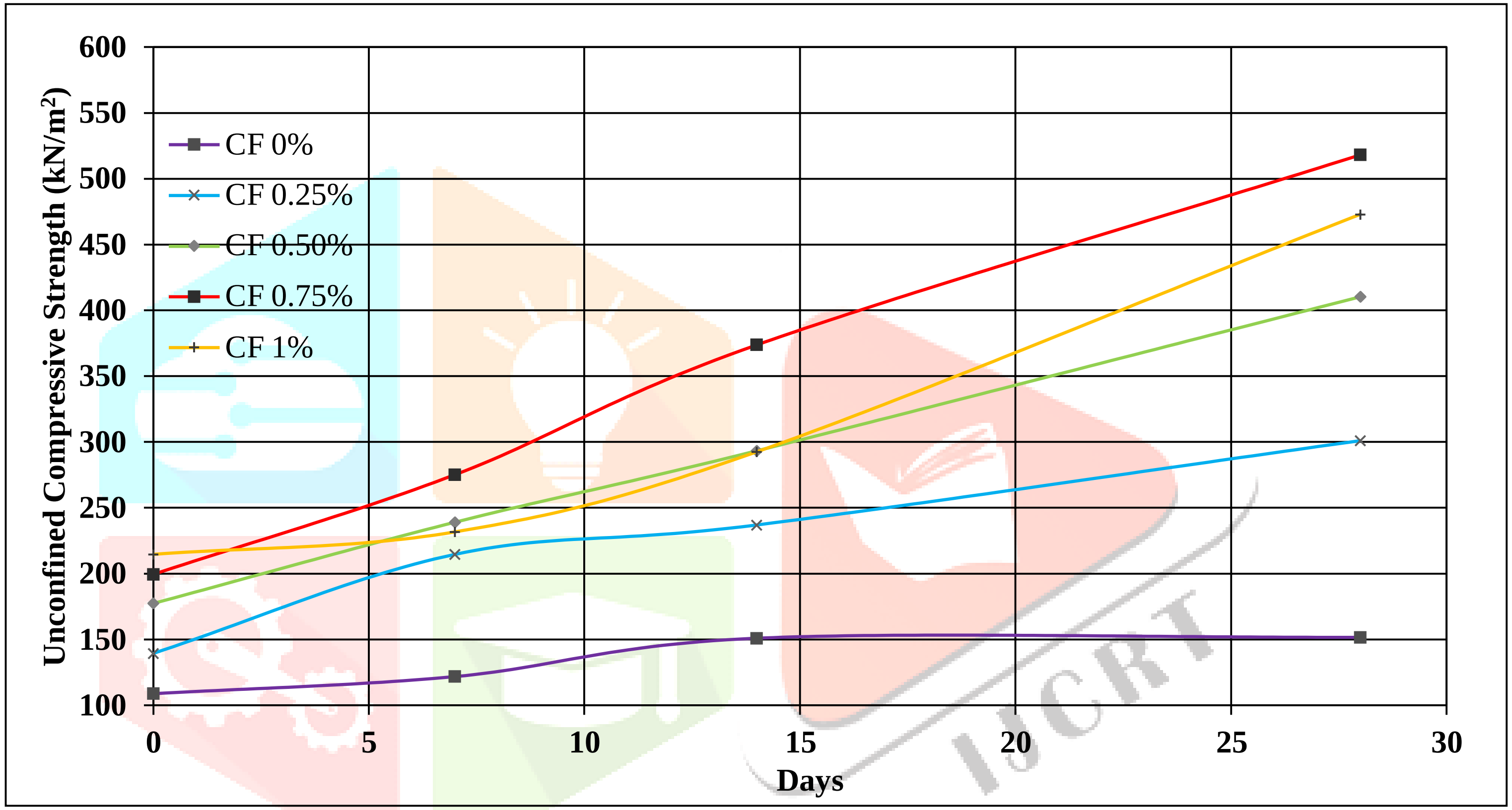


Fig. D1: Variation of UCS with Percentages of Coir Fibre

Appendix E

Triaxial Shear Parameters

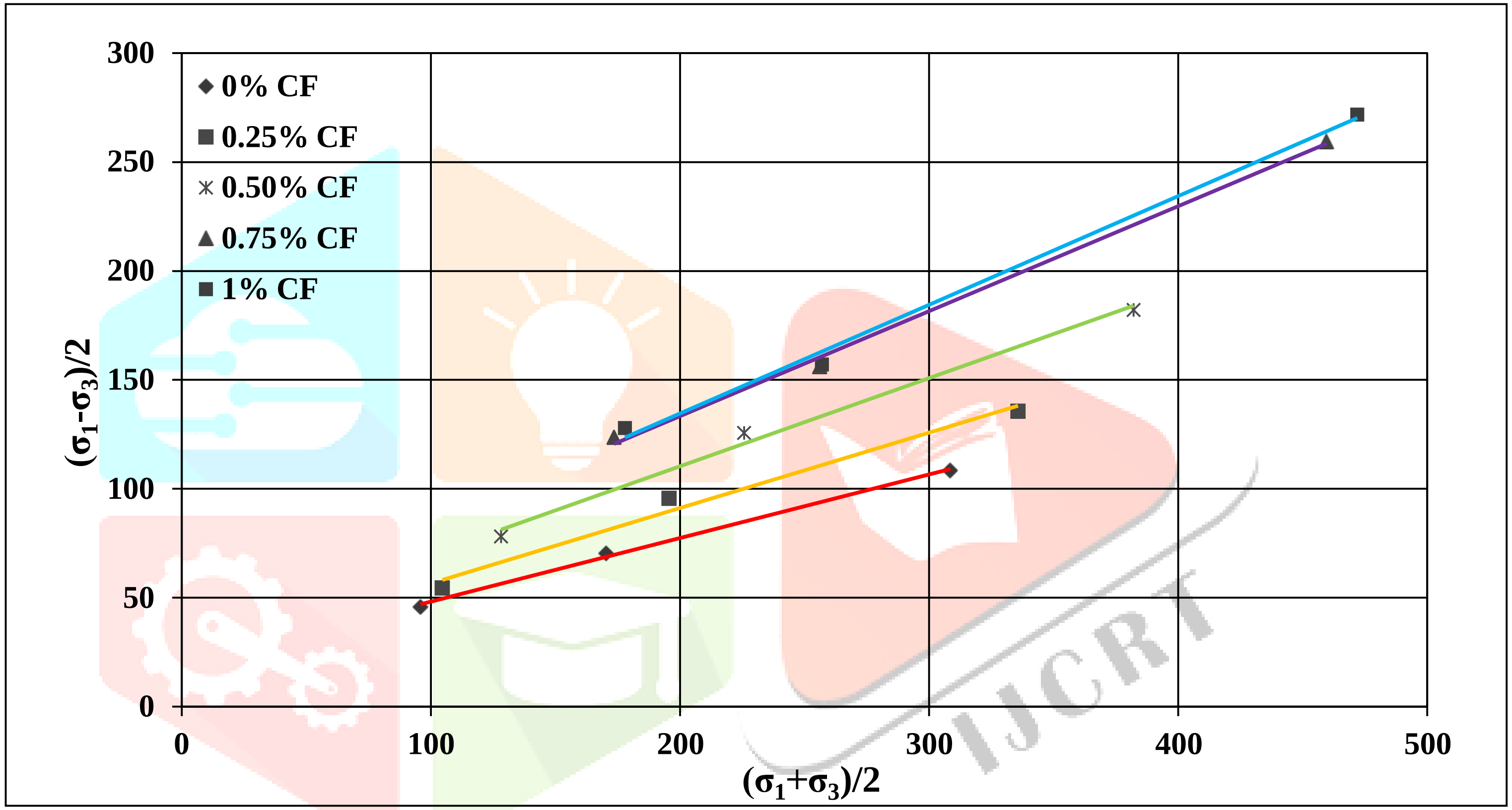


Fig. E1: Variation of Triaxial Shear Parameters with Percentages of Coir Fibre

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