Enhancing Strength Properties of Soft Soil Using Carbon Fiber

Swati Sucharita Rout[1[✉]] and Rupashree Ragini Sahoo[2]

[1 2] Civil Engineering Department,
Veer Surendra Sai University of Technology, Burla, Odisha,India-768018
swatisucharita05@gmail.com and rupashreesec@gmail.com

Abstract. Civil engineers are always ambitious when it comes to new materials that can face many challenges which have cropped up with time in the world. This paper enquires the effectiveness of Carbon Fiber (CF) as a better reinforcing agent to augment the engineering characteristics of soil, especially the Shear Strength, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) using CI-CH soil. Varying percentage of Carbon Fiber (0.05%. 0.1%, 0.2%, 0.4% and 0.6% by weight of soil) were included to analyze the gain in relative strength of soil. The research was conducted to assess the Shear Parameters, Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) of soil with respect to varying percentage of Carbon Fiber. The analysis revealed that, 0.4% of Carbon Fiber in the soil mixture resulted in enhancing the strength properties of the soil to the maximum. The soil reinforced with Carbon Fiber increased cohesion, internal angle of friction, UCS, both soaked and unsoaked CBR by factor 4.1, 1.78, 1.25, 1.56, and 1.52 respectively.

Keywords: Carbon fiber (CF). CI-CH. Shear Parameters. UCS. CBR.

1 Introduction

Civil engineering constructions over soft soil arise to many cases due to shortage of good bearing soil. The characteristic properties of soft soil being differential settlement, low shear strength and high compressibility. It is extremely essential to raise the load bearing capacity of soil for constructing high rise buildings over soft soil. Numerous techniques like soil stabilization, soil reinforcement, grouting, addition of admixtures, etc. have been adopted to tackle the issues of soft soil. Explosive cost of materials and lack of accessible resources have encouraged geotechnical engineers to innovate and formulate better alternatives. Depending up on the benefits of excellent dispersion and smooth blending of the fiber, a definite quantity of the fiber and soil is blended to achieve a consistent mixture. The wondrous properties of the fiber have put it under careful study of the researchers which has led to its varied applications in the industry and advancements in the reinforcing technology. Polypropylene fiber had been shown to raise the strength properties of soil [Natraj et. al 1997, Tang et. al 2010, Zimoglu, Yetimoglu 2011]. Random distribution of polypropylene fibers in soil had been intensively studied by researchers [Pradhan et al. 2012] who had found it to raise the strength properties of cohesive soils. The effect of polypropylene fiber on the compressive, triaxial shear strength of the cement treated soil had been investigated [Tang et. al 2007, Park 2009, Hamidi et. al 2013]. Mirzababaei et al. [2013] had analyzed the swelling properties of clay using waste carpet fiber. Hair, a natural fiber was used to enhance the shear strength and bearing capacity of soil [Butt et al. 2015]. Changizi and Haddad [2016] had investigated the consequences of the strength and underlying structure of glass fiber-reinforced soil.

Carbon fiber is another fiber material containing over 90% carbon. The fiber is obtained from different organic filaments in inert atmosphere which imparts it the properties of high temperature carbonization and low temperature oxidation. This fiber is filamentous thus having a several advantages. The fiber has high strength, high stiffness, lightweight, high heat tolerances and resistant, high tensile modulus, low density, high thermal and electrical conductivity, low coefficient of thermal expansion, corrosion resistance, superior fatigue properties, high creep resistance, excellent strength to weight ratio etc. Its appearance is distinctive, one of kind and almost not possible to replicate. In comparison with steel it is 70% lighter; whereas with aluminum it's 40% less. This unique property finds its place of use in Aerospace industry, Aircraft industry, Automotive industry, Military, Recreational application, Sport equipment, Medical equipment, Entertainment, Wind energy technology and huge numbers of various fields. In civil construction, design and development, carbon fiber finds its application in concrete beams and columns; whereas it strives to improve the compressive strength, tensile strength, shear strength, load capacity and seismic performances [Tabatabaei et al. 2013 and Olofin et al. 2015]. It also helps in strengthening the structures like concrete, steel, cast iron, masonry, timber etc. Lavanya et al. [2014] had conducted the Direct Shear test to analyze the angle of interface friction between well graded and poorly graded gravel and Carbon Fiber Reinforced Polymer (CFRP) wrapped concrete specimens to resolve the soil-substructure interaction problem. The test outcomes indicated that there was a considerable reduction in the angle of interface friction by wrapping the CFRP. Gao et al. [2015] conducted a progression of unconfined compression tests for clay reinforced with carbon fiber of 9mm long which was blended into soil with 0.01%, 0.02%, 0.03%, 0.05%, 0.1%, 0.15%, 0.25%, 0.35%, and 0.5%. From his investigation, the unconfined compressive strength increased in the starting and showed a gradual decline with further increase of fiber percentage, the increment impact was the most evident when the carbon fiber content was 0.1%. Firoozi et al. [2016] had investigated the stabilization of soft soil using Carbon NanoTubes (CNT). Increase in the amount of CNT can lead to raise durability, reduced brittleness and increased tensile strength. Wang et al. [2016] conducted shear strength and compaction tests of clay soil reinforced with carbon fiber of 3mm and 6mm length. The results indicated that the OMC decreased while MDD increased and the internal friction angle, cohesion increased firstly, followed by a decreased. It should be noticed that in the above researches, there has not been a consent concerning the impact of carbon fiber on the CBR value of soil. Hence, the aim of this experiment was to evaluate both soaked and unsoaked CBR values, shear parameters and unconfined compressive strength of soil when mixed with carbon fiber. A sequence of Direct Shear tests, Unconfined Compression tests, California Bearing Ratio (soaked, unsoaked) tests were carried out and the outcomes observed from laboratory tests were collated with the unreinforced soil.

2 Materials and Methods

2.1 Materials

The soil, utilized for experimental work was obtained at a depth of 3 ft beneath ground level from a site at Sambalpur, Odisha, India. Table 1 & Table 2 present various Geotechnical properties of soil and Engineering characteristics of soil respectively.

Carbon fiber was obtained from CFW Enterprises, Delhi. The carbon fiber was chopped in to small pieces of 12 mm length.

Fig. 1. Carbon fiber

Table 1. Physical Properties of Soil.

Properties	Values
IS Classification	CI-CH
Specific Gravity	2.40
Grain Size Distribution	
a) Sand (%)	12.04
b) Silt (%)	41.74
c) Clay (%)	46.22
Liquid Limit (%)	49.72
Plastic Limit (%)	26.12
Plasticity Index (%)	23.60

Table 2. Engineering Characteristics of Soil

Properties	Values
Compaction test	
a) MDD (g/cc)	1.63
b) OMC (%)	19.42
UCS (kN/m²)	77.72
Shear Strength Parameters	
Cohesion(c) (kN/m²)	13.73
Angle of Internal Friction(φ) (°)	18
CBR (%)	
Unsoaked	4.71
Soaked	1.63

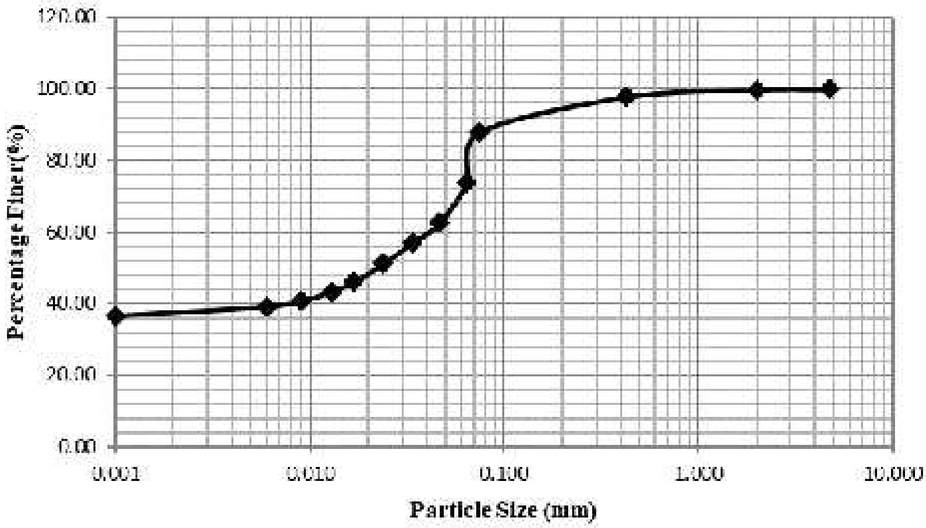

Fig. 2. Particle Size Distribution Curve of Soft Soil

2.2 Test Method

Preparation of Sample. The sample obtained from the ground level was air dried and pulverized. The soil sample was sieved through a 4.75mm sieve for segregation of vegetative substances. For the test, length of Carbon fiber used was 12 mm in five various samples that were made with the mixture of oven dried soil and 0.05%, 0.1%, 0.2%, 0.4% & 0.6% of carbon fiber depends on the weight of the soil respectively. Then optimal water content achieved from Standard Proctor test was mixed and blended until the water diffuses throughout the soil. The soil-fiber was mixed with water homogeneously in an impervious metal tray to prevent water loss. Then the direct shear, UCS and CBR test specimens were prepared from the mix obtained. The above-mentioned tests were carried out on both unreinforced and reinforced soil specimens to compare the strength of the soil by varying the fiber content.

Direct Shear Test. A sequence of direct shear tests were carried out as per the IS 2720 (part 13) 1986. The mixture of soil-carbon fiber was compacted in a shear box of size 60 mm × 60 mm × 24 mm by ramming to Standard Proctor's MDD in order to get the specimens for the experiments. The specimens had a Carbon Fiber percentage of 0.05%, 0.1%, 0.2%, 0.4% and 0.6% w.r.t the soil. Three test samples were prepared for each specimen. Each sample was put through a sequence of tests at normal stress of 5 kPa, 10 kPa, 20 kPa and 50 kPa in an unconsolidated undrained condition. The loading rate was kept to 0.125 mm per second in the tests. Readings from the proving ring dial gauge were recorded with respect to fixed intervals of horizontal dial gauge readings in order to analyze the stress-displacement behavior of both unreinforced and fiber reinforced soil. From the shear stress-normal stress plot, the shear parameters were calculated.

Unconfined Compression Test. To figure out the consequences of embedding carbon fiber with soil on its strength properties, five groups of the specimens were arranged, UCS test was executed on them and the UCS values of each sample was measured. Based on Standard Proctor's MDD, the mixture of soil-carbon fiber was compacted in a cylindrical mould of 50mm diameter and 100mm height. The mixture had a percentage of 0.05%, 0.1%, 0.2%, 0.4% and 0.6% carbon fiber for each of the samples. Samples were extracted from the mould for further tests. According to IS 2720 (part 10) 1991, the experiments were modulated at a consistent strain rate of 0.125mm/min. Three samples of each specimen were studied for each varying proportion. The Stress-Strain curve was observed and the UCS value was calculated**.**

CBR Test. CBR value is the important engineering parameter for assessing the strength of sub-grade and sub-base materials for design and construction of pavement. The CBR tests were executed for different percentage of Carbon fiber as per IS 2720 (part-16) 1987.Based on Standard Proctor's MDD, the preparation of soil specimens was performed in a cylindrical mould of 150mm dia and 175mm height by compaction of the mixture of soil-Carbon fiber. The specimens had a Carbon Fiber percentage of 0.05%, 0.1%, 0.2%, 0.4% and 0.6% respectively. Three samples of each specimen were experimented for a variable proportion. Then the samples were immersed in water for ninety-six hours and again the tests were performed. All experiments were executed at a penetration rate of 1.25mm/min until a penetration of 12.5mm was attained. CBR values for both soaked and unsoaked samples were calculated and the Load-Penetration curve was plotted for all the specimens.

3 Results and Discussion

Over the entire experimental period, several tests were performed on soft soil without and with carbon fiber reinforcement. The effect of carbon fiber addition on stress-displacement behavior, shear parameters, unconfined compression test and soaked and unsoaked CBR values were examined. The details of the experimental outcomes are presented in the below sections.

3.1 Direct Shear Test

The Shear parameters of soil reinforced with varied percentages of carbon fiber of length 12mm, attained from the direct shear tests which are briefed in Table 3. The relationship between Shear stress and Horizontal displacement of soil reinforced with fiber is depicted in Fig. 3. As observed from Fig. 3, for each specimen the shear stress of carbon fiber reinforced soil was observed to be occurring at larger displacements compared to the unreinforced soil. It was observed that enhancement in normal stress hiked the strength of soil to the topper level after inclusion of carbon fiber and the reason could be such that rising in normal stress caused contact force and interlock between normal stress, contact force and interlock between soil particles to rise. Increase in carbon fiber percentage of the mixture in turn increases its shear strength. From Fig 3, the conclusion can be drawn that the inclusion of 0.4% carbon fiber leads to maximum shear stress in comparison to the unreinforced soil. The relation between Typical Shear stress & Normal stress of reinforced soil are shown in Fig. 4. Based on the outcomes a graph has been plotted with various percentages of Carbon fiber which has been represented in Fig. 5. It was obtained from the tests that, Cohesion and Internal angle of friction varied from 13.73 kPa to 55.90 kPa and 18º to 32º respectively. These strengths were raised up to 0.4% carbon fiber content, beyond which they started decreasing. Thus, the experiment suggests that the optimal fiber content was 0.4%. Similar outcomes were also recorded by Y. Wang et al. [2016]. The observation might be an outcome of interaction between soil and fiber.

Table 3. Shear Parameters of Carbon Fiber Reinforced Soil Obtained from Direct Shear Test

Sl. No.	Mix Proportion	Cohesion (kPa)	Internal Angle of Friction (º)
1	Soil+0% CF	13.73	18
2	Soil+ 0.05% CF	23.54	22
3	Soil+0.1% CF	32.36	24
4	Soil+0.2% CF	37.27	28
5	Soil+0.4% CF	55.90	32
6	Soil+0.6% CF	40.20	25

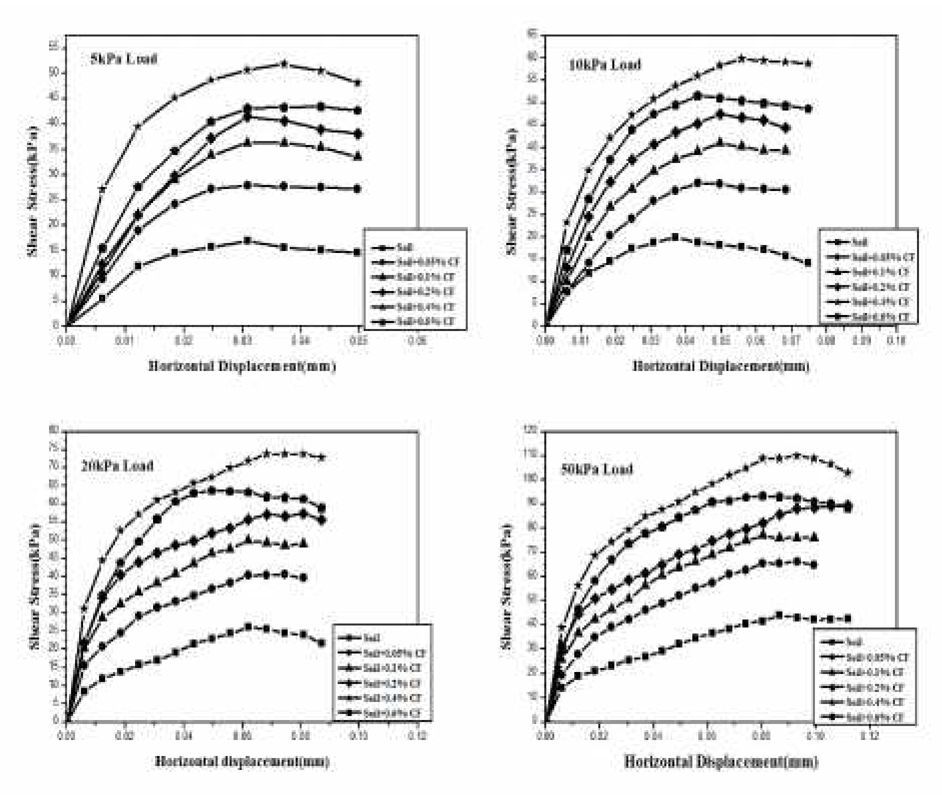

Fig. 3. Stress-Displacement curves of Soil reinforced by Carbon fiber obtained from Direct Shear Test

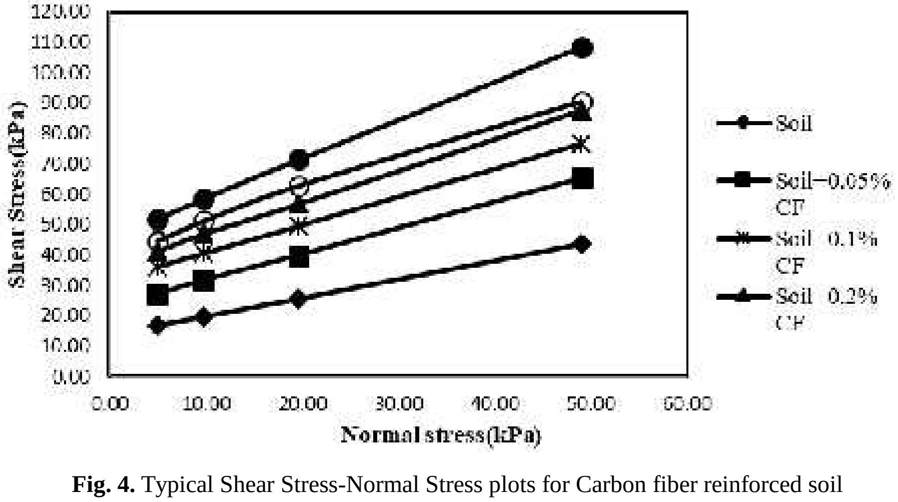

Fig. 4. Typical Shear Stress-Normal Stress plots for Carbon fiber reinforced soil

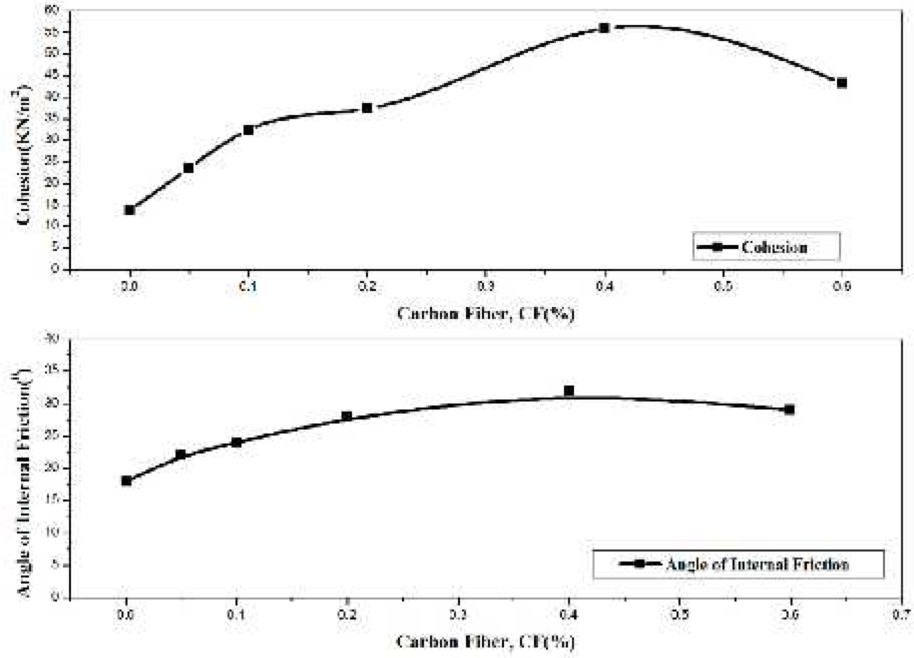

Fig. 5. Effect of Carbon fiber on Cohesion and Angle of internal friction of Soil

3.2 Unconfined Compression Test

The experimental outcomes of UCS tests are represented by stress–strain curve in Fig. 6 and Fig. 7. The conclusion can be attained from the figure that that inclusion of fiber into soil raises the unconfined compressive strength (q_u) and the strain. By increasing the percentage of addition of carbon fiber, the UCS of soil were increased up to 0.4%, further additions of fiber content decreased the UCS value. The carbon fiber effect on the UCS value was marginal when the percentage of fiber was beyond 0.4%. Thus, the maximum percentage of carbon fiber content was noted to be 0.4% and corresponding UCS value was 97.38 kPa. As compare to the native soil, it was observed that the UCS value of all soil specimens reinforced with carbon fiber occurs at maximum strain. Similarly, Gao et al. [2015] mixed carbon fiber into soil with ten different percentages and obtained that carbon fiber improved the unconfined compressive strength till a certain strain percentage after which it started decreasing.

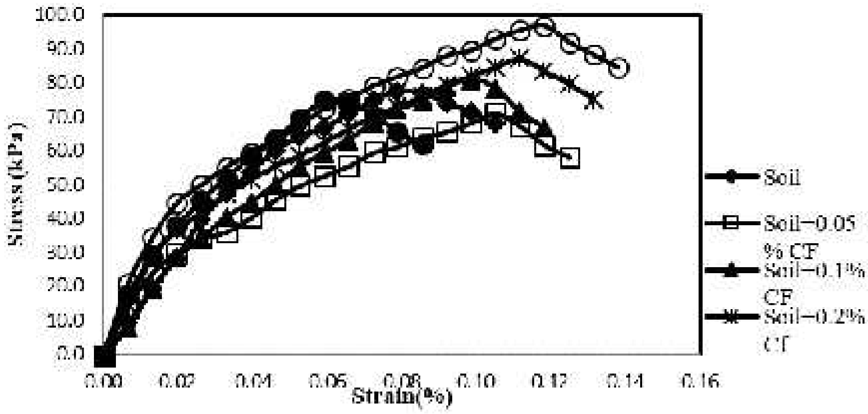

Fig. 6. Stress-Strain Curve for Carbon Fiber Reinforced Soil Obtained from Unconfined Compression Test

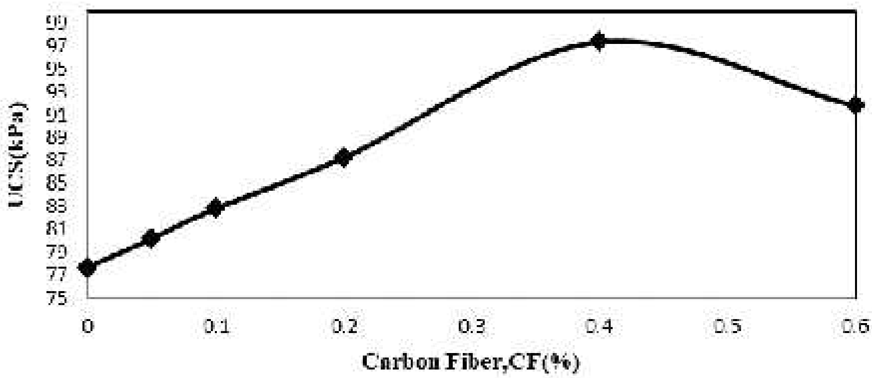

Fig.7. Effect of Carbon fiber on UCS of Soil

3.3 CBR Test

Soaked CBR. The load-penetration curve which was plotted from soaked CBR tests for soil sample treated with various proportions of carbon fiber are given in Fig. 8 and Fig. 10. The observations can be done from the figure that soaked CBR values of soft soil increase with inclusion of Carbon fiber up to 0.4% of fiber content. The CBR value was raised from 1.63% for natural soil to 2.55% for reinforced soil, when 0.4% fiber was added.

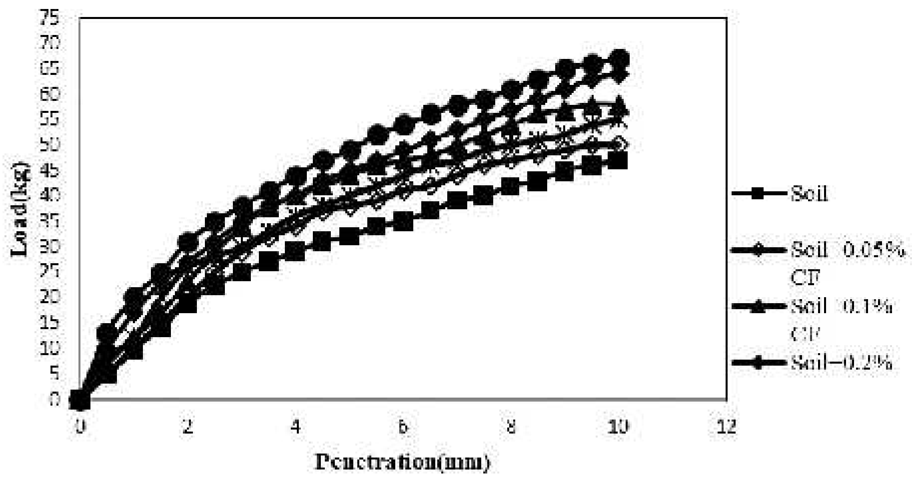

Fig. 8. Load-Penetration Curve for Carbon Fiber Reinforced Soil Obtained from Soaked CBR test

Unsoaked CBR. On the basis of the test outcomes, the Load-Penetration curve and the variation of CBR w.r.t different Carbon fiber content were plotted as shown in Fig. 9 and Fig. 10 respectively. It was clear from the figures that, over the increment of fiber percentage up to 0.4%, the CBR of soil increased, but upon further addition of fiber, the CBR value decreased. The unsoaked CBR of reinforced soil increased to 7.14% from 4.71% of native soil. Here, the optimum value of Carbon fiber content was 0.4%.

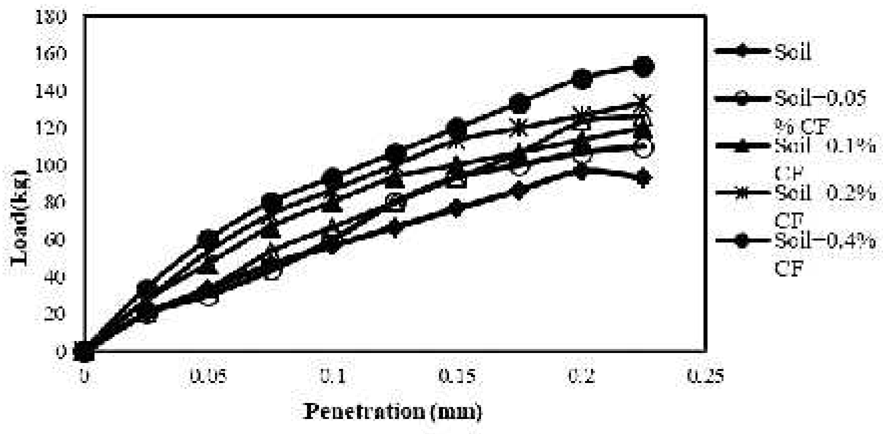

Fig. 9. Load-Penetration Curve for Carbon Fiber Reinforced Soil Obtained from Unsoaked CBR Test

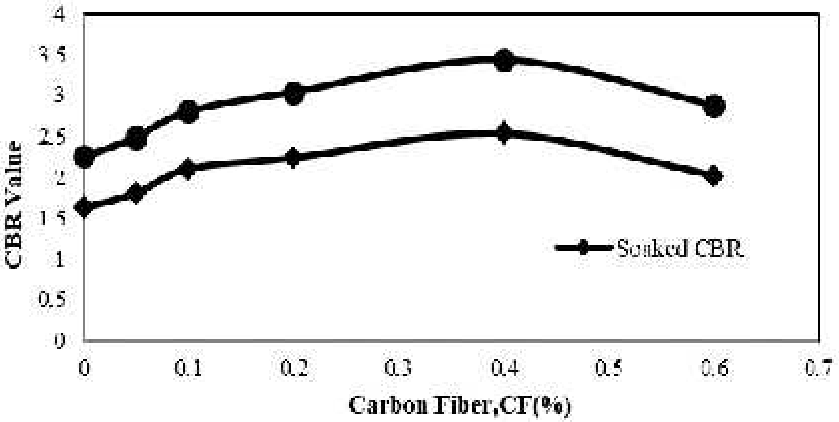

Fig. 10. Effect of Carbon fiber on Soaked and Unsoaked CBR of Soil

4 Conclusions

The study was taken to observe the appropriateness of carbon fiber blend as soul reinforcement for soft soil. The accompanying conclusions can be drawn from observations.

1. With increase in the percentage of Carbon fiber the shear strength of compacted fiber reinforced soil was obtained to increase up to a certain point, then decreased. The optimal value of shear strength was achieved for the mixture containing 0.4% carbon fiber.
2. With the increase in the Carbon fiber content, initially there was corresponding increase of cohesion and angle of internal friction and then decreased with increasing fiber content. The maximum rise noted at the content of 0.4% fiber and a factor of increase of cohesion and angle of internal friction being 4.1 and 1.78 respectively as compared to parent soil.
3. With inclusion Carbon fiber, the UCS value of soil increased up to 0.4% fiber percentage, and then decreased. So, the maximum UCS value was found at 0.4% Carbon fiber content and the value was found with increment of 1.25 factors in comparison to unreinforced soil.
4. Soaked and unsoaked CBR values increased till 0.4% of Carbon fiber addition in different proportions to soil. In comparison to unreinforced soil, the both soaked and unsoaked CBR value of 0.4% of reinforced soil was raised to optimum. The value of both soaked and unsoaked CBR was improved by the factor 1.56 and 1.52 respectively.

On the basis of the result obtained, it is recommended that carbon fiber can be utilized as reinforced material and it has significant impact on ground improvement techniques. In line with our study, this technique can be considered as a viable and extremely practical option to bring about a revolutionary change in construction by enhancing the mechanical characteristics of soil of civil projects.

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