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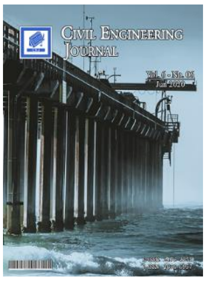

Influence of Jute Fibre on CBR Value of Expansive Soil

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Abstract

Construction of structures on expansive soil is highly risky due to its susceptible behavior towards differential settlements. Different soil stabilization techniques including soil reinforcement have been adopted to improve the properties of the unsuitable soils. In this present study, randomly distributed jute fibres have been used to improve geotechnical properties of expansive soil collected from South Delhi (India). California Bearing Ratio (CBR) tests were carried out on the expansive soil blended with jute fibres. Jute fibres of length 10 mm and 30 mm were included in different percentages viz. 0.25, 0.50, 0.75, 1.00, 1.25 and 1.50 by the dry weight of the soil. The test results indicate that the inclusion of randomly distributed jute fibres significantly improves the CBR value of the soil. The Optimum value of fibre content is found to be 1.25%. An improvement of 226.92% in CBR value of the reinforced soil as compared to unreinforced soil has been observed at the optimum jute fibre content. Since Jute is agricultural waste, the present study provides a cost-effective solution to problematic clayey soils.

Keywords: Random Inclusion; Jute Fibre; California Bearing Ratio; Expansive Soil; CBR Value.

1. Introduction

Infrastructure development like buildings, roads, bridges etc. on expansive soil is a challenging job for Civil engineers due to its swelling and shrinking nature in wet and dry conditions respectively. Nearly 20% of total area in India is covered by black cotton soils. Due to the changes in moisture content, these types of soils exhibit much variation in swelling, compressibility; shear strength and results in failure of structures. Therefore, certain properties of these types of soils require improvement. Among different proven techniques chemical stabilization using lime or cement is one of the technique to improve soil properties [1-3] but soil reinforcement is reliable and effective technique to improve properties of fine grained soils. The established methods of soil reinforcement include metallic strips, bars, geogrids, geotextile or fibres. The reinforced soil obtained using ideally inextensible inclusions like metallic strips or bars is known as reinforced earth [4] whereas that obtained using ideally extensible inclusions like geogrids, geotextile or fibres is known as ply-soil [5].

The stress deformation behavior is different in these two types of reinforced soils. The reinforcement using metallic strips, geogrid or Geotextiles increases tensile strength of soil in one particular direction. Despite the fact that the role of tensile stresses may be considerable but there may be possibility to develop planes of weakness at soil-reinforcement interface. Random mixing of fibres with soil is also considered as more effective soil reinforcement technique [6-8] and is quite similar to that of admixture stabilization. Fibres in this technique are simply added and

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mixed with the soil in the same way as other additives like fly ash, lime or cement. The use of randomly distributed fibres mimics the behavior of plant roots and has advantages: (1) These maintain strength isotropy and limit the possibility to develop weak planes along the direction of reinforcement. (2) Inclusion of these fibres changes only the physical properties of soil and has no adverse effect on the environment [9]. Fibre reinforced soils shows enhanced ductile behavior and little loss in post peak strength compared to unreinforced soils. Synthetic and metal fibres had been considered useful reinforcing materials due to their reproducibility and the uniform material properties. Use of natural fibres as reinforcement in soil is prevailing for quite a long time due to their low cost, strength, bulk availability and eco-friendly nature. Besides advantages natural fibres have certain drawbacks like reproducibility and biodegradability. The biodegradability of natural fibres can be controlled by chemically treating them with polymer compounds [10].

Initially the work on fibre reinforced soil dates back to 1970 when main attention was on the effects of the roots of fibrous plant on the shear strength of soil and the subsequent improvement in slope stability [11]. Through Direct shear experiments Gray and Ohashi [12] confirmed the improvement in shear strength and ductility, decrease in the post peak strength, loss of soil mass due to the addition of discrete fibres as a function of fibre type, fibre length, fibre content, fibre orientation, aspect ratio, and soil properties. Al-Refeai [13] conducted triaxial tests to investigate load deformation behavior of fine and medium sands reinforced with glass fibre or mesh element. Prabhakar and Sridhar [14] conducted a number of triaxial compression tests to conclude that improvement in strength of soil due to inclusion of fibres as a function of fibre weight fraction. Through triaxial compression tests Michalowski and Cermak [15] concluded that shear strength of soil reinforced with fibres increases with the increase in aspect ratio and fibre content. In constant aspect ratio the longer fibres contribute more than the shorter ones. Yetimoglu and Salbas [8] studied the effects of fibre content on shear strength of sand reinforced with randomly distributed discrete fibres and reported that the ultimate strength and the initial stiffness of the sand was not affected considerably by fiber content. Miller and Rifai [16] based upon the test results of both standard and modified compaction tests concluded that the fibre addition improved crack reduction and hydraulic conductivity of the compacted clay soil.

Yetimoglu et al. [17] performed laboratory CBR tests to investigate the effects of fibre content on bearing capacity, stiffness and ductility of fibre reinforced sand fill-soft clay system. Kumar et al. [18] performed unconfined compression tests to show that the there is significant improvement in the compressive strength of highly compressible clay. It has been reported that the strength increases with the increase in fibre content. Consoli et al. [6] conducted drained triaxial tests to study the influence of fibre reinforcement on uniform sand and reported that the failure envelope is independent of the stress path. Dutta and Sarda [19] carried out an experiment study to investigate the CBR behaviour of waste plastic strips reinforced with stone dust/fly ash overlaying saturated clay. Tang et al. [20] through scanned electron microscope test analysed interfacial mechanical interaction of fibre with soil particles and reported that inclusion of fibre as reinforcement benefit the mechanical properties as a function of cohesion and interfacial friction. Shivkumar Babu and Vasudevan [21] through triaxial tests have reported that random inclusion of coir fibre as reinforcing material in clay soil improved its stiffness and strength. This improved behaviour is attributed to the reinforcing effect of fibres. Shivkumar Babu et al. [22] discusses the mechanism of improvement in strength, shrinkage, swelling and compressibility behaviour of black cotton soil due to the inclusion of coir fibres through an experimental investigation using tri-axial swelling and compressibility tests. Park [23] carried out a number of unconfined compression tests to investigate the effect of fibres as reinforcement and its distribution on the strength of cemented sand reinforced with fibre and concluded that strength depends on the degree and distribution of fibre reinforcement as well as on the fibre content.

Diambra et al. [24] concluded that in triaxial compression the contribution of fibres to soil strength is significant while in triaxial tension it is limited. It was attributed to the preferred fibre orientation. Sadek et al. [25] performed direct shear tests to study the parameters which are known to affect the composite shear strength of fibre reinforced sands. Tang et al. [7] carried out a number of single fibre pull out tests to measure interfacial shear strength of fibre soil matrix and reported that with the increase in compaction; dry density, interfacial shear strength increases. Pradhan et al. [26] performed Direct Shear tests, Unconfined Compression tests and CBR tests to investigate the effect of random inclusion of polypropylene fibres on strength characteristics of cohesive soil.

Gumuser and Senol [27] carried out laboratory unconfined compression tests, compaction tests and Atterberg limit tests to investigate the effects of Multifilament and Fibrillated polypropylene fibre on the compaction and strength behavior of soft soils. Li and Zornberg [28] conducted Triaxial Compression tests and Fibre Pull-out tests to study the mobilization of fibre tension for varying shear strain levels. Sarbaz et al. [29] discusses the effect of inclusion of randomly spaced palm fibre in soil matrix by performing CBR tests under dry and submerged conditions. Li et al. [30] conducted direct tensile tests on soil reinforced with discrete fibre content. Parameters like fibre content, water content and dry density of soil were examined and concluded that tensile strength and tensile failure ductility of soil can be improved significantly with the fibre inclusion. Naval et al. [31] conducted a series of laboratory footing load tests on strip footing to investigate the effectiveness of waste tire fibres in granular soil.

Butt et al. [32] studied strength properties of clayey soil reinforced with human hair as a natural fibre by performing CBR and Tri-axial tests. Peter et al. [33] performed laboratory investigation through standard proctor test, Static Triaxial test and California Bearing Ratio (CBR) tests to study improvement of subgrade characteristics of expansive soil stabilized with coir waste. Wang et al. [34] performed direct shear and triaxial tests on expansive soil mixed with fibre and distributed at random to investigate the effect of jute fibre on the shear strength characteristics.

Karthikeyan et al. [35] conducted an experimental study to improve the characteristics and strength of weak clayey soil by adding bottom ash and coir fibres. Tanko et al. [36] evaluated the reinforcing effect of randomly oriented sisal fibre on the geotechnical properties of lateritic soil. Aside index test, Unconfined Compression test, California Bearing Ratio test and Durability tests were performed. Brahmachary and Rokonuzzaman [37] performed soaked and unsoaked CBR tests on normal and reinforced soil using bamboo fibre. Das and Singh [38] studied the geotechnical characteristics of a lateritic soil due to the inclusion of locally available brown waste materials and commercial synthetic fibre either individual or in combination. Wang et al. [39] performed laboratory California Bearing Ratio tests on fine grained soil reinforced with polypropylene fibres. The effect of random inclusion of polypropylene fibres in the London clay was evaluated.

Ramesh et al. [40] performed California Bearing Ratio and Unconfined Compression tests on silty sand reinforced with basalt fibres and plastic PET bottles in the form of geocells to enhance the properties of silty soil as sub grade. Abdullah et al. [41] conducted Unconfined Compression tests to investigate the effect of fibre type, fibre content and moisture condition on the shear strength of soft soil. Meena et al. [42] evaluated the engineering properties of Dhanauri clay reinforced with wheat straw fibres by performing Unconfined Compression tests and CBR tests. Garesh et al. [43] examined the behavior of fine-grained soils reinforced with granular rubber tires as a suitable replacement for reinforced concrete piles in old buildings. Munirwan et al. [44] conducted CBR tests for determining the effect of coir fibres to stabilize the clayey soil. Sani et al. [45] performed compaction tests and Unconfined Compression tests to estimate the effect of rice husk ash admixed with treated sisal fibre on properties of lateritic soil as a road construction material. In this study, a number of California bearing ratio (CBR) tests were performed on expansive soil reinforced with randomly distributed jute fibres and. The effect of fibre length, fibre content and various percentages of fibres of different length mixed together were studied on CBR value of expansive soil.

In this study, black cotton soil from South Delhi (India) was collected and unsoaked and soaked CBR tests were carried out in unreinforced and reinforced conditions by mixing jute fibres in different lengths to improve the properties of black cotton soil. Since Jute is an agricultural waste, the present study provides a cost effective solution to problematic clayey soils. Out of all natural fibres, jute has high elastic modulus and tensile strength. It has the capacity to withstand the rotting and heat as well [34]. Since jute is an agriculture waste, natural materials and products are, therefore, a cost effective solution for construction industry.

2. Materials and Method

2.1. Materials

2.1.1. Soil

Expansive soil procured in this experimental program was naturally occurring black cotton soil from South Delhi (India) having 96% particle fraction finer than 75 microns and 64.5% that of 2 microns. Different soil properties are listed in Table 1. Soil is classified as highly plastic clay and designated as CH according to the Bureau of Indian Standard (BIS) Classification. The particle size distribution curve is shown in Figure 2. Based on activity of soil, it is concluded that the soil is a normally active and contains illite clay minerals.

The methodology adopted in this research programme is shown in Figure 1.

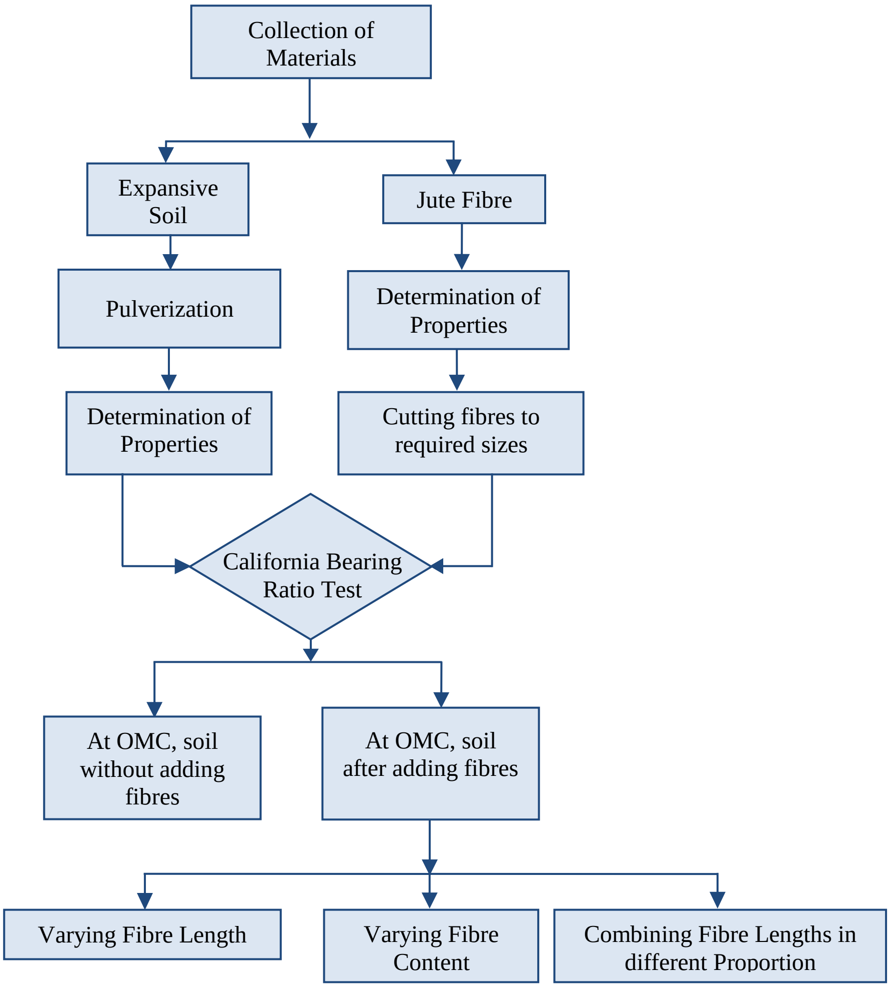

Figure 1. Flowchart showing Methodology Adopted

2.1.2. Fiber

Jute is one of the most multifunctional and commercial natural fibre, therefore, it is also known as the gold fibre. Among all the natural fibres available jute has the highest tensile strength. Different properties of jute fibre are listed in Table 2. Researcher in the past reported that CBR value of soil increases considerably when reinforced with jute fibre, thus causing reduction in the pavement thickness. Subsequently a significant saving in the overall construction cost of the project. Figure 3 shows the image of jute fibre used in this experimental program.

Table 1. Properties of soil

S.No.	Parameter	Value
1.	Specific Gravity	2.33
2.	% Finer than 4.75 mm, %	100.00
3.	% Finer than 75µ, %	94.00
4.	% Finer than 2µ, %	64.50
5.	Liquid Limit, %	87.27
6.	Plastic Limit, %	38.60
7.	Plasticity Index, %	48.67
8.	Free Swelling Index, %	72.50
9.	Activity	0.76
10	Maximum Dry Density, kN/m^3	14.85
11.	Optimum Moisture Content, %	22.50
12.	CBR, % Unsoaked	6.28
	Soaked	1.82
13.	Unconfined Compressive Strength, kN/m^2	66.54
14.	Cohession, kN/m^2 (uu Test)	33.27

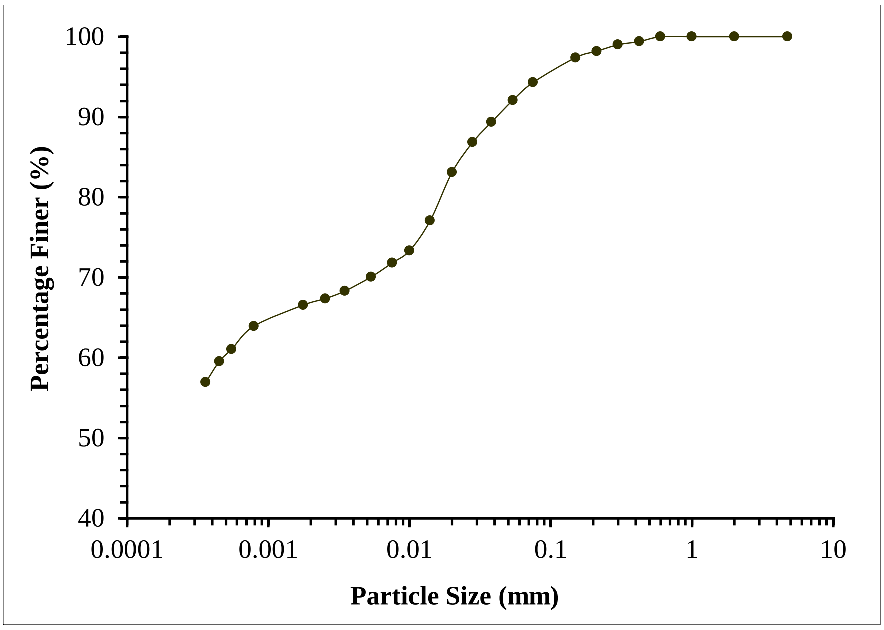

Figure 2. Particle Size Distribution Curve

2.2. Preparation of Sample

The soil procured for this study was dried, pulverized and passed through 75 micron IS sieve. Long jute fibre bunch were cut in the required lengths of 10 mm and 30 mm to have an aspect ratio of 33.33 and 100 respectively. The tests were conducted at fibre content (p) = 0.25, 0.50, 0.75, 1.0, 1.25, and 1.50%. Fibre content (p) is expressed as the ratio of the weight of fibres (W_f) to the weight of dry soil (W_s), mathematically:

$$p = \frac{Wf}{Ws} \times 100 \quad (1)$$

Table 2. Properties of Jute Fibre

S.No.	Parameter	Value
1.	Diameter, micron	300
2.	Color	Brown
3.	Specific Area, mm^2	70.65
4.	Density, kN/m^3	14.00
5.	Tensile Strength, MPa	518.0
6.	Young Modulus, GPa	26.40
7.	Elongation, %	1.60
8.	Water Absorption, %	32.00

Note: All tests on fibres as detailed above were performed at Shree Ram Laboratories, Noida (U. P.)

Figure 3. Jute Fibre cut to required size

Since the soil mass contains pores of different forms namely microspores, macrospores, large pores, star pores according to the shape, size and orientation of the pores. Therefore, fibres of different lengths are mixed in the soil to improve the properties of the subgrade. For each fibre contents (p), the fibres of length 10 mm and 30 mm were mixed in the mix proportion p_1:p_2 as given in Table 3. Where p_1 is the mix proportion for fibre of length 10 mm and p_2 is the mix proportion for fibre length 30 mm in particular fibre content (p).

To prepare unreinforced soil sample required quantity of water for OMC is added in 4.5 kg of dry soil and mixed manually in an impermeable tray to prevent loss of moisture. For fibre reinforced samples density and water content were kept same to that of the unreinforced one. Reinforced soil samples were prepared by mixing pulverized soil, fibre and water in required quantities manually by hand. During mixing soil was first moistened by adding a small quantity of the required water to prevent floating and segregation of fibres. Fibres were then added randomly and mixed with the moistened soil in small increments along with the remaining quantity of water until all the fibres were effectively distributed into the soil. To obtain fairly a homogeneous mix; fibres added were mixed thoroughly. Visual examination of exhumed fibre reinforced soil sample indicated that the mixture to be reasonably homogeneous for the fibre contents selected in the study. However, mixing of fibres created difficulty with increasing fibre content. The soil specimen thus prepared was kept for 24 hours under covers for maturing before compacting it into the CBR mould.

Table 3. Mix Proportions of Fibre

Fibre Content (p)	Mix Proportion		Fibres Weight (gms)	
	p_1 (%)	p_2 (%)	10 mm	30 mm
0.25%	0	100	0	11.25
	25	75	2.81	8.44
	50	50	5.63	5.63
	75	25	8.44	2.81
	100	0	11.25	0
0.50%	0	100	0	22.5
	25	75	5.62	16.88
	50	50	11.25	11.25
	75	25	16.88	5.62
	100	0	22.5	0
0.75%	0	100	0	33.75
	25	75	8.44	25.31
	50	50	16.88	16.88
	75	25	25.31	8.44
	100	0	33.75	0
1.00%	0	100	0	45
	25	75	11.25	33.75
	50	50	22.5	22.5
	75	25	33.75	11.25
	100	0	45	0
1.25%	0	100	0	56.25
	25	75	14.06	42.19
	50	50	28.13	28.13
	75	25	42.19	14.06
	100	0	56.25	0
1.50%	0	100	0	67.5
	25	75	16.88	50.62
	50	50	33.75	33.75
	75	25	50.62	16.88
	100	0	67.5	0

2.3. Test Procedure

A series of CBR tests were performed on unreinforced and randomly distributed fibre reinforced soil for this experimental study. The tests were conducted in unsoaked and soaked state in accordance with IS 2720 (Part XVI). The mould used was a rigid metallic cylindrical in shape having inside diameter as 152 mm and height 178 mm. The matured soil specimen was filled in the mould in three layers having equal thickness. Each layer was compacted by giving 56 well distributed blows of a 26 N rammer dropped from a height of 310 mm. An electrically operated loading machine having a movable base which travels at a constant rate of 1.25 mm/minute to force a 50 mm diameter piston to penetration in to the soil specimen. The loads were carefully recorded as a function of penetration up to a total penetration of 12.5 mm on a pre-calibrated proving ring. CBR test setup is shown in Figure 4.

Figure 4. CBR test setup

Due to the small size of CBR test apparatus used in this experimental study causes some problems. The small size of test apparatus restricts the inclusion of fibre content. Test method need modification in the gradation of materials used when the materials with greatest particle size larger than 19 mm are to be tested. Such modification in materials may have considerable effect on strength properties over the original materials. In comparison to other large scale tests the end effect may be more significant in such a small size sample. Regardless of these disadvantages of CBR test apparatus a significant experience has been developed and a few standard design methods are in use depending upon the results of this test.

3. Results and Discussion

Figures 5 and 6 shows the behavior of load penetration curves in unsoaked condition drawn based on the data obtained from the series of CBR tests conducted on unreinforced and reinforced soil with varying percentages of jute fibre, from 0.25% fibre content to 1.50% fibre content, having aspect ratio 100 and 33.33 respectively. These curves indicate that the inclusion of randomly distributed jute fibre improved load resisting capacity of the expansive soil significantly. Peak load is greater at higher penetrations of the plunger which shows that fibre reinforcement is more effective in resisting penetration and hence improving the strength of expansive soil. No significant change in initial stiffness of soil is observed and compared to unreinforced soil reinforced soil does not show any sign of failure since the load resisted continued to increase with the inclusion of fibres. This can be attributed to the fact that more frictional resistance is mobilized between the soil particles and the fibres at the surface of fibres, thereby, developing higher tensile stress in the fibres added. Further it appears that the failure of fibres is mainly through the fibre pull-out rather than the fibre breakage. From these figures it is also observed that load resisting capacity of soil is greater when mixed with fibres having aspect ratio 100 compared to that of 33.33. The possible reason for this may be attributed to the fact that in case of fibres of large aspect ratio the resisting area offered is greater than for lesser aspect ratio fibres.

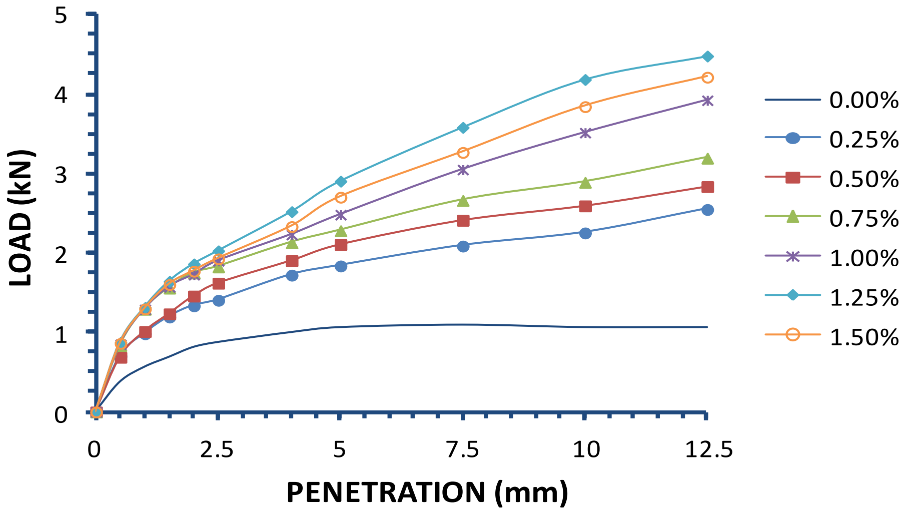

Figure 5. Load penetration curve in unsoaked condition for soil blended with fibres of aspect ratio 100 corresponding to different fibre content

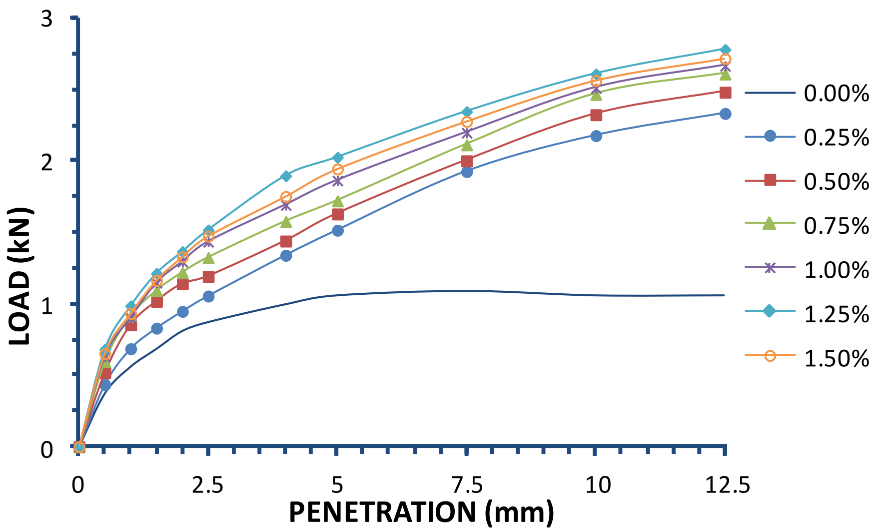

Figure 6. Load penetration curve in unsoaked condition for soil blended with fibres of aspect ratio 33.33 corresponding to different fibre content

Figures 7 and 8 show the behavior of load penetration curves in soaked condition drawn based on the data obtained from the series of CBR tests conducted on unreinforced and reinforced soil with varying percentages of jute fibre, from 0.25% fibre content to 1.50% fibre content, having aspect ratio 100 and 33.33 respectively. Similar to unsoaked specimen these curves revealed that the addition of jute fibres improved the load resisting ability of the expansive soil but not as noticeable as was observed with the unsoaked specimen. In case of soaked condition the initial stiffness is less than that of the unsoaked condition. Soaking the soil specimen has an important influence on its behavior. Because of the interaction of water with the fine soil particles soaking decrease the strength of soil. With soaking there is loss of capillarity which reduces effective stresses and subsequently the soil bearing capacity. Further soaking of soil specimen lubricates the surface of soil particles as well as that of the fibres resulting in the reduction in frictional resistance between fibre and soil particles which reduces pull-out ability of fibres. Since failure of the unsoaked specimen is mainly due to pull-out rather than the breakage as explained earlier, therefore, loss of frictional resistance is the main cause of reduction in load resisting capacity of soaked specimen.

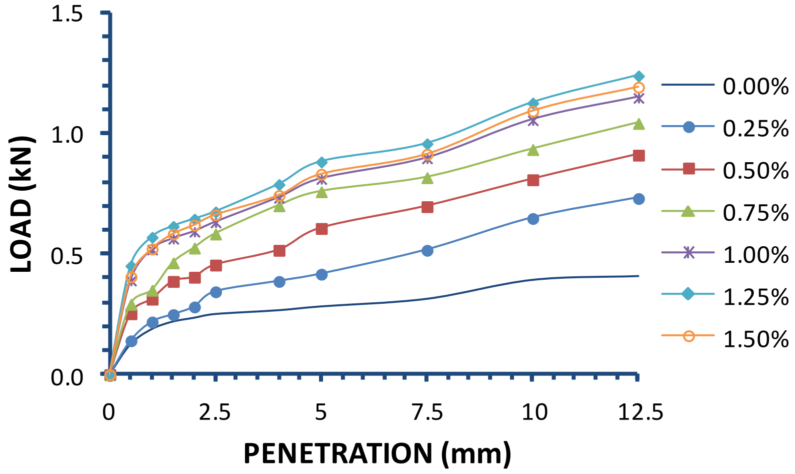

Figure 7. Load penetration curve in soaked condition for soil blended with fibres of aspect ratio 100 corresponding to different fibre content

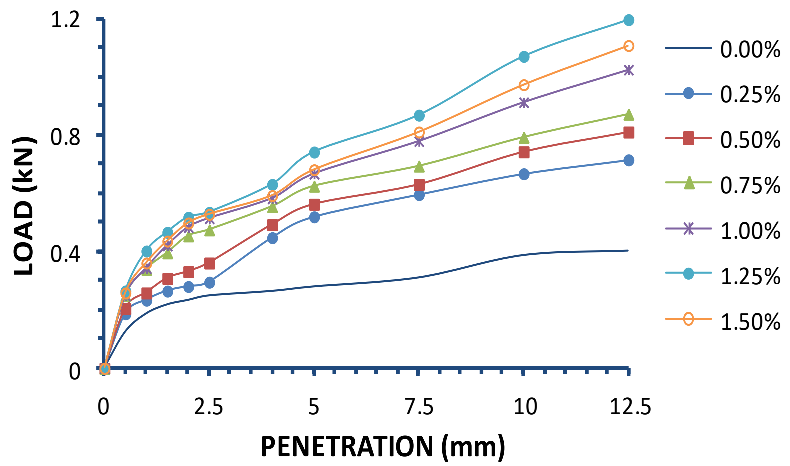

Figure 8. Load penetration curve in soaked condition for soil blended with fibres of aspect ratio 33.33 corresponding to different fibre content

From the above discussion it is concluded that for all the cases of soaked samples, the load penetration behavior of soil fibre matrix is similar to that of the unsoaked one and differs only in terms of load resisting capacity and the initial stiffness. Both the load resisting capacity and the initial stiffness are less in case of soaked samples than for unsoaked samples. Since IRC 37 (Indian Road Congress "Guidelines for the Design of Flexible Pavements") recommends that to design a flexible pavement, CBR of the subgrade should be determined at the most critical moisture conditions likely to occur at site and pavement thickness should be based on 4-day soaked CBR value of the soil [46]. Therefore, in the rest of the paper only soaked cases will be discussed.

3.1. Effect of Fibre Content

Variation of CBR value with respect to fibre content in soaked condition is shown in Figure 9. This plot indicates that by adding fibres in expansive soil, its CBR value improves which increases with the increase in fibre content. It is observed that peak load increases with the increase in fibre contents up to 1.25% fibre content thereafter it decreased. This improvement in CBR value is due to the more efficient load transfer taking place at the soil fibre interface as a result of improved interfacial adhesion between the surface of soil particle and that of the fibre [37, 38]. Increase in fibre content results in more number of fibres to resist soil movement which enhances the load carrying capacity of soil. Decrease in CBR value after 1.25% fibre content is attributed to the fact that beyond this fibre content the fibre to fibre interaction increases and soil to fibre interaction reduces since more number of fibres replaces soil particles. Insufficient quantity of soil is available to develop an effective bond with fibres and mixing of fibres with soil becomes difficult at higher fibre content, [26]. Therefore, 1.25% fibre content is regarded as optimum fibre content.

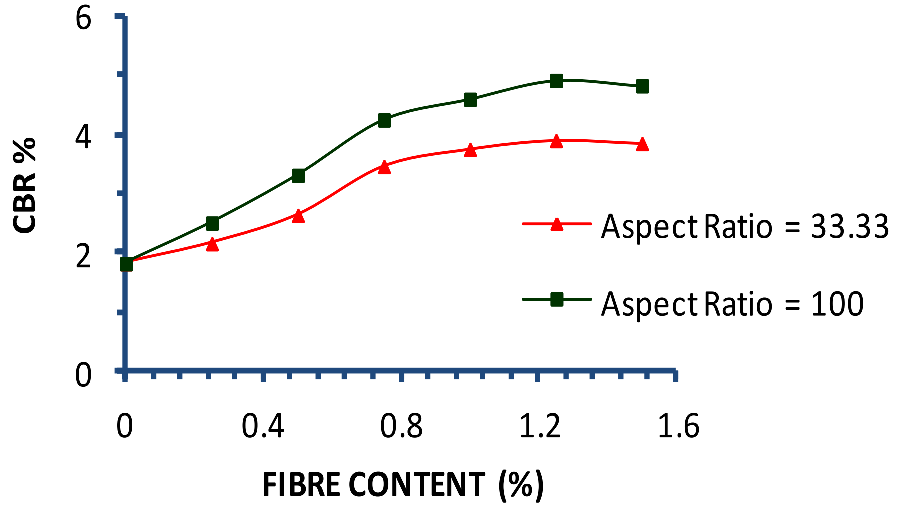

Figure 9. Variation of CBR value with fibre content at different fibre aspect ratios in unsoaked condition

3.2. Effect of Fibre Length

To study the effect of fibre length on CBR values of expansive soil, relationship between fibre length and CBR values are plotted and shown in Figure 10 in soaked condition. From this plot, it is observed that with the increase in fibre length CBR value of the expansive soil increases. This plot also revealed that the peak load resisted by the soil is greater with longer fibres compared to the short fibres. Therefore, it is concluded that by increasing fibre length CBR value of the soil improves significantly. This improvement in CBR value may be attributed to increased interaction taking place amongst soil particles and the fibres since this interaction is a function of the surface area of fibre in contact [22]. With the increase in the fibre length the surface area of fibre increases thereby increasing more frictional resistance due to which more tensile stresses in fibre mobilizes. The increased frictional resistance in case of long fibres is the main factor for increase in the CBR value of reinforced soil. For fibres with smaller length because of their small surface area these have insufficient fictional resistance, therefore, have lesser pull-out resistance [13, 21]. Hence the fibres with smaller length have lesser improvement in CBR value than the longer ones.

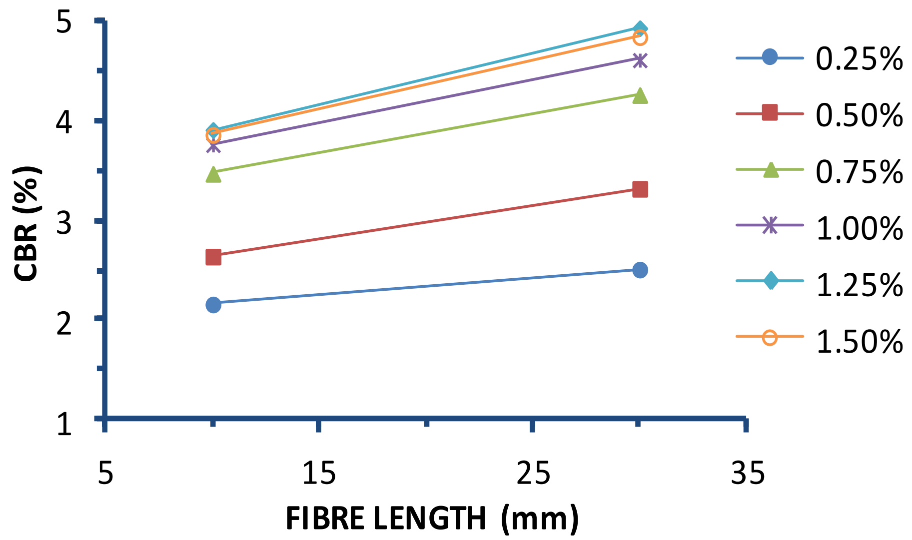

Figure 10. Effect of fibre length on CBR value in soaked condition

3.3. Effect of Combining Different Fibre Lengths

Figures 11 to 13 gives an idea about the variation of load penetration curves in soaked condition obtained from the soil mixed with fibres at different mixing ratios of length 10 and 30 mm. These curves show that in all cases the peak load resisted is greater for 1.25% fibre content corresponding to each level of penetration. Further addition in the fibre content results in decrease in the load resisting ability of soil fibre composite.

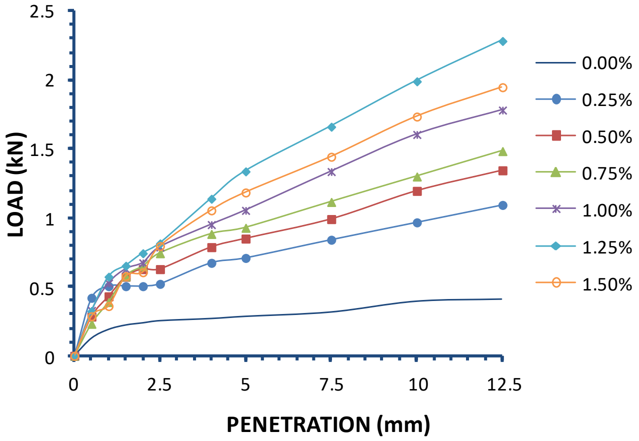

Figure 11. Load penetration curve in soaked condition for soil blended with fibres of length 10 mm (25%) and 30 mm (75%) corresponding to various fibre content

Percentage improvement in CBR value is calculated using Equation 2.

$$\text{Percentage improvement in CBR value} = \frac{(CBR_R - CBR_{UR})}{CBR_{UR}} \times 100 \quad (2)$$

Where CBR_R represents the CBR value for fibre reinforced soil and CBR_{UR} represent CBR value for unreinforced soil.

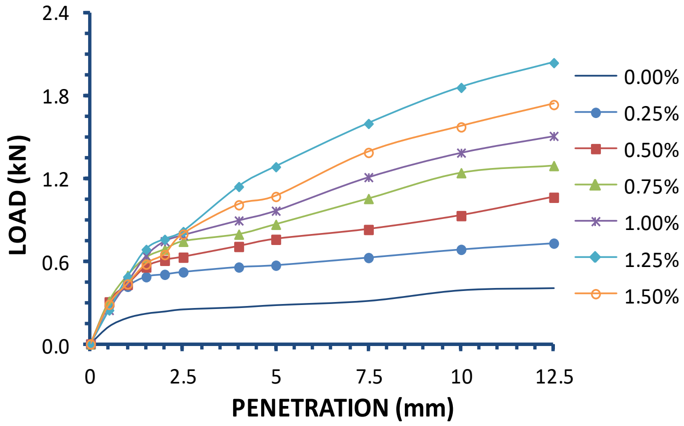

Figure 12. Load penetration curve in soaked condition for soil blended with fibres of length 10 mm (50%) and 30 mm (50%) corresponding to different fibre content

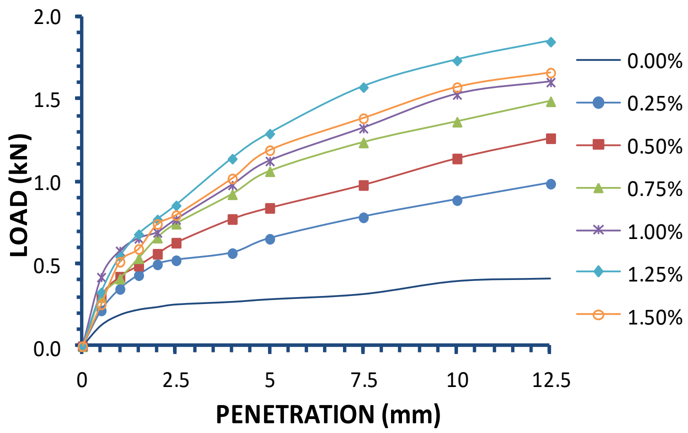

Figure 13. Load penetration curve in soaked condition for soil blended with fibres of length 10 mm (75%) and 30 mm (25%) corresponding to different fibre content

Table 4 shows percentage improvement in CBR values for fibre reinforced soil over the unreinforced soil in soaked condition. This variation of percentage improvement in CBR values is depicted in Figure 14. From this figure it is concluded that the percentage increase in CBR value is greatest for fibre percentage 1.25% and for soil blended with fibres in mixed proportions. p_1 = 25% and p_2 = 75% is maximum. For other mix proportions the percentage improvement in CBR values is lower. This improvement in CBR value is attributed to the increased interaction between the fibres and the soil particles that result in improved frictional resistance due to combining of different lengths of fibres. For other mix proportions the content of short fibres increases which results in less mobilization of frictional resistance and hence reduction in CBR value.

Table 4. Percentage improvement in CBR Values

Fibre %	p_1 = 0% + p_2 = 100%	p_1 = 25% + p_2 = 75%	p_1 = 50% + p_2 = 50%	p_1 = 75% + p_2 = 25%	p_1 = 100% + p_2 = 0%
0.00	1.00	1.00	1.00	1.00	1.00
0.25	37.91	109.34	87.91	35.71	18.68
0.50	82.42	152.20	118.13	65.93	45.05
0.75	134.07	198.35	164.29	115.38	90.66
1.00	153.30	216.48	185.16	135.71	106.59
1.25	170.88	226.92	192.31	139.56	114.84
1.50	165.93	219.23	187.36	129.67	112.09

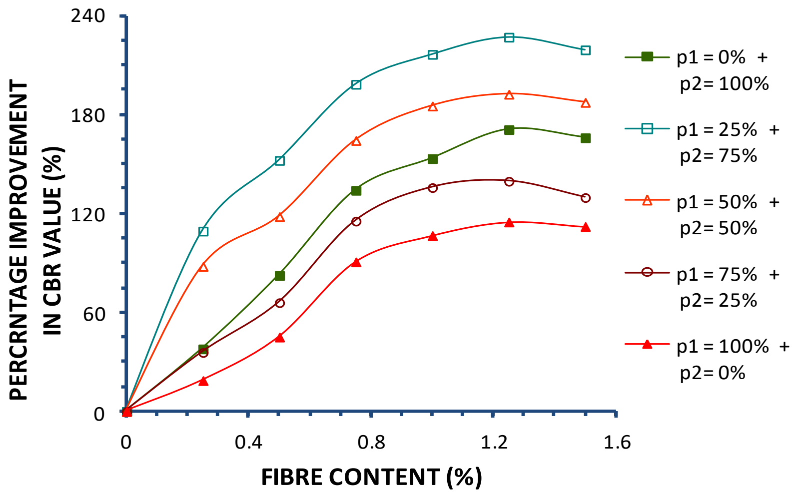

Figure 14. Variation of Percent Improvement in CBR Value with Fibre Content at different Mix Proportions of 10 mm and 30 mm fibre length

3.4. Statistical Analysis of Experimental Results

For exploring the relationship between dependent variable and independent variables, statistical analysis of the results obtained from the experimental programme was conducted. Multiple regression analysis was performed for this purpose using "xlstat" statistical software. Multiple regression analysis is a statistical method to know the correlation between two or more independent and the dependent variables. Based upon the experimental results, a multiple regression model (3), was developed at 95% confidence level that correlates the CBR value of expansive soil with various fibre contents of p_1 for 10 mm, p_2 for 30 mm fibre length, optimum moisture content (OMC) and maximum dry density (MDD) as under:

$$CBR\ (\%) = 1.4471 + 0.0574 \times OMC\ (\%) - 0.5538 \times MDD\ (gm/cc) + 0.0299 \times p_1 + 0.0488 \times p_2 \quad (3)$$

From the regression model (3), value of the term R^2, known as coefficient of determination and an index of reliability, is worked out. A higher value of R^2 close to unity is desirable for strong relationship between the dependent variable and independent variables. Value of R^2 calculated for the above regression equation is 0.91. This indicates that nearly 91% of the variability of the dependent variable CBR (%) is explained by the four independent variables. Therefore, the relationship shown by the above regression model can be considered as satisfactory. Relationship between observed CBR values and the predicted CBR values is shown in Figure 15.

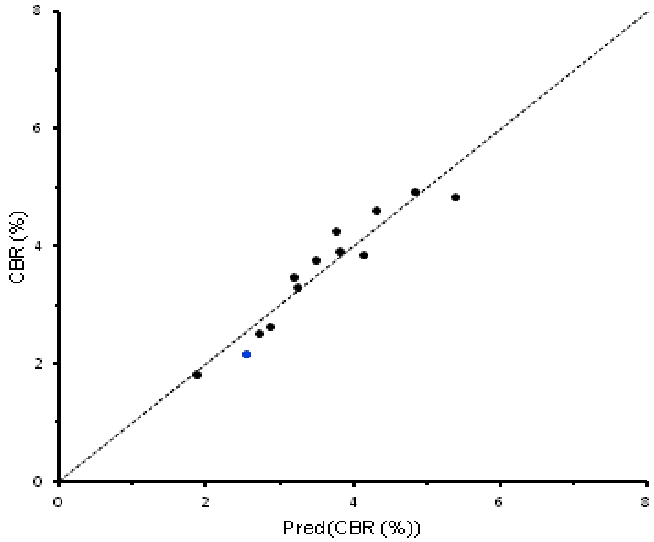

Figure 15. Predicted CBR vs. Observed CBR

4. Conclusions

On the basis of laboratory investigations on California Bearing Ratio tests conducted on expansive soil reinforced with randomly distributed jute fibres, following conclusions are drawn:

- CBR value of expansive soil improved significantly with the inclusion of randomly distributed jute fibres;
- Jute fibre inclusion at 1.25% fibre content is found to give maximum CBR value for reinforced soil afterwards it decreases with increasing fibre content;
- CBR value of soil obtained in unsoaked condition is greater than in the soaked condition;
- CBR value of soil is higher at 4.93% when reinforced with fibres of aspect ratio 100 compared to 3.91% for fibres of aspect ratio 33.33 in soaked condition;
- Percentage increase in CBR value obtained for soil reinforced with 30 mm and 10 mm long fibres is 170.88 and 114.84 respectively compared to the unreinforced soil;
- At optimum fibre content, when reinforced with mix proportion p_1 = 25 and p_2 = 75 compared to unreinforced soil CBR value further increases to 5.95 in soaked condition and 226.92% increase in CBR value was obtained;
- The results of the study indicate that at 1.25% optimum fibre content soil reinforced with mix proportion p_1 = 25 and p_2 = 75 gives maximum improvement.

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6. Conflicts of Interest

The authors declare no conflict of interest.

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