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California Bearing Ratio Variations in Soil Reinforced with Natural Fibres (A Case Study Bhopal Bypass Road)

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ABSTRACT: Application of natural fibres are increasing day by day in civil engineering construction works where very high strength of bonding material is not in demand. Natural fibres are cheap, locally available, biodegradable and eco-friendly. Natural fibres used in specified manner and in optimum quantity can causes significant improvement in tensile strength, shear strength, bearing capacity and other engineering properties of the soil. In the present work a comparative experimental study is made on locally available soil (of Bhopal district in M.P. of India) reinforced with Jute and Coir fiber. Five soil samples were prepared at its maximum dry density corresponding to its optimum moisture content. The Jute and Coir fibres were reinforced in different percentage in the soil samples. Both the soaked and Unsoaked CBR values are measured and compared for both the fibres. The improvement in CBR over an unreinforced sample is reported to justify the test. Tests result indicates that CBR value of soil increases with the increase in fiber content to some extent, and further addition of fibre results in decreased strength due to excess organic matter content. Study results can be used by the regulatory authorities (particularly engaged in rural road construction) to think over the adoption of natural fibre in the roads where subgrade CBR is poor and natural fibres are easily available.

Key Words: Subgrade, Rural Road, Natural, Jute, Coir, Bearing Capacity, Dry Density

I. INTRODUCTION

Soil has been used as a construction material for buildings, roads, irrigation structure etc. all over the world. Because of weakness in tensile and shear strength, soil needs to be improved according to the work requirement, which varies from site to site. The stabilization of soils has been performed since many past centuries to improve engineering properties of soil. The main method of stabilization includes mixing the soil with soil of higher strength or binding materials like limestone / cement / calcium or reinforcing with suitable element / fibre (McGrown, *et al*., 1978).

Reinforcement techniques of soil stabilization can broadly be divided as physical, mechanical and chemical methods. Mechanical stabilization can be achieved by compaction and reinforcement of fibrous materials in the form of either geo-synthetics or as randomly distributed fibre of synthetic or natural origin (Hejazi *et al*., 2012). During last few decades, much work has been done to improve the engineering properties of soil and it has been established that addition of fibre is an efficient way to enhance the overall engineering performance of soil. Fiber reinforced soil is effective in all types of soils (i.e. sand, silt and clay). The concept of reinforcing soil with natural fibers is ancient one. Soil reinforcement by inclusion of relatively low modulus natural fibres is in practice in many developing countries (Ola, 1989). Reinforcement in soil mass increases its strength, bearing capacity, stability and ductility; reduces settlement, and inhibits lateral deformations (Binici *et al*., 2005; Puppala and Musenda, 2000). Natural fibers are locally available, can make composites with cement / lime, cheaper, biodegradable and environmental friendly (Ghavami *et al*., 1999; Sayastano *et al*., 2000). There are many natural fibre e.g. Coconut (coir), Sisal, palm, Jute, rice husk, barley straw etc., are in use for soil stabilization. Among natural fibers Jute and Coir (coconut) are more popular and extensively used. Jute fibers are bark extract of jute plants abundantly found in coastal region of India and other tropical countries. The jute fibre is better than other natural fibre because of its better durability and capacity to withstand rotting and heat, porous texture (giving rise in drainage and filtration properties), wide diameter range (25-60 µm), specific gravity (is about 1.4 g/cm^3), higher elasticity (22 GPa) and more average ultimate tensile strength (about 500 MPa) (Swami, 1984; Web Resource 1, 2014 and Sen and Reddy, 2011). Coir is the fibrous waste separated from the outer covering of a coconut shell. It if found in large quantity in religious places like temples. Coir fibers are normally 50–350 mm long with diameter 10–20 µm and consist mainly of lignin, tannin, cellulose, pectin and other water soluble substances. The service life of coir is more (upto 10 years) than jute fibre because of its high lignin content. The water absorption of that is about 130–180% and diameter is about 0.1–0.6 mm (Rowell *et al*., 2000). Coir retains much of its tensile strength when wet and shows reduced swelling tendency of the soil (Subaida *et al*., 2009, Ravishankar and Raghavan, 2004). The coir fibre possesses specific gravity, elasticity, ultimate tensile strength and water absorption about 1.24 g/cm^3, 4.5 GPa, 250 MPa, and 150% respectively (Rowell *et al*., 2000).

It has low tenacity but the elongation is much higher (Babu and Vasudevan, 2008). Mainly, coir fiber shows better resilient response against synthetic fibers by higher coefficient of friction (Chouhan *et al*., 2008).

California bearing ratio (CBR) is an empirical test used mainly to measure the bearing capacity of soil as a subgrade material in the design of pavement. The method was developed by the California Highway Department in USA for design of suitable road materials, (Brown, 1996). In the Bhojpur area (along the bank of River Betwa) coir fibre is easily and freely available from the Bhojpur and nearby Temples. The soil of the Bhojpur and nearby region is composed of silt and clay fraction with high value of liquid limit and small value of CBR and hence exhibits swelling during the summer. In present study use of jute and coir are made to stabilize the local soil material which is supposed to improve the soil quality economically. The objective of present work is to study the most appropriate proportion of jute and coir (with a particular length and diameter) which will give maximum value of CBR at the optimum moisture content and maximum dry density. A comparison in terms of engineering properties and economical use of both the fibre is made for reasonable recommendations in civil engineering applications.

II LITERATURE REVIEW

In the last century systematic studied were started to use fibres as soil reinforcement and many researcher have reported about the behaviour of soil reinforced with randomly distributed natural fibers (Gray and Al Refeai, 1986; Mahar and Gray, 1990; Ranjan *et.al*, 1996; Charan, 1995; Michalowski and Cermak, 2003; Gosavi *et al*., 2004; Rao *et al*., 2006; Chanda *et al*., 2008; Singh, 2011; Fatani *et al*., 1999; Lawton *et. al*, 1993; etc.). Gray and Ohashi (1983) conducted a series of direct shear tests on dry sand reinforced with different synthetic, natural and metallic fiber to evaluate the effects of fiber orientation, fiber content, fiber area ratios, and fiber stiffness. Based on the test results they concluded that an increase in shear strength is directly proportional to the fiber area ratios.

McGown *et al*. (1978) studied effect of inclusion of jute fibre in the engineering properties and improved behavior of sand. Aziz and Ramaswamy (1984 and 1989) used Jute and Coir grid matting for road subgrade strengthening. Ola (1989) used jute fibre for stabilization of lateritic soils by extensible fiber reinforcement. Ramaswamy (1994) invented method for development of Natural Geotextiles using jute fibre and studied trends of the improved performance upon application on various projects. Talukdar *et al*. (1994) studied performance of jute fibre after treating with antimicrobial solution in the form of non-woven fabrics. Ghavami *et al*. (1999) studied behaviour of composite soil reinforced with natural fibers jute and coir.

In the 21th century application of jute fibre in civil construction work has attend pace especially for subgrade of flexible pavement. Savastano *et al*. (2000) used waste jute fibers as reinforcement for cement-based composites in construction work instead of concrete. Dhariwal (2003) carried out performance study on California bearing ratio (CBR) of fly ash reinforced with jute and non-oven fibers. Sanyal (2005) studied soil improvement by using jute fibre and applied Jute Geotextiles in Rural Roads. Chandra *et al*. (2008), studied CBR and shear values of Jute fibre for preparation of fibre reinforced flexible pavements. Saran (2010) gives brief discussion about the reinforced soil and its engineering applications. Islam and Iwashita, (2010) used jute reinforced material to construct earthquake resistance building for low income stack holders. Aggarwal and Sharma (2010), used bitumen coated jute with different fibre lengths and varying percentages to reinforce soil and found that jute fiber reduces the MDD with the increases the OMC. They obtained Maximum CBR value (2.5 times than plain soil CBR) with 10 mm long and 0.8% jute fiber. Islam and Ivashita (2010) showed that jute fibers are effective for improving the mortar strength as well as coherence between block and mortar. Singh (2012) studied improvement in CBR value of soil reinforced with jute and coir fiber in comparative manner and suggested dominance of jute fibre. Singh and Bagra (2013) studied the influence of different length and diameter of Jute fiber on the CBR value of Itanagar, A.P., India soil used in the construction of embankments and pavement subgrade and results were compared with that of unreinforced soil.

Pandey *et al.* (2013) studied soil stabilization using pozzolanic material and Jute fibre. Ayyar *et al.* and Viswanadham have reported about the efficacy of randomly distributed coir fibers in reducing the swelling tendency of the soil. Ravishankar and Raghavan (2004) confirmed that for coir-stabilized lateritic soils, the maximum dry density (MDD) of the soil decreases with addition of coir and the value of optimum moisture content (OMC) of the soil increases with an increase in percentage of coir. The compressive strength of the composite soil increases up to 1% of coir content and further increase in coir quantity results in the reduction of the values. The percentage of water absorption increases with an increase in the percentage of coir. Tensile strength of coir-reinforced soil (oven dry samples) increases with an increase in the percentage of coir (Chouhan *et al*., 2008; Ravishankar and Raghavan, 2004). Khedari *et al*. (2006) introduced a new type of soil–cement block reinforced with coir fibers with low thermal conductivity. Black cotton soil treated with 4% lime and reinforced with coir fiber shows ductility behavior before and after failure. An optimum fiber content of 1% (by weight) with aspect ratio of 20 for fiber was recommended for strengthening the BC soil [Ramesh *et al*., 2010]. Lekha (2004) and Vishnudas *et al*. (2006) have presented a few case studies of construction and performance monitoring of coir geotextile reinforced bunds and suggested that the use of coir is a cost effective ecohydrological measure compared to stone-pitching and other stabilization measures used in the protection of slopes and bunds in rural areas.

III. MATERIALS AND METHODS

A. Soil

The soil used in this study was collected from the bank of Betwa River near Bhojpur, Bhopal, Madhya Pradesh, India. The soil sample has been taken from ten (10) different site in the vicinity of Bhojpur area, about 200-500 m apart. The samples were then mixed altogether to make a composite and representative sample of the area. To determine the properties of soil sample, grain size analysis has been conducted. The other test conducted on composite sample includes the specific gravity, and atterberg Limit test (such as Plasticity Index, Plastic / Liquid and Shrinkage Limit) and compaction properties (maximum dry density and optimum moisture content) of soil. The grain size distribution curve of soil is shown in Fig.1.

B. Reinforcement

The reinforcing material used in this study is Natural Jute fiber of diameters 1 mm, and 2mm. The length of fiber corresponding to each diameter of fiber was taken as 20, 40 mm, 60 mm, 80 mm and 100 mm. A typical view of Jute fiber is shown in Fig. 2.

C. Test Procedure

The soil samples of unreinforced and reinforced soil for CBR test were prepared as per standard procedure laid down in IS:2720-XVI, (1974). The desired amount of oven dried (100-105°C) soil was taken and mixed thoroughly with water corresponding to its optimum moisture content (OMC) in the CBR mould for unreinforced CBR.

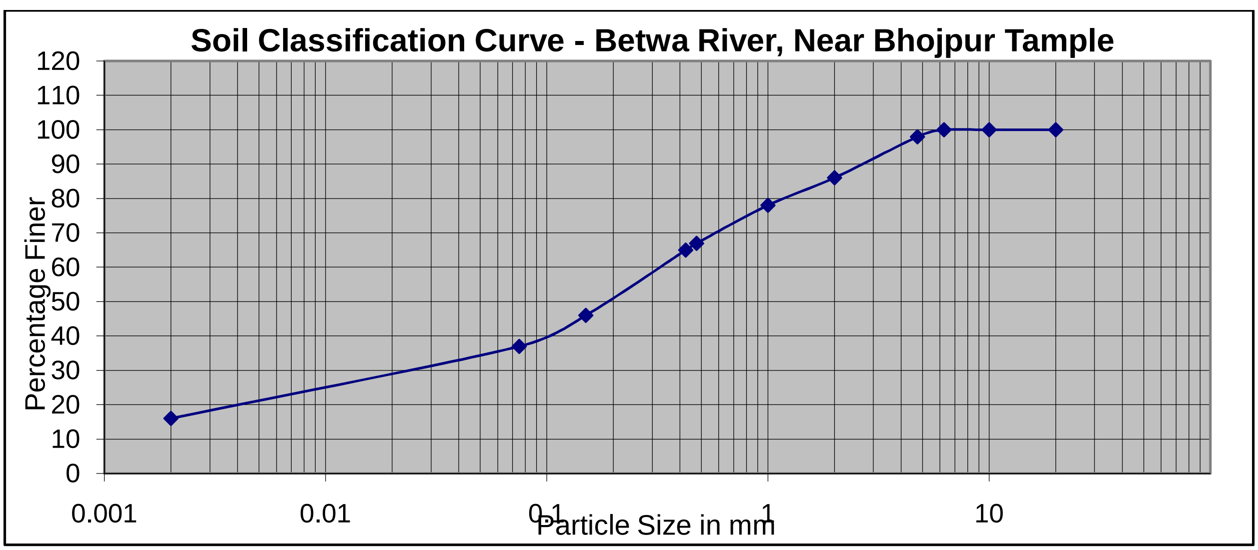


Fig. 1. Particle Size Distribution Curve of Soil.

The soil was then compacted to its maximum dry density obtained by laboratory standard Proctor test. For the preparation of soil samples of reinforced soil the desired amount of fiber was mixed in dry state before the addition of water and then compacted to same Proctor density. The top surface of the specimen in the CBR mould was made level and a filter paper and a perforated metallic disc were placed over the specimen. With spacer disc placed inside the mould, the effective height remains only 127.3 mm and the net capacity is 2250 cm^3. The CBR values of the test samples of unreinforced and reinforced soil were determined corresponding to plunger penetrations of 2.5 mm and 5 mm as per the standard procedure laid down.

Table 1: Index and Compaction Properties of Soil.

S.No.	Soil Properties	Values
1.	Specific Gravity (G)	2.58
2.	Liquid Limit, LL (%)	34
3.	Plastic Limit, PL (%)	22
4.	Particle Size Distribution Curve Gravel Size (> 4.75 mm) Sand Size (0.075- 4.75 mm) Silt Size (0.002-0.075 mm) Clay Size (<0.002 mm)	2 33 % 49 % 16 %
5.	Coefficient of uniformity (Cu)	8
6.	Coefficient of curvature (Cc)	1.53
7.	Maximum Dry Density (kN/m^3)	17.3
8.	Optimum Moisture Content, OMC (%)	16.45

Fig. 2. View of Jute and Coir Fiber (Natural Origin and Developed fibres).

IV. RESULTS AND DISCUSSIONS

The CBR values of soil and soil reinforced with different combinations of Jute and Coir fiber determined in the laboratory are plotted in figure 3. Two set of experiments have conducted using fibre diameter of 1 mm and 2 mm. The effect of fibre reinforcement is studied for two types of variation in fibre length and in fibre contents. The CBR values are worked out for each diameter size of jute and coir fibre for varying fibre lengths from 20, 40, 60, 80 and 100 mm. For each combination of fibre diameter and length, the fibre content is varied in fraction of 1% of dry weight of soil to 5% of dry weight of soil in increment of 1% fibre weight. The interpretation of tests result such as effects of fiber content, length of fiber and diameter of fiber on CBR value of soil have been discussed in the following sections.

A. Effect of Fiber Content

Results of CBR tests carried out at different fiber content varying from 0 % to 5 % by dry weight of soil in increment of 1% for each fibre length. It is clear from the tests results that the CBR value of soil increases as the fiber content increases. This aspect can be observed for all the fiber lengths and fiber diameters (1 mm and 2 mm). Results show that maximum increase in CBR value is nearly 1.85 and 1.97 times than CBR of unreinforced soil in case of 80 mm jute fibre length with 1 mm and 2 mm fibre diameter respectively in case of jute fibre and nearly 1.49 and 1.58 times than CBR of unreinforced soil in case of 100 mm coir fibre length with 1 and 2 mm diameter respectively in case of coir fibre.

Thus it is clear that increase in CBR is not proportional to the fibre length, however, the increase in fibre content to the extent included in our study (upto 5%) indicates an increasing trend in CBR value. This is due to reason that randomly oriented discrete inclusions incorporated into soil mass improves its load deformation behaviour by interacting with the soil particles mechanically through surface friction and also by interlocking. The function of bond or interlock is to transfer the stress from soil to the discrete inclusion by mobilizing the tensile strength of discrete inclusion. Thus, fibre reinforcement works as frictional and tension resistance element. The interfacial friction characteristics increase with increase in density or the fibre content of soil. This fact can be best interpreted with the fibre content variation is the difference in CBR values between Jute and Coir fibre, which is increasing with the increase in fibre contents. This difference is maximum in case of 2 mm fibre diameter and 40 mm fibre length for 4 to 5% fibre content. Also from the graphs of figure 3 it is clear that the variation in CBR is more in case of jute fibre than coir fibre since the strength of jute is more than coir.

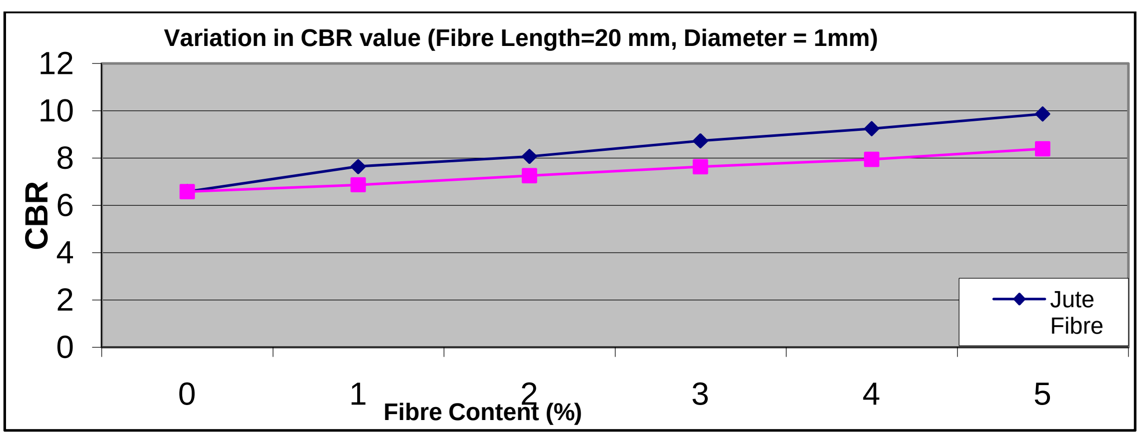
B. Effect of Length of Fiber

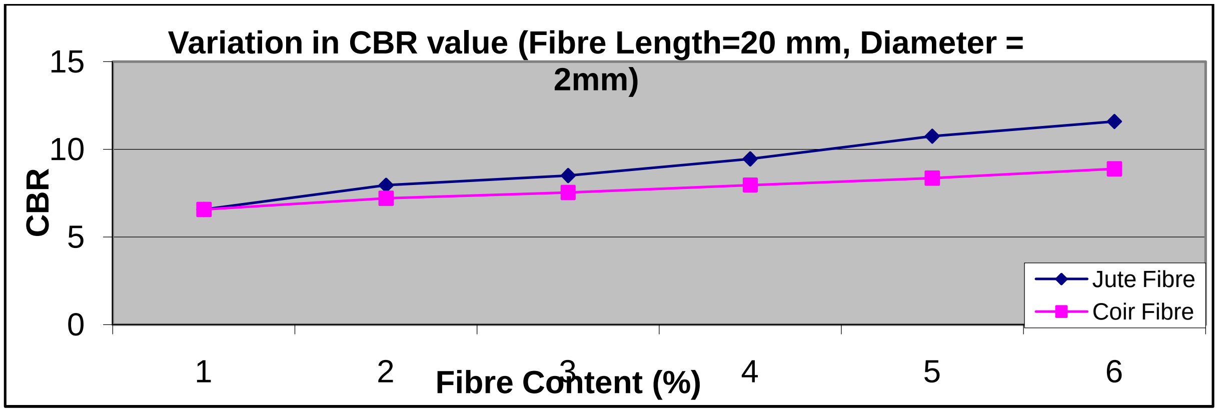
It is observed from graphs of figure 3 that the CBR value of soil reinforced with same fiber content and of same fiber diameter increases with the increase in length of fiber. For instance the CBR values of soil reinforced with fiber length of 20 mm, 40 mm etc. at 1 % fiber having diameter 1 mm are increasing respectively as fibre content increases. This aspect can be observed for all other fiber content and fiber diameter also. This is attributed to the fact that for shorter fibers, the area in contact with soil is comparatively less and hence there is a less improvement in strength and stiffness of soil. After particular lengths the fibre reinforces do not impart any strength in soil, in fact the more length of fibre remains unattached / untouched with soil particles and to some extent interfere with interlocking of particles. This fact is also clear from the graph of figure 4, which depicts that change in CBR is not a linear function of Fibre length and the difference in CBR values may be even decreasing beyond 60 mm length.

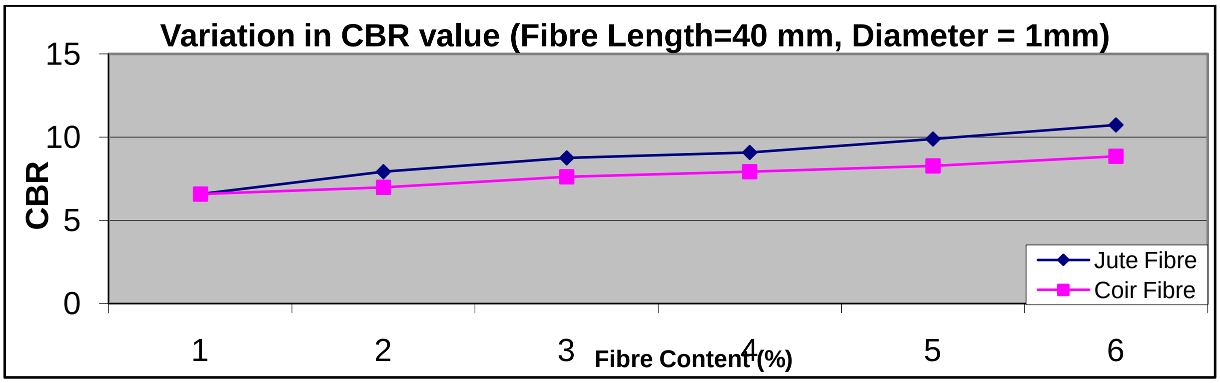
In case of jute fibre for a given length the difference in CBR values are generally decreasing when fibre content is 1-2% with minimum at 2% (except in case of 40 mm length where minimum is at 3%). A further increase in fibre content increases the CBR difference till 5% fibre content. In case of coir fibre for a given length the variation is appreciable when first time the fibres are mixed (1% content), then after for further increase in fibre content (2-3%) the variation are very little and random (mostly decreasing). The rate of CBR variation again increases when fibre content is increased in the range of 4 to 5%. In general the more diameter of fibre implies a too better CBR value which is increasing with the fibre content as well as fibre length too. In some case the violation of fibre diameter may be attributed to experimental error resulting due to improper mixing or sample preparation.

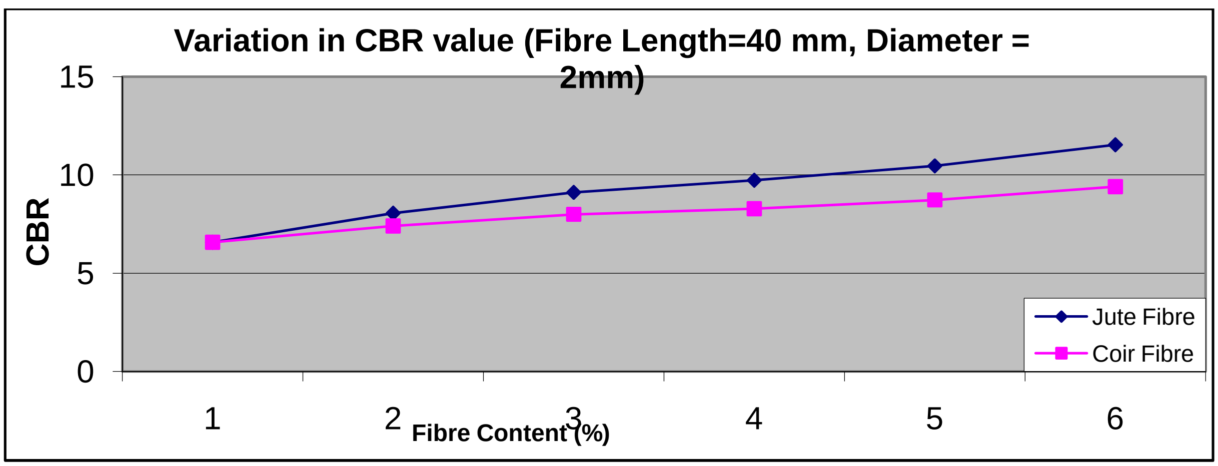
C. Effect of Fiber Diameter

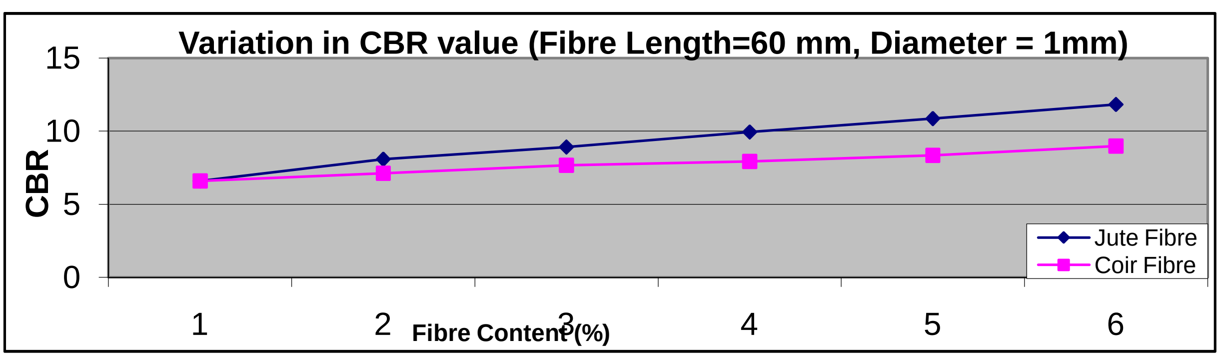
In this study two types of fibre diameter are used 1 mm and 2 mm. From the graphs of figure 3 and 4, it is clear that for every combination of fibre length and fibre content, the soil sample reinforced with 2 mm diameter fibre exhibits more CBR value. This is because of more strength imparted by the thick jute fibre both in shear and direct load sustaining capacity. Also more diameter of fibre provided more surface area (nearly four times) for developing adhesive bond between jute fibre and soil particles. This is attributed to the fact that due to increase in diameter of fiber increases the pull out resistance of fiber. In addition, large diameters fibers are capable of sharing more stresses induced in the soil specimens.

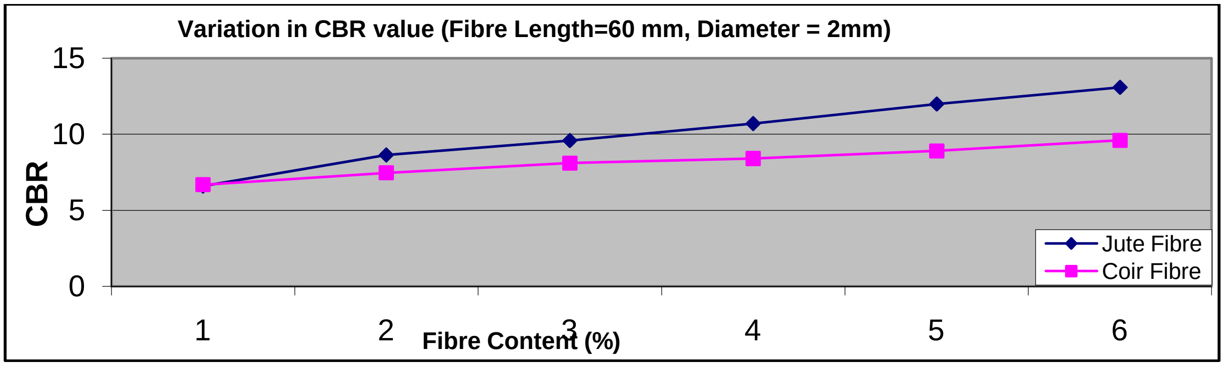


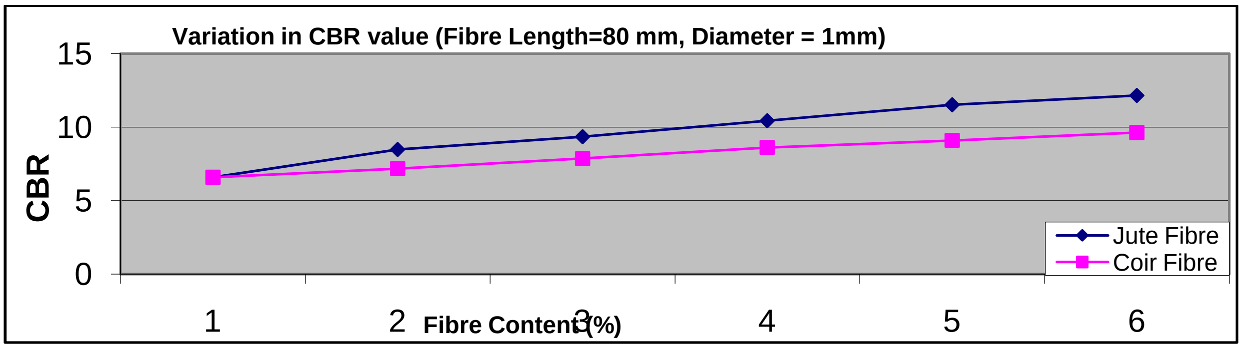

Variation in CBR value (Fibre Length=20 mm, Diameter = 2mm)
CBR
Fibre Content (%)
Jute Fibre
Coir Fibre

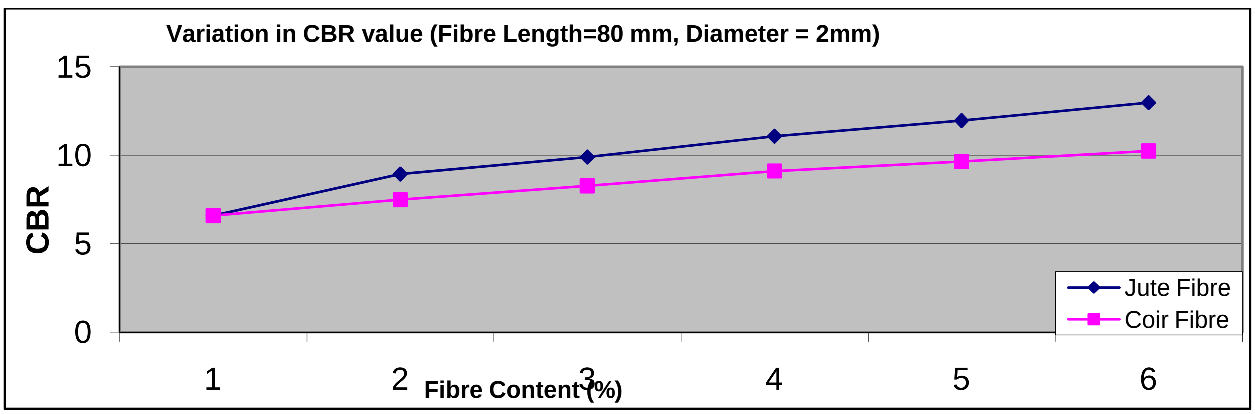

Variation in CBR value (Fibre Length=40 mm, Diameter = 1mm)
CBR
Fibre Content (%)
Jute Fibre
Coir Fibre

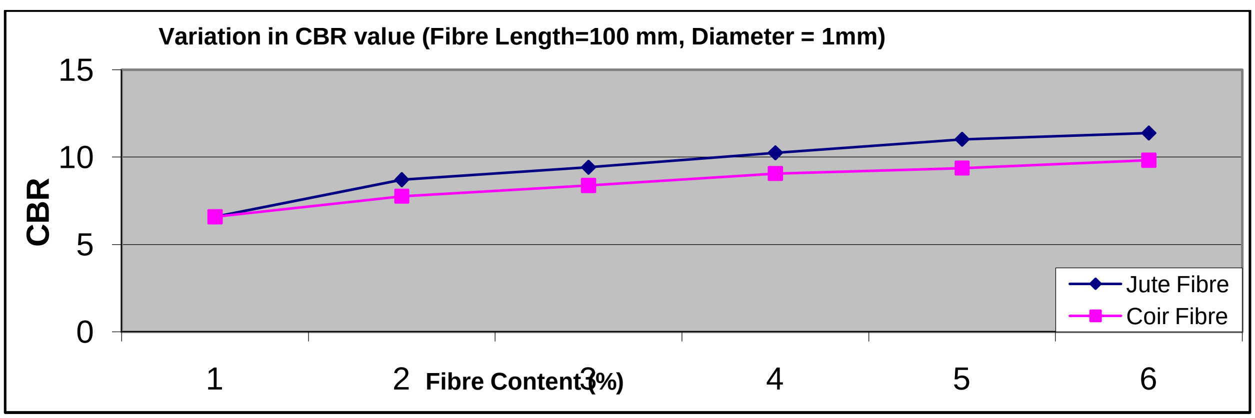

Variation in CBR value (Fibre Length=40 mm, Diameter = 2mm)
CBR
Fibre Content (%)
Jute Fibre
Coir Fibre


Variation in CBR value (Fibre Length=60 mm, Diameter = 1mm)
CBR
Fibre Content (%)
Jute Fibre
Coir Fibre


Variation in CBR value (Fibre Length=60 mm, Diameter = 2mm)
CBR
15
10
5
0
1
2
3
4
5
6
Fibre Content (%)
Jute Fibre
Coir Fibre


Variation in CBR value (Fibre Length=80 mm, Diameter = 1mm)
CBR
15
10
5
0
1
2
3
4
5
6
Fibre Content (%)
Jute Fibre
Coir Fibre


Variation in CBR value (Fibre Length=80 mm, Diameter = 2mm)
CBR
15
10
5
0
1
2
3
4
5
6
Fibre Content (%)
Jute Fibre
Coir Fibre


Variation in CBR value (Fibre Length=100 mm, Diameter = 1mm)
CBR
15
10
5
0
1
2
3
4
5
6
Fibre Content (%)
Jute Fibre
Coir Fibre

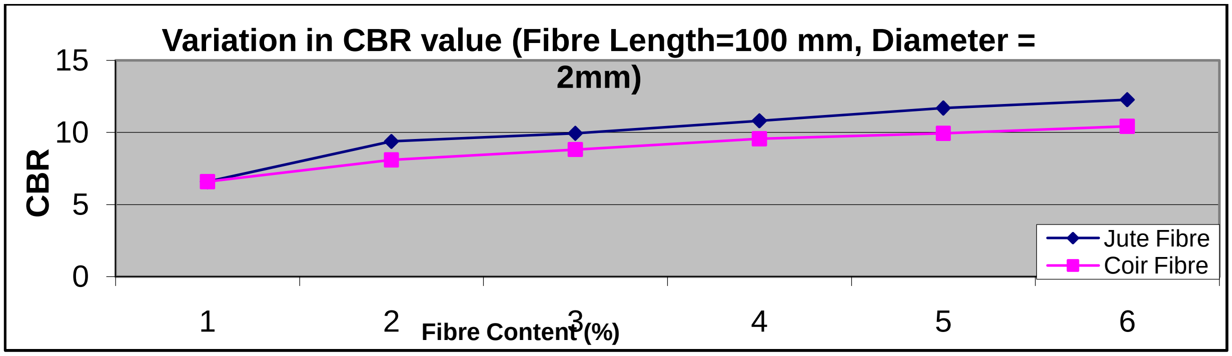
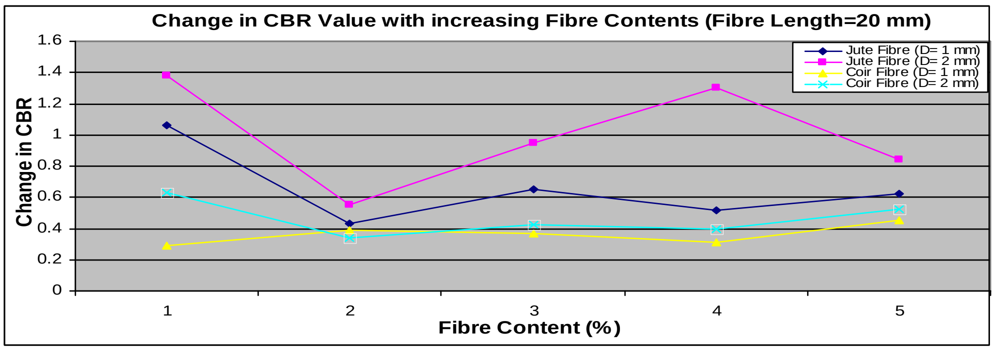
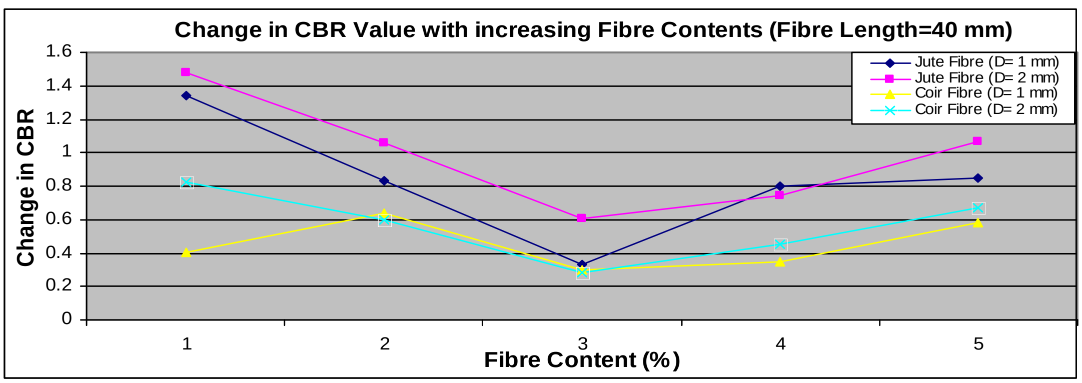
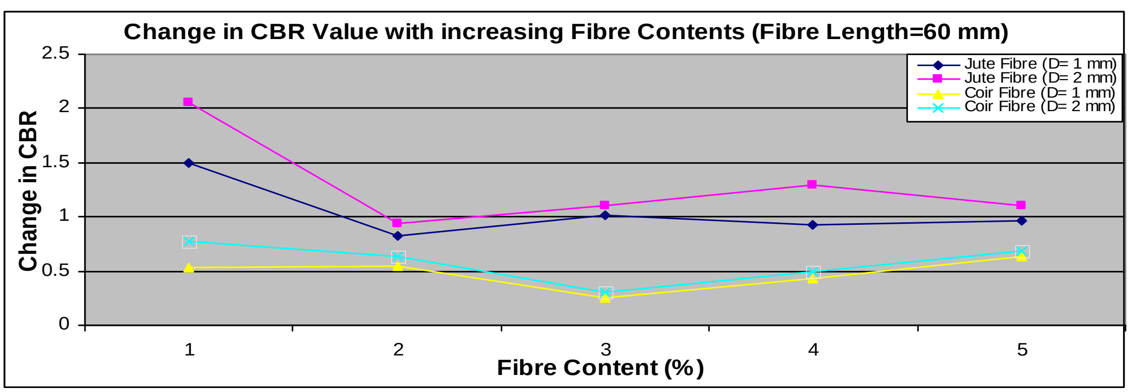


Fig. 3. Variation in CBR Values with reference to Fibre Length and Fibre Content.







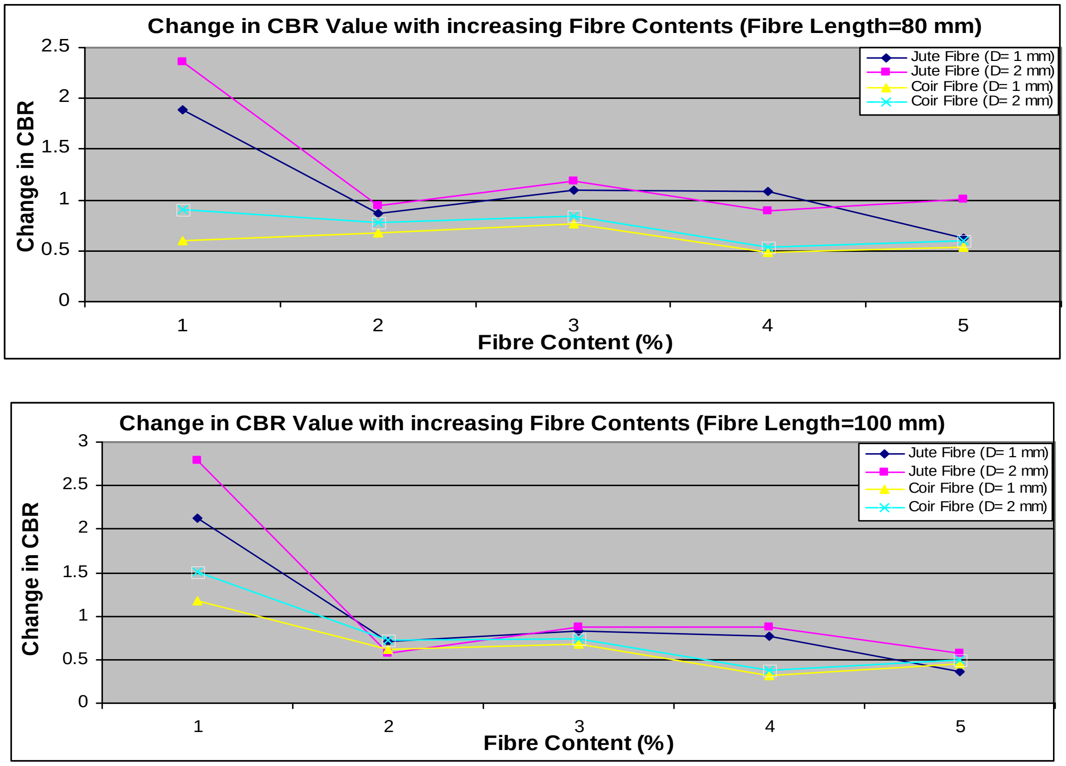


Fig. 4. Variation in CBR Values Keeping Fibre Length Constant and Fibre Content Varying.

V. CONCLUSIONS

Based on the present investigation it is concluded that CBR value of soil increases with the inclusion of both the Jute and Coir fiber. When the fiber content is increases, the CBR value of soil is further increases and this increase is substantial up to fiber content of 5%. It is found that preparation of identical soil samples for CBR test beyond 5 % of fiber content is not possible and optimum fiber content is expected to be between 4-5 % by dry weight of soil. The optimum length of fibre is somewhere between 60 to 80 mm. It is also concluded that there is significant effects of length and diameter of fiber on the CBR value of soil. The CBR value of soil increases with the increase in length and diameter of fiber. The test results indicated that the particle size, shape and gradation affect the interfacial shear at a given stress level and hence CBR also. Further, addition of jute and coir fiber makes the soil a composite material whose strength and stiffness is greater than that of unreinforced soil. Jute and Coir fibres are useful natural biodegradable eco friendly material, for the construction of unpaved roads and embankments in a beneficial manner since they are comparatively economical than polymeric substitutes.

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