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Investigation of random inclusion of bamboo fiber on ordinary soil and its effect CBR value

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Abstract

Stability of any structure depends on strength properties of underground soil on which it is constructed. Structures basically transfer all the loads comes on itself directly to the ground. If the underlying soil is not stable enough to support transferred loads then various types of failure occur such as settlement of the structure, cracks and so on. To solve this issue, soil improvement is necessary because it not only lowers the construction cost but also cuts the risk of any damage of structure later on. Numerous improvement methods can be adopted to make ordinary soil stable enough to support the structural loads. In this research work a number of tests were conducted using both ordinary soil and fiber reinforced soil. Soil samples for unsoaked and soaked CBR tests were prepared at its maximum dry density analogous to its optimum moisture content in the CBR mould with and without fiber. The reinforcing agent used in this study are natural bamboo fibers having diameter of 3 and 6 mm and length of 10 and 20 mm respectively. The proportion of bamboo fiber by waterless weight of normal soil was used as 0.20, 0.40, 0.60, 0.80, 1.00, 1.20 and 1.40%. Bamboo fiber is natural fiber, acts as a strengthening material for ordinary soil. It binds the soil particles together and helps in reduction of rapid change in volumetric properties. Addition of fiber improves the ductility behavior and increases the CBR value of ordinary soil. It was observed from the test results that unsoaked and soaked CBR value of soil increases with the increase in length and diameter of bamboo fiber. It was also found that increasing the percentage of bamboo fiber increases the CBR value of reinforced soil, and this increment is significant at fiber dosage of 1.2%. This significant increase of CBR value will diminish the thickness of pavement.

Keywords: Subgrade, Unsoaked CBR, Soaked CBR, Unconfined compressive strength, Maximum dry density, Bamboo fiber, Fiber content, Fiber length, Fiber diameter

Introduction

Soil may be defined upper layer of the earth containing of air, water and hard elements is normally formed by fragmentation of rocks. Soil is one of the most significant and primary media for any kinds of construction work all over the world. The soil that lies under ground level and spreads to such distance as may influence the support of the pavement is called subgrade soil. The subgrade should be susceptible to support loads dispatched from the pavement structure. The strength of a soil to be used as a subgrade in pavement is evaluated from its CBR value. If the CBR value of soil is poor, the thickness of pavement will be high, which will result in high cost of construction and vice versa. Subgrade soil improvement has always been momentous aspect in transportation and geotechnical engineering fields to improve its load bearing capacity. Soil improvement is of main concern in the construction works due to fast growth of urbanization and industrialization.

Khulna is the third biggest metropolitan and second port city in Bangladesh, which is situated at the southwestern part of the country, bounded by the latitude from 22°58′0″ north and longitude 89°28′0″ to 89°37′0″ east [1]. The sub-soil of this region consists of fine grained soils with a considerable part of decomposed and semi-decomposed organic matter [2]. The alluvial deposits from different rivers form the soil in this region and it was once a side of the mangrove forest Sunderban, so the soil of this area is typically soft and organic with small bearing capacity [3]. High water content, high compressibility and low workability of these soils often caused problems in the civil engineering construction projects [4]. Due to the presence of organic soil layer, the Civil Engineering constructions in such sites need special consideration to overcome the possible adversative consequences. It is an immense challenge to the Geotechnical Engineers in designing economic foundations to construct the necessary infrastructures [5]. Because of poorness in mechanical properties and strength, soil necessities to be upgraded according to the requirement which differs from place to place [6].

Soil improvement in its broadest sense is the alteration of any property of a soil to improve its engineering performance. This may be either an impermanent manner to allow the construction of a facility or may be an enduring investigate to improve the performance of the completed facility. The outcome of an investigation of a method may be improved strength, decreased compressibility, lowered permeability, or developed ground water condition. Soil reinforcement is in the system of a poor soil reinforced by high strength slim horizontal substances. A large variety of materials such as rubber, aluminum, thermoplastics, randomly distributed natural fiber and synthetic fiber have been used successfully.

Discrete fiber reinforcement is a newly established method to improve soil mechanical behavior [7–9]. Fibers for strengthening may be derived from paper, metal, nylon, polyester and other materials having broadly varied physical properties [10–12] but mostly using synthetic fibers and polymers; which are not biodegradable, hence posture a serious disposal problem at their life. The idea of strengthening soil with natural fibers is antique one. Soil reinforcement by addition of relatively low modulus natural fibers is in practice in many developing countries [13]. There are many natural fiber, e.g. cotton, coconut (coir), sisal, palm, jute, barley straw, bamboo and so on are in use for soil improvement. Natural fibers are locally available, can create composites with cement/lime, inexpensive, biodegradable and environmental friendly [14, 15]. Reinforcement in soil mass increases its strength, bearing capacity, stability and ductility; reduces settlement, and inhibits lateral deformations [16, 17].

Ghavami et al. investigated performance of composite soil strengthened with strengthening agent natural fibers jute and coir [14]. Karthika et al. used coir geotextile for soil stabilization and observed that soil reinforced with coir geotextile can improve strength characteristics as well as increase CBR value of soil almost 140%

and rut depth about 17% [18]. Peter et al. used different proportions of coir pith (0–3%) and coir fiber (0–1%) for subgrade improvement and found that the CBR value increases up to 192% for 2% coir pith and 335% for 0.6% short coir fiber but combined treatment increases the CBR 4.6 times more than general soil [19]. Sujatha et al. used coir fiber to improve the geotechnical performance of normal soil and observed that the soil stiffness and UCS value increase maximum for 0.75% of coir fiber [20]. Jagan, conducted a case study on a critical analysis on applications of natural jute fibers and observed that the CBR test value of normal soil was increased after inclusion of jute fiber in soil [21]. Butt et al. used human hair fiber for subgrade improvement and found a decrement in CBR value for inclusion of 0.5% human hair fiber but after increasing the fiber content percentage CBR value increases up to 2% of fiber [22]. Kumar et al. used coir and jute as natural fiber to improve California Bearing Ratio (CBR) value of Bhopal Bypass Road and found that CBR value increases with increase in fiber length, diameter and fiber content up to 5% [23]. Bairagi et al. studied the impact of jute fibers on engineering characteristics of black cotton soil and presented outcome that CBR and UCS values of soil were improved considerably when mixed with jute fiber from 0 to 5% [24]. Singh et al. used jute fiber and investigated that CBR value increases up to 6.07% for 2-layer reinforced soil with jute fiber but when the jute layer reinforcement was increased to 4-layers CBR value increase up to 11.85% [25]. Maurya et al. made a review on soil stabilization by coir fiber having different proportion and different lengths and observed a significant effect on soil properties [26]. Hamid et al. used jute fiber as a reinforcing agent for subgrade soil stabilization and observed that CBR value increase more than 200% that of normal soil sample at fiber content of 0.75% for fiber having diameter 2 mm and length 90 mm [27]. Abhijith investigated effect of natural coir fiber on CBR strength of subgrade soil and found that best result for 1.5 cm fiber length at 5% fiber content [28]. Singh et al. used coconut coir fiber to improve local subgrade soil for road construction and observed that 1.0% of fiber content increase the soaked and unsoaked CBR value up to 94 and 55% respectively that of ordinary soil [29].

In the current investigation, an attempt is made to study how bamboo fibers may be efficiently utilized in combination with organic soil of Khulna region to improve its performance which can be used in various Subgrades and Embankments. The number of soaked and unsoaked CBR value tests have been carried out on ordinary soil and soil mixed with different quantity of bamboo fiber (0.20, 0.40, 0.60, 0.8, 1.0, 1.20, 1.4%). The effects of different lengths (10 and 20 mm) and diameters (3 and 6 mm) of bamboo fiber on unsoaked and soaked CBR value of strengthened soil have also been observed and outcomes were likened with that of normal soil.

Materials and methods

Soil

The soft organic soil having organic content of 32.8% was collected from nearby side of Heat Engine Lab, KUET, Khulna, Bangladesh whose latitude is 22°54.008′N and longitude is 89°30.074′E. Soil samples were collected about seven feet below from the

Fig. 1 View of bamboo fiber (native origin and advanced fiber)

Table 1 Physical properties of bamboo fiber [30, 31, 33]

Serial number	Bamboo fiber properties	Values
1.	Density	0.6–1.1
2.	Young's modulus (GPa)	11–17
3.	Tensile strength (MPa)	140–230
4.	Elongation (%)	16
5.	Uniformity index (%)	92.7
6.	Moisture (%)	6.5

existing ground surface. The collected soil was taken to the geotechnical engineering laboratory by a large polythene bag and dried in air for about 7 days.

Bamboo fiber

Bamboo, a perennial grass, is one of the rapid thriving grasses, which belongs to family of poaceae/graminae. Bamboo fiber is a regenerated cellulosic fiber produced from bamboo. It is a common fact that bamboo can grow naturally without using any pesticide. The root rhizomes of bamboo are tremendous soil binders which can prevent erosion [30]. Bamboo fiber is s a satisfactory fiber for incorporation into the cement matrix [31, 32]. Bamboo fiber is a higher degree of water retainer and also rich in micronutrients. Repeated technological analysis has proved that this kind of fiber has a thinness degree and whiteness degree close to normal finely bleached viscose and has a strong durability, stability and tenacity. Physical properties of bamboo fiber are given in Table 1. A typical view of Jute fiber is shown in Fig. 1.

Experimental work

The collected samples were brought to the laboratory and spraded it over the floor to get air dry soil samples. After drying the soil was broken and grinding by using wooden hammer as fine as possible without applying unnecessary force. The soil powder was passed through #40 standard sieves. Air dry soil powder free from foreign materials.

Various index properties of soil such as moisture content, specific gravity, G_S, liquid limit, W_L, plastic limit, W_P, shrinkage limit, W_S, plasticity index, I_P, Shrinkage ratio, SR, grain size distribution, pH were determined. The index properties of the organic soil were determined according to ASTM D2976-15 [34]. Typical soil properties are given in Table 2. Standard Proctor compaction tests were carried out to determine the optimum

Table 2 Typical soil properties

Serial numbers	Name of the experiment	Experimental results
1.	Specific gravity	$G_S = 2.43$
2.	Water content, W (%)	W (%) = 86..38
3.	Atterberg's limit test	
	Liquid limit, W_L (%)	W_L (%) = 79.98
	Plastic limit, W_P (%)	W_P (%) = 58.87
	Shrinkage limit, W_S (%)	W_S (%) = 26.96
	Plasticity index, I_P (%)	I_P (%) = 21.11
	Shrinkage ratio, SR	SR = 1.19
4.	Sieve analysis	Percentage of gravel = 2%
		Percentage of sand = 43.0%
		Percentage of silt and clay = 55.0%
5.	Sedimentation analysis	Percentage of silt = 40.5%
		Percentage of clay = 14.5%
6.	Organic content (%)	34.76
7.	pH	6.42
8.	Classification USCS AASHTO	OH

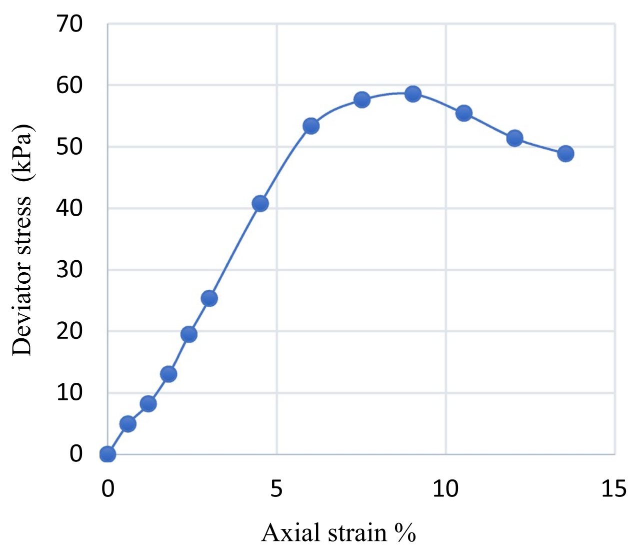

Fig. 2 Unconfined compressive test graph

moisture content (OMC) and maximum dry density (MDD) of soil sample according to ASTM D698-12e2 [35]. Dry density versus water content graphs is shown in Fig. 2. From the dry density and moisture content relationship, optimum moisture content (OMC) and maximum dry density (MDD) were determined. Cylindrical samples having a diameter of 38 mm and height of 76 mm, used in the unconfined compressive strength (UCS) test, were prepared at their corresponding optimum moisture content and maximum dry density by static compaction. The unconfined compressive strength of the soil samples was assessed according to ASTM D5102-09 [36]. The unconfined compressive

Table 3 Experimental results of mechanical properties for unreinforced soil sample

Serial numbers	Name of the experiment	Experimental results
1.	Unconfined compression test	UCS = 58.52 kPa
2.	Compaction test	Maximum dry density (MDD) = 21.15 kN/m^3
		Optimum moisture content (OMC) = 15.90%

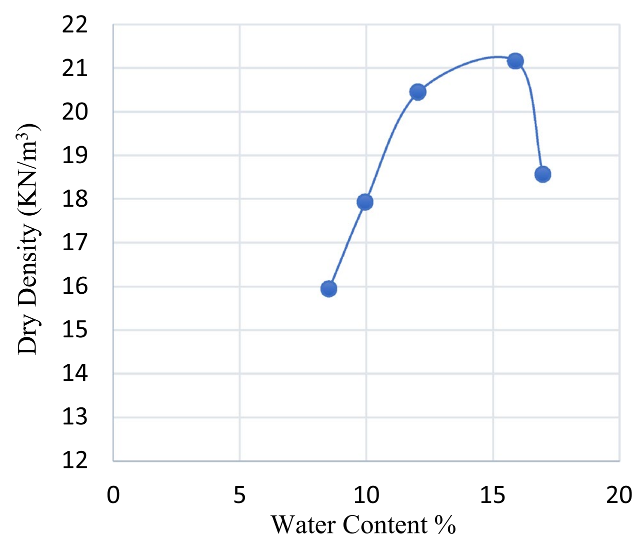

Fig. 3 Compaction test graph

strengths (UCS) values of specimens were determined from deviator stress versus axial strain curves (Fig. 3). Experimental results of Mechanical properties for unreinforced soil sample is given in Table 3.

CBR test value for unsoaked and soaked environments were ascertained for normal soil (0% bamboo fiber) and reinforced soil for different proportions of bamboo fiber (Fig. 4a) such as 0.20, 0.4, 0.60, 0.80, 1.00, 1.20 and 1.40% by waterless weight of ordinary soil. To determine CBR value first of all empty mold was taken (Fig. 4b) and weighted. After that sample was taken in CBR mould having 150 mm diameter and 175 mm high with removable perforated base plate. Then the soil was compacted with 5 layers by 56 blows (Fig. 4c) according to ASTM D 1557 [37]. After that the top surface of the specimen in the CBR mould was made level and (Fig. 4d) a filter paper and a perforated metallic disc were positioned over the specimen. With spacer disc settled inside the CBR mould, the effective length leftovers only 127.3 mm and the net volume is 2237 cm^3. A surcharge load of 4.5 kg was placed on the surface of the compacted specimens.

Two types of tests were run, unsoaked and soaked. For soaked CBR test, CBR mould was transferred to a tank containing water for soaking of the sample (Fig. 4e). After 96 h (i.e. 4 days) of soaking, all the CBR mould was taken out from water and the top surface of sample was left uncovered to air for half an hour. CBR mould along with soaked soil sample and unsoaked soil sample were transported to a motorized loading frame for testing (Fig. 4f). A strain rate of 1.20 mm/min was used for all the tests, and all the

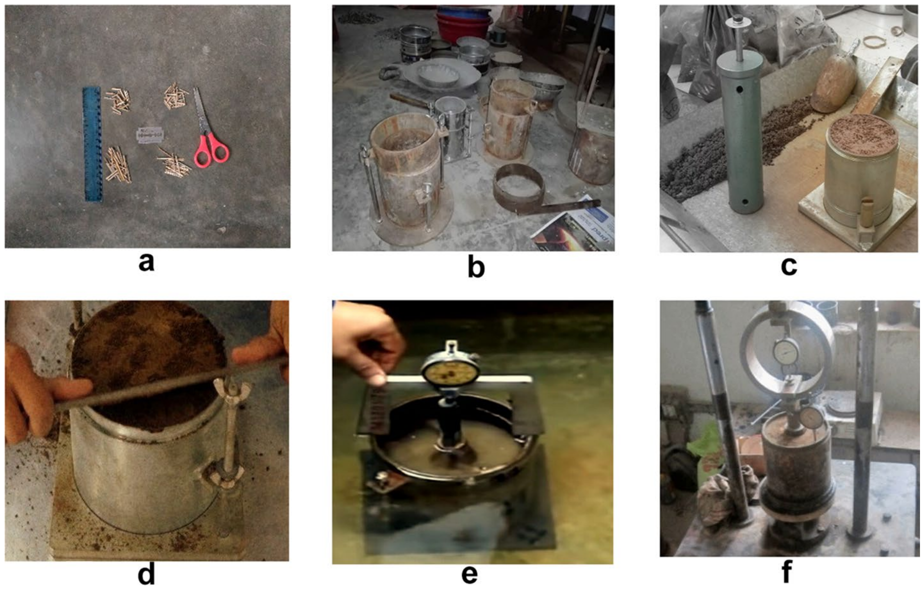

Fig. 4 **a** Reinforcement. **b** Test apparatus. **c** Compaction in 5 layers. **d** Top surface leveling. **e** Soaked condition. **f** Loading frame

Table 4 CBR value for (L = 10 mm, D = 3 mm and L = 10 mm, D = 6 mm)

Fiber length (mm)	Fiber content	Fiber diameter 3 mm				Fiber diameter 6 mm			
		Unsocked CBR value (%)	% increase in CBR value	Socked CBR Value (%)	% increase in CBR value	Unsocked CBR value (%)	% increase in CBR value	Socked CBR value (%)	% increase in CBR value
10	0	6.13	–	3.01	–	6.13	–	3.01	–
10	0.2	9.42	53.67	3.74	24.25	9.72	58.56	3.97	31.89
10	0.4	11.64	89.89	4.12	36.88	12.09	97.22	4.47	48.50
10	0.6	13.87	126.26	4.90	62.79	14.32	133.61	5.18	72.09
10	0.8	14.69	139.64	5.59	85.71	15.49	152.69	5.69	89.04
10	1.0	15.76	157.10	6.26	107.97	16.56	170.14	6.73	123.58
10	1.2	16.71	172.59	6.98	131.89	17.37	183.36	7.33	143.52
10	1.4	16.10	162.64	6.52	116.61	16.95	176.50	6.85	127.57

Table 5 CBR value for (L = 20 mm, D = 3 mm and L = 20 mm, D = 6 mm)

Fiber length (mm)	Fiber content	Fiber diameter 3 mm				Fiber diameter 6 mm			
		Unsocked CBR value (%)	% increase in CBR Value	Soocked CBR value (%)	% increase in CBR value	Unsocked CBR value (%)	% increase in CBR value	Soocked CBR value (%)	% increase in CBR value
20	0	6.13	–	3.01	–	6.13	–	3.01	–
20	0.2	9.98	62.80	3.99	32.56	10.79	76.01	4.87	61.79
20	0.4	11.92	94.45	4.68	55.84	12.81	108.97	5.65	87.70
20	0.6	14.62	138.50	5.57	85.05	15.31	149.76	5.96	98.01
20	0.8	16.33	166.39	6.48	115.28	17.09	178.79	6.88	128.57
20	1.0	16.98	176.99	7.21	139.53	18.52	202.12	7.95	164.12
20	1.2	17.97	193.14	7.86	161.13	19.43	216.97	8.92	196.35
20	1.4	17.48	185.15	7.42	146.51	18.59	203.26	8.33	176.74

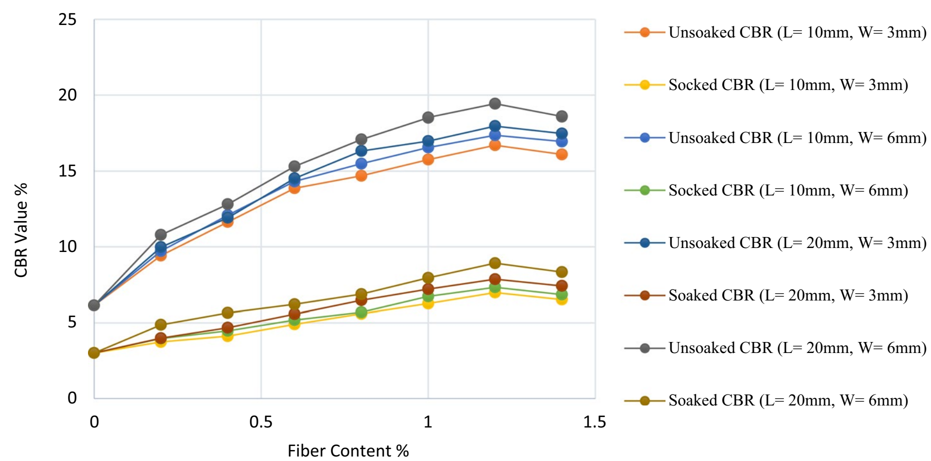

Fig. 5 Variation of CBR value for bamboo fiber at different (content, length and diameter)

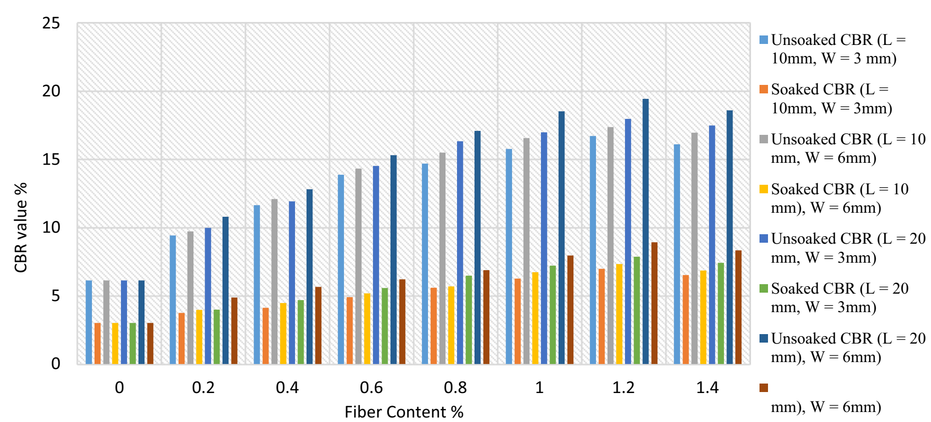

Fig. 6 Comparison of CBR value

specimens were tested in a similar manner. A series of unsoaked and soaked laboratory CBR tests were performed on plain soil and fiber reinforced soil accordance with ASTM D 1883 [38].

Results and discussion

The unsoaked and soaked CBR values of ordinary soil and soil strengthened with varying percentages, length and diameter of bamboo fiber determined in the laboratory are shown in Tables 4 and 5. Figures 5 and 6 represents the variation and comparison of unsoaked and soaked CBR test value respectively for different content, length and diameter of bamboo fiber. The clarification of tests results such as effects of bamboo fiber content, length of bamboo fiber and diameter of bamboo fiber on CBR value for both soaked and unsoaked condition of soil have been discussed in the subsequent sections.

Effect of bamboo fiber content CBR value

CBR tests carried out for different Bamboo fiber dosage varying such as 0, 0.2, 0.4, 0.6, 1.0, 1.20, 1.40% by waterless weight of normal soil are given in Tables 4 and 5 for different length and diameters of bamboo fiber. Figure 5 illustrates that the CBR value increases with increases in bamboo fiber content up to 1.2% and beyond this gradual decrement was occurred. This aspect can be observed for all the fiber lengths (10 and 20 mm) and fiber diameters (3 and 6 mm). For instance, unsoaked and soaked CBR value for 10 mm length with 3 mm diameter was found 16.71 and 6.98% respectively at 1.2% bamboo fiber content which is 2.73 and 2.32 times greater than the unreinforced soil.

Some researchers were observed similar trend by using natural or geosynthetic fiber and ash for soil improvement. This may have occurred due to randomly inclusion of bamboo fiber in normal soil. This randomly oriented bamboo fiber has capability to make combined form with soil mass. This systematized form is mainly responsible for development of its load deformation behavior by mechanical interaction of soil particle with fiber by surface abrasion as well as interlocking. This interlock or interconnect mainly transmit stress from soil to the discrete inclusion by mobilizing the tensile strength of fiber initiated. In this way fiber reinforcement performs like a tension and frictional inhibitor component. Furthermore, soil become a composite material due to addition of fiber and its toughness and strength is higher than ordinary soil. This may have the real reason that CBR value of reinforced soil was seen higher than normal soil. The most appropriate percentage of coir fiber respect to the highest CBR value was established 1.2% by anhydrous weight of normal soil sample [29, 39–43].

Effect of length of bamboo fiber

In this research two types of bamboo fiber length (10 and 20 mm) were used. From Fig. 5 it is clearly seen that unsoaked and soaked CBR value of soil increases with increase in bamboo fiber length for same fiber content and of same fiber diameter. For instance, unsoaked and soaked CBR values of soil reinforced with bamboo fiber length of 10 mm at 1.2% fiber dosages having diameter 3 mm are 16.71 and 6.98% respectively. When fiber length increased 10 mm to 20 mm then unsoaked and soaked CBR value were observed 17.97 and 7.86% respectively for same fiber content and diameter of bamboo fiber.

This is attributed to the fact that for smaller fibers, the area in contact with soil is comparatively less and hence there is a less improvement in strength and stiffness of soil [23, 43].

Effect of diameter of bamboo fiber

In this investigation two types of bamboo fiber diameter (3 and 6 mm) were used. Figure 5 illustrates that experimental unsoaked and soaked CBR value of soil reinforced with bamboo fiber increases with the increase in bamboo fiber diameter. For instance, unsoaked and soaked CBR value of soil reinforced with bamboo fiber for 10 mm length and 3 mm diameter is found 16.71 and 6.98% respectively at bamboo fiber content of 1.2%. When the diameter of fiber is increased from 3 to 6 mm, the unsoaked and soaked CBR value of reinforced soil increases up to 17.37 and 7.33% respectively for the same fiber content and same fiber length.

This is imposed to the datum that due to increase in diameter of fiber increases the pull out resistance of fiber. Additionally, large diameters fibers are proficient of distribution more stresses initiated in the soil specimens [23, 43].

Conclusion

Based on the current investigation and study it is concluded that both unsoaked and soaked California Bearing Ratio (CBR) value of soil increases due to the addition of bamboo fiber. When bamboo fiber quantity is increases, unsoaked and soaked California Bearing Ratio (CBR) value of soil are considerable increase and this increase is occurred up to 1.2% of bamboo fiber dosage. It is observed that the preparation of identical soil samples for soaked and unsoaked CBR test beyond 1.2% of bamboo fiber dosage is not feasible and optimal proportion of bamboo fiber is found 1.2% by waterless weight of ordinary soil. It is also explored that there is highly impacts of length and diameter of bamboo fiber on the unsoaked and soaked CBR test value of normal soil. The unsoaked and soaked CBR test value of soil increases with the increase in bamboo fiber length and diameter. In addition, bamboo fiber makes the soil an amalgamate elements whose stiffness and strength is better than that of ordinary soil. Moreover, bamboo fibers are helpful natural biodegradable and environmental friendly material, for the construction of high-rise buildings construction, oil storing tanks, long span bridges, harbors, port structures, embankments for flood protection and barrages in a profitable way since they are relatively inexpensive than polymeric alternates.

Authors' contributions

TKB conducted a number of experiments and drafted the manuscript. MdR have equally and continuously contributed towards supervision of the research work and revised the manuscript in accordance with strategies of the journal. Both authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

Not applicable.

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