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PERFORMANCE OF SHALLOW FOUNDATIONS RESTING ON COIR GEOTEXTILE REINFORCED SAND BED

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Soil reinforcement by natural fibers is a cost-effective and reliable technique for improving the stiffness and stability of soil. Coir is an eco-friendly, biodegradable organic material that has high tearing strength, stiffness, and durability compared to other natural reinforcement materials. In this study, the potential of coir geotextile as a reinforcement material was studied through a set of laboratory experiments. Remarkable improvement in strength and settlement properties were obtained with the provision of geotextiles. Bearing capacity improvement by a factor of 5 and a reduction of footing settlement by 87% was obtained by the suggested method. The optimum benefit was realized with the provision of three layers of reinforcement for a width of 3B (B is the foundation width), the topmost geotextile layer being positioned at a distance of 0.25B from the base of footing. Bearing capacity enhancement by a factor of 2.57 and settlement reduction of 73% was obtained even with the provision of a single layer of coir geotextile.

Introduction

Geosynthetic materials as soil reinforcement has been widely used as an efficient means of improving the performance of shallow foundations. Geosynthetic materials like geotextiles, geogrids etc. generally provide better performance but are costly and non-eco-friendly. Natural geotextiles are manufactured mainly from jute and coir fibers, among which coir fiber (obtained from coconut husk) is the strongest and most durable owing to its high lignin content [1]. However, its benefit as a potential reinforcement applicant is underutilized. Studies on various forms of geosynthetic reinforcement were conducted by [2-8]. A few studies have been conducted on reinforced soils under square footing [9-11]. Omar et al. [12] observed that the zone up to which the reinforcement effect was smaller for sand beds under square footing compared to strip footings. Its use as a reinforcement material for slope protection, in erosion-controlling blankets, and for subgrade stabilization has been studied in [13-16]. Tension and pullout behavior of coir geotextiles were investigated in [17]. Studies of various researchers have shown that the durability of coir is sufficient for long-term reinforcement applications [18, 19]. Generally, the lifetime of coir geotextiles is around 10-12 years, but it can be enhanced by various treatment methods (i.e., cement coating, bitumen coating, biological treatment, etc.) [20]. Literature survey shows that the use of coir geotextile in reinforcing sand foundations is underexplored.

This paper reports a set of laboratory experimental results of woven coir geotextile reinforced footings. The results reveal the potential of coir geotextiles as an efficient low-cost reinforcement material for shallow foundations. The optimum layout for the placement of geotextile was found.

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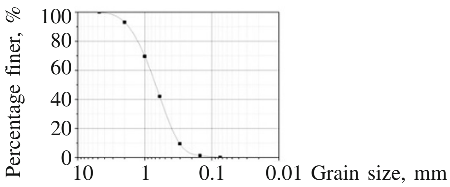

Fig. 1. Grain size distribution of soil.

Materials

The sand used for the tests had a specific gravity of 2.65, effective size 0.32, coefficient of uniformity 2.56, coefficient of curvature 0.88, and friction angle 38.5°. Classification according to the Unified Soil Classification System (USCS) is SP (poorly graded sand). The grain size distribution curve of sand is illustrated in Fig. 1. The maximum and minimum dry densities obtained were 16.4 and 14.9 kN/m^3 respectively. All tests were done at a relative density of 60% to simulate medium dense condition. The properties of woven coir geotextiles were determined as per Indian standards: mass 720 g/m^2, ultimate load 12.6 kN/m and failure strain (warp direction) 22%, ultimate load 7.2 kN/m and failure strain (weft direction) 23%, aperture size 6×10 mm, thickness 6.4 mm.

Experimental Procedure

All tests were conducted on a square steel tank of side 750 mm. The footing used for the study was a square plate 150 × 150 mm with a thickness of 25 mm. A hand-operated hydraulic jack was used for loading the footing, and a pressure gauge of 100 kN was fitted to measure the load applied. Sand was poured from different heights, and the height required to get 60% relative density was found (sand raining technique) [3, 7-9]. After filling the sand up to the top, the footing was placed centrally, so the load distribution was uniform throughout. The hydraulic jack was carefully positioned above the footing and was loaded in small increments. Two displacement dial gauges were positioned on either side of the foundation. The geotextiles were placed at a depth *u* from the base of footing; *d* is the distance between successive layers of reinforcement, and *b* is the width of reinforcement. The distance *d* is kept equal to the optimum placement depth *u* obtained from [7, 8, 11]. Parameters *u*, *d*, *b*, and settlement *S* are normalized by dividing it by the footing width *B*. Normalized settlements are expressed in percentage. To evaluate the degree of improvement [5-8]:

$$\text{Strength improvement factor } = \frac{BC_r}{BC_u}, \tag{1}$$

where BC_r is the bearing capacity of geotextile reinforced soil and BC_u is the bearing capacity of unreinforced soil at the same settlement;

$$\text{Settlement reduction factor } = \frac{(S_u - S_r)}{S_u}, \tag{2}$$

where S_u is the settlement of unreinforced soil and S_r is the footing settlement for the geotextile reinforced case at the same pressure.

Results and Discussion

The applied pressure versus footing settlement by placing the reinforcement at different *d*, *b*, and *n* is shown in Fig. 2. Figure 3a shows the strength improvement for reinforcement placed at various depths, measured at different normalized settlement of 2.5, 5, 10, 15, 20, 25, and 30% [13]. It can be seen that the woven coir geotextile reinforced foundation provides better performance than the unreinforced one. This is mainly due to the interface friction developed between soil and coir geotextile. A

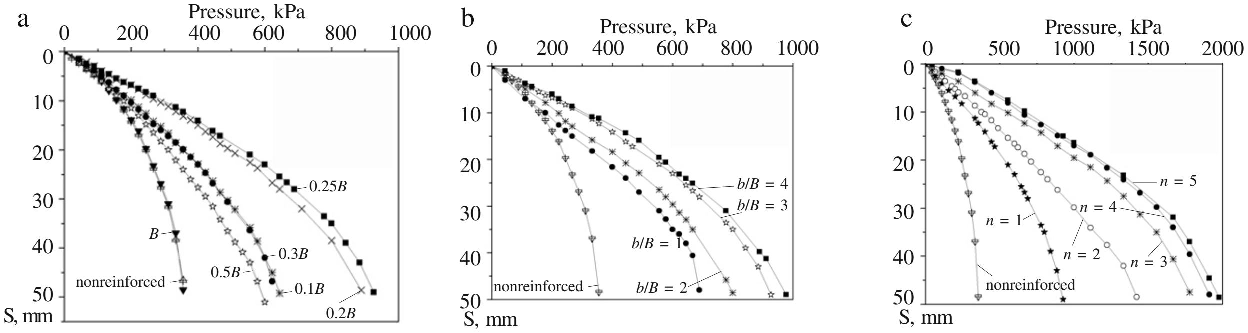

Fig. 2. Applied pressure versus footing settlement: a) at different placement depths of reinforcement; b) at different widths of geotextiles; c) for several layers of geotextile.

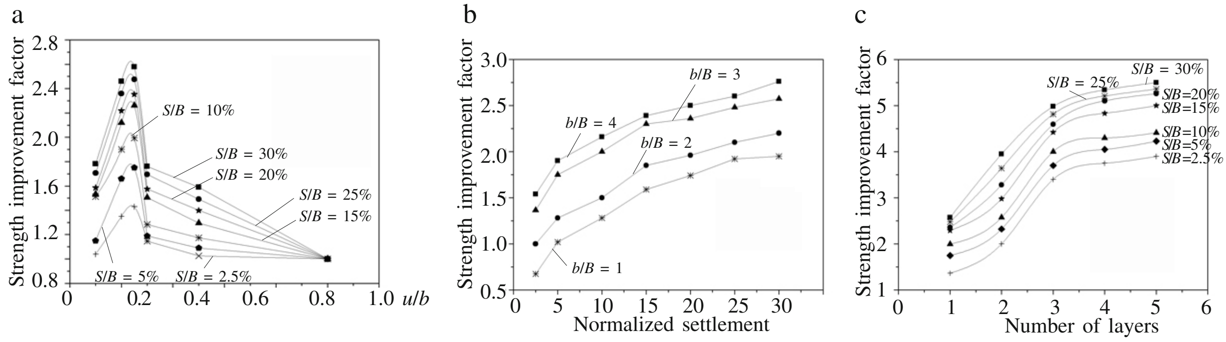

Fig. 3. Strength improvement factor versus: a) u/B for different normalized settlements; b) normalized settlement at different widths; c) number of layers.

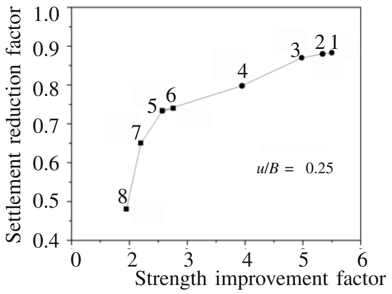

Fig. 4. Settlement reduction factor versus strength improvement factor for different widths and number of layers of reinforcement: 1) $b/B = 3$, $n = 5$; 2) $b/B = 3$, $n = 4$; 3) $b/B = 3$, $n = 3$; 4) $b/B = 3$, $n = 2$; 5) $b/B = 4$, $n = 1$; 6) $b/B = 3$, $n = 1$; 7) $b/B = 2$, $n = 1$; 8) $b/B = 1$, $n = 1$.

minimum overburden length is necessary for the mobilization of frictional resistance between coir geotextile and soil. The optimum benefit was attained when the reinforcement was positioned at a distance of $0.25B$ from the base of the footing, beyond which the improvement was found to decrease as the reinforcement falls out of the most effective zone. It was also noticed that by placing the geotextile at B, the soil behavior was similar to the non-reinforced case. For a normalized settlement of 30%, the increase in bearing capacity by placing the geotextile at a distance of $0.25B$ was about 2.57 times that of the non-reinforced soil, i.e., an increase of about 157% was obtained.

The position of reinforcement was fixed at $0.25B$ from the base of the footing, and the width of the reinforcement b was varied ($b/B = 1, 2, 3, 4$). The strength improvement factor for various widths of reinforcement at different normalized settlements is shown in Fig. 3b. The settlement reduction factor versus improvement factor for different b at a normalized settlement of 30% of the non-reinforced soil [13] is shown in Fig. 4. It can be seen that with the addition of width greater than $3B$, there is no appreciable

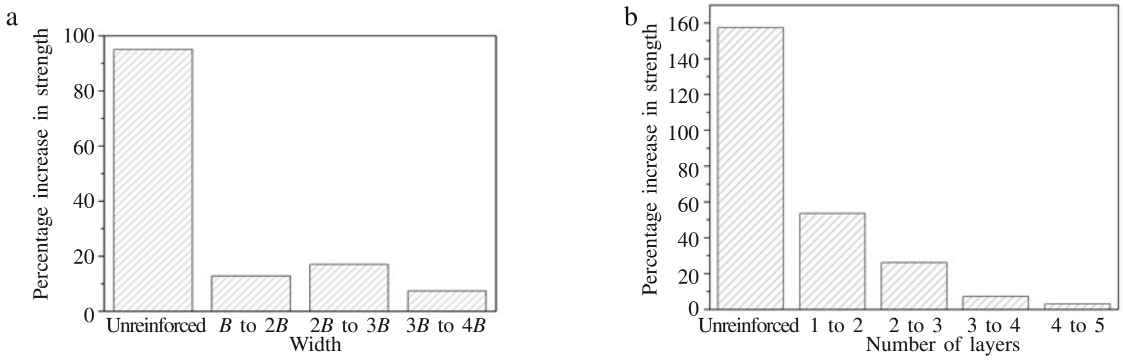

Fig. 5. Percentage increase in strength with: a) geotextile width; b) number of layers.

enhancement in strength improvement factor and settlement reduction factor. This signifies that a length of 3*B* is sufficient for effective mobilization of passive pressure and for providing necessary anchorage. Hence, 3*B* is taken as the optimum width of reinforcement. The percentage increase in strength with increase in width of geotextile for a normalized settlement of 30% of unreinforced sand bed [13] is shown in Fig. 5a. It is seen that 95% improvement can be obtained even by providing coir geotextile of width *B*.

A reinforcement width of 3*B* is provided at optimum placement depth (*u*), and the number of layers are increased from 1 to 5. Figure 2c depicts the variation of footing settlement with applied pressure for several layers of reinforcement. The strength improvement factor for various numbers of layers of reinforcement at different normalized settlements is shown in Fig. 3c. It shows that the bearing capacity increased from 1.363 to 5.5 as the number of layers increased from 1 to 5. The settlement reduction factor versus strength improvement factor for various layers of reinforcement at a normalized settlement of 30% of the non-reinforced soil is shown in Fig. 4. It is clear that a decrease in settlement of about 80% and a bearing capacity improvement of about 4 is obtained by providing two layers of reinforcement. By the inclusion of three layers of reinforcement, a settlement reduction of 87% and strength improvement of about 5 is obtained. Beyond three layers there is hardly any improvement as the reinforcement may be placed out of the effective zone. Therefore, in this study the number of layers considered to be optimum is 3. Figure 5b shows the percentage increase in strength with increase in number of layers for a normalized settlement of 30% of unreinforced sand bed.

Conclusions

1. Coir geotextile as a sustainable cost-efficient reinforcement application in shallow foundations has tremendous possibilities.

2. Optimum placement depth, width of reinforcement, and number of layers of reinforcement were obtained as 0.25*B*, 3*B* and 3 respectively (*B* is the width of footing).

3. An increase in bearing capacity of 95% can be obtained even by providing a single layer of geotextile for a width *B*.

4. An increase in bearing capacity of 2.57 and a settlement reduction of 73% was obtained by providing optimum width and placement depth of reinforcement.

5. A bearing capacity improvement of 5 and a settlement reduction of 87% was obtained when the number of layers of reinforcement at optimum width and placement depth of reinforcement was 3.

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