

EXPERIMENTAL INVESTIGATION ON BEHAVIOUR OF CIRCULAR FOOTINGS RESTING ON REINFORCED SAND

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Abstract

Several parts of India have inadequate bearing capacity and may not support the weight of the superstructure by the weak soil alone. Soil reinforcing techniques can be used for in-situ soils as a viable building material for a variety of projects with reinforcing materials like geogrid, geocell, confinement, etc and these are extremely expensive. In order to reduce the cost of construction, alternate and local available waste materials are needed as sustainability is the key. The increasing use of plastic goods has led to new issues with waste management; hence these waste items can be used to enhance the geotechnical qualities of the soil to increase the soil's bearing capacity, which avoid disposal issues. In this study series of model tests are conducted with plastic bottles as reinforcement, using sand at varying densities, reinforcement layers and the distance between the base of footing to first reinforcement layer. It is observed that the parameter selected in the present study has increased the load carrying capacity up to 262.5% compared with unreinforced soil.

Keywords: Bearing Capacity, Reinforcement, Plastic Bottle.

1. INTRODUCTION

The quality of civil engineering has long been at the heart of social infrastructure; builders must prioritize this aspect of the field in order to produce results that live up to expectations. Since the start of the 21st century, the construction industry has grown exponentially as science and technology advanced rapidly, the construction industry has grown exponentially.

Also in past few decades, it is observed that adding reinforcements to the soil improves its engineering properties. Soil reinforcement is utilised in many applications like retaining walls, embankments, foundations, slopes, highway and airport pavements, and railway tracks.

Geosynthetic reinforcement are used in shallow foundations shows cost-effectiveness, versatility, and reproducibility make fiber-reinforced soil an efficient ground improvement approach [1-5]. Geosynthetic reinforcements allow large tensile loads to be supported at prescribed deformations over long design lives. Physical model tests and numerical studies were done to evaluate performance of soil reinforced foundations [1, 6-9].

Foundations reinforced using geosynthetics have been shown to have a much higher bearing capacity and less foundation settlement in the research that have been published to date [2-3].

Different scholars have provided varying opinions on the optimal design parameter for maximizing bearing capacity are, (a) depth of initial reinforcement below footing base, (b) ratio of the width of the footing to the depth of the reinforcement layers, (c) distance in height between the reinforcement layers.

The ratio between distance in height between the reinforcement layers to width of footing (can be between 0.20 to 0.46) (d) reinforcement layer width [10-13]. The ratio between reinforcement layer and width of footing (can take on values between 2.5 and 4.0) [11, 12] (e) number of layers of reinforcement (value between 3 and 5) [11, 13, 14].

The behaviour of reinforced sand foundations was also found to be significantly impacted by reinforcing configuration. At all levels of footing pressure, settling can be decreased by 20% with two or more layers of reinforcement. Compared to sand reinforced with either geogrid or geotextile alone, the composite of the two proved to be the most effective.

Reinforcing a footing can help redistribution of applied loads in a way that causes less concentrated stress, leading to less settlement [15, 16]. The results of finite element calculations demonstrate that the reinforcement ratio (R_r) of the reinforced zone has a significant bearing on the scale effect of reinforced soil foundation.

The difference in bearing capacity becomes insignificant as long as the reinforcement depth ratio (d/B) and reinforcement ratio (R_r) of the reinforced zone remain constant for all footing sizes [17].

In the present study, the soil reinforcement is done with waste plastic bottles which are modified and arranged to make geocell. These produced geocells are used as reinforcement for sand.

The experimental investigation was carried out understand the responses of a circular footing to a load, with and without sand reinforcement and the impact of combined loads on sand footings of variable densities and reinforced spacing. The primary goal of this research is to examine the load bearing capability and settling of a circular foundation which is reinforced by plastic geocells in sand medium. It will be helpful in understanding the interaction between soil and produced geocell from waste plastic and same can be implemented in field applications. This study also provides the base for further research for the invention of the new plastic based soil reinforcement materials.

2. MATERIALS AND ITS PROPERTIES

2.1. Sand

Studies often require the use of sand, which is procured locally from the Kumaradara River at Uppinangadi. The sand is oven dried and sieved to remove any traces of dirt, grass roots, or other organic matter. The procured sand is tested of its physical properties as per Indian Standards [18, 19].

The test results are presented in the Table 1.

Table 1: Properties of sand

Tests conducted	Characteristics	Values obtained
Sieve Analysis IS: 2720 (Part 4) – 1983 [18]	D_{10}	0.37
	D_{30}	0.49
	D_{60}	0.62
	Coefficient of Uniformity (C_u)	1.68
	Coefficient of Curvature (C_c)	1.04
Density of Sand IS: 2720 (Part 14) [19]	Minimum dry density (γ_{min})	14.07 kN/m ³
	Maximum dry density (γ_{max})	15.78 kN/m ³

2.2. Reinforcement

In the present work reinforcement consists of recycled plastic bottles procured locally from the Bindhu Factory in close proximity to Puttur. The bottle has a diameter of 75 mm and a capacity of 1 litre. The aspect ratio {height to diameter (h/d)} of the geocell was selected based the on the availability of the plastic bottle. The circular cut portion of the bottle selected was having the diameter of 75mm at and 100mm height at centre was suitably taken to have the aspect ratio of 1.33. The load carrying capacity increases as the h/d ratio increases, Sitharam et al. (2005) [20] for circular footing.



Fig 1: Reinforcement produced using plastic

Geocells in the field either they ultrasonically weld or stapled, hence we stapled the circular cut part of the bottle to form cellular structure which are used as reinforcement as presented in Fig 1. Again the load taking capacity also depends on the bond strength, with increase in the bond strength the load carrying capacity also increases. We checked that there is no failure of stapled parts at the failure load. Test conducted on the plastic as per ASTM D882 [21] are present in Fig 2, and the test results are presented in the Table 2.



Fig 2: Test conducted on plastic

Table 2: Properties of waste plastic bottle ASTM D882 [21]

Characteristics	Average values
Tensile strength (N/mm ²)	165.17
Percentage elongation at peak	203.92
Secant Modulus (MPa)	133.62

3. EXPERIMENTAL SETUP

In the present study the experiment is carried out on miniature models are described herein. The following section provides specifics on the testing, materials, technique, and analysis of data for model studies. The experimental setup is depicted as a line diagram in Fig. 3.

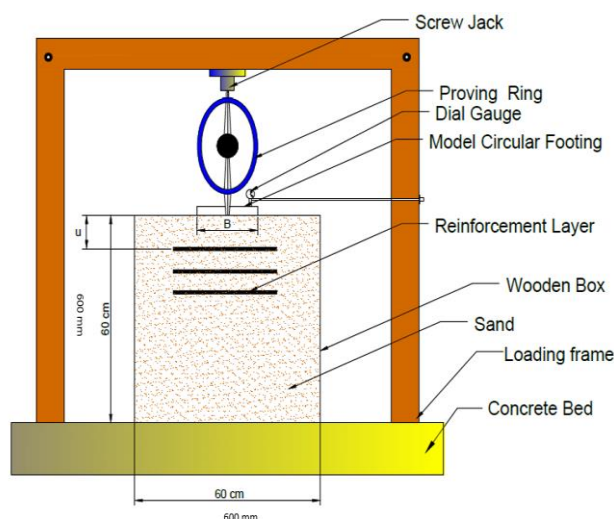


Fig 3: Experimental Setup

The sand is evenly distributed throughout the tank and its density is maintained throughout the tank's depth by using a funnel during the filling process. After determining the maximum and minimum densities of the sand, the desired density can be achieved by sand raining technique (Fig 4) by adjusting the height of the sand's fall (Table 3) using funnel. The circular mild steel base of diameter 150 mm and thickness 5 mm is used as model footing.



Fig 4: Sand Raining Technique using Funnel

Table 3: Density and the associated heights of fall in the sand raining technique

Height of fall (mm)	Density (kN/m ³)
250	14.23
300	14.36
350	14.56
400	14.67
450	14.78

Reinforcement is placed by adjusting the u/B ratio, where u is the height from the footing's bottom surface to the top surface of the first reinforcement and B is the footing's diameter. Here, the value of u is varied from 50 mm to 100 mm while B remains unchanged throughout. The number of reinforcement layers will vary as the u/B ratio is adjusted. Study is conducted till the three layers reinforcement.

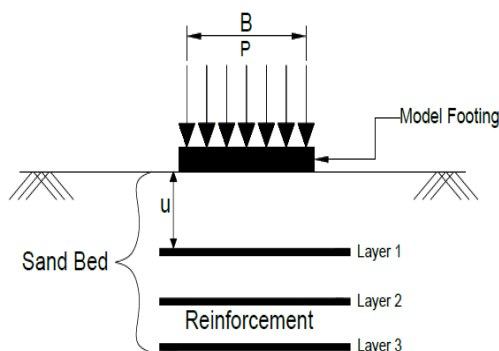


Fig 5: Layout and configuration of reinforcement layers in the test

The footing can be placed in the centre above the sand once the sand bed is prepared with or without reinforcement as shown in Fig 5. The necessary capacity proving ring is fastened to the screw jack installed at the top of the frame. To ensure that loading is performed vertically, this proving ring is brought into touch with the footing as per guidelines of IS 1888 [22]. The Linear Variable Differential Transformer (LVDT) is located in a edge of the circular footing and measures the settlement or displacement of the footing.

4. TEST PROCEDURE



Fig 6: Reinforcement arrangement during specimen preparation

First, a wooden box is packed with sand to the desired density using sand raining technique, and then reinforcement is added to achieve a certain u/B value (Fig 6). A calibrated proving ring No. 50kN529 of capacity 50kN is used to measure the applied load on the foundation during the experimental work. Top of proving ring is attached with the metallic frame of the set up at top of static loading unit while the bottom is in contact with the metallic ball which is resting on the footing. The rigid metallic ball between the footing and the proving ring acts as a hinge. When load is applied, the load is transmitted from proving ring to the footing via this metallic ball. Settlements are recorded with the help of LVDT which is capable of measuring 0.01mm. (Fig.7).

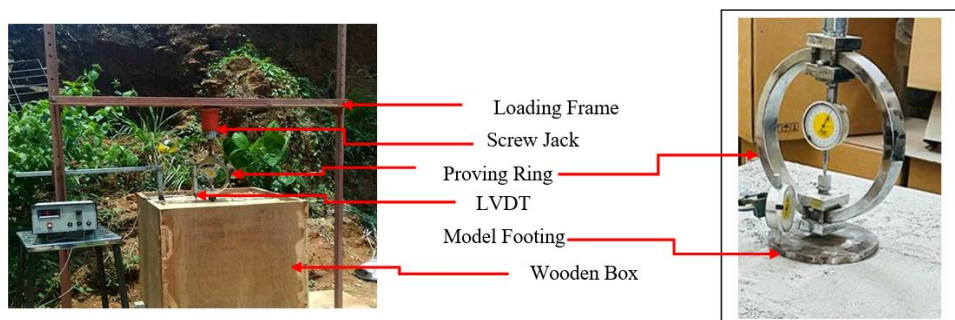


Fig 7: Complete experimental setup during the testing

5. RESULTS AND DISCUSSION

The load-settlement results were observed and compared between the reinforced and unreinforced soil conditions. The load-settlement curve for the density of 14.36 kN/m^3 with varying u/B ratios of 0.66, 0.53 and 0.33 are presented in Fig. 8 (a) to (c) and Table 4, for all unreinforced and reinforcement conditions. It is observed that the load carrying capacity of the soil for unreinforced soil condition was found to take an ultimate load of 1.06 kN and load carrying capacity for reinforced soil conditions with varying u/B are also observed. From figures for density 14.36 kN/m^3 maximum load carrying capacity is 2.15 kN for u/B ratio 0.33 with 3 layers of reinforcement.

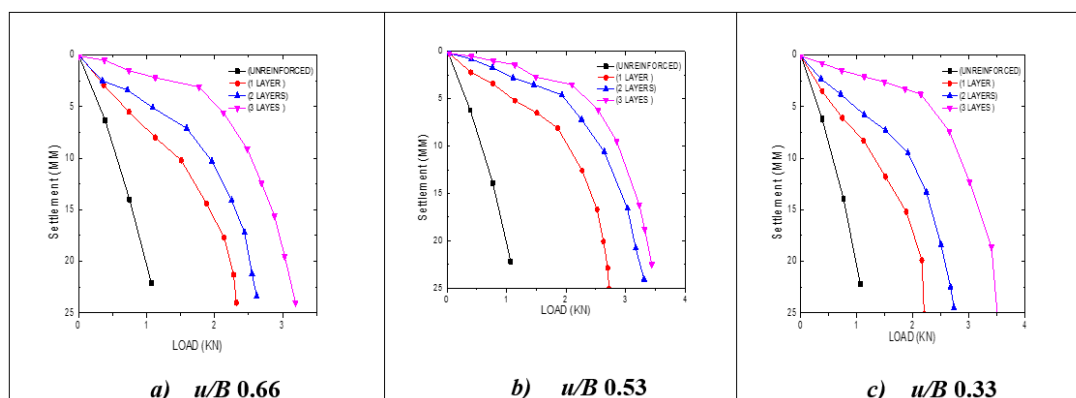


Fig 8: Load Settlement curve for density 14.36 kN/m^3

Table 4: Ultimate load carrying capacity for density 14.36 kN/m³

Density (kN/m ³)	u/B Ratio	Number of layers	Ultimate Load (kN)
14.36	0.33	Unreinforced	1.06
		1	1.89
		2	1.95
		3	2.15
	0.53	1	1.85
		2	1.93
		3	2.10
	0.66	1	1.51
		2	1.62
		3	1.78

The load-settlement curve for the density of 14.56 kN/m³ with varying u/B ratios of 0.66, 0.53 and 0.33 are presented in Fig. 9 (a) to (c) and Table.5, for all unreinforced and reinforcement conditions. From figures for density 14.56 kN/m³ maximum load carrying capacity is 2.6 kN for u/B ratio 0.33 with 3 layers of reinforcement.

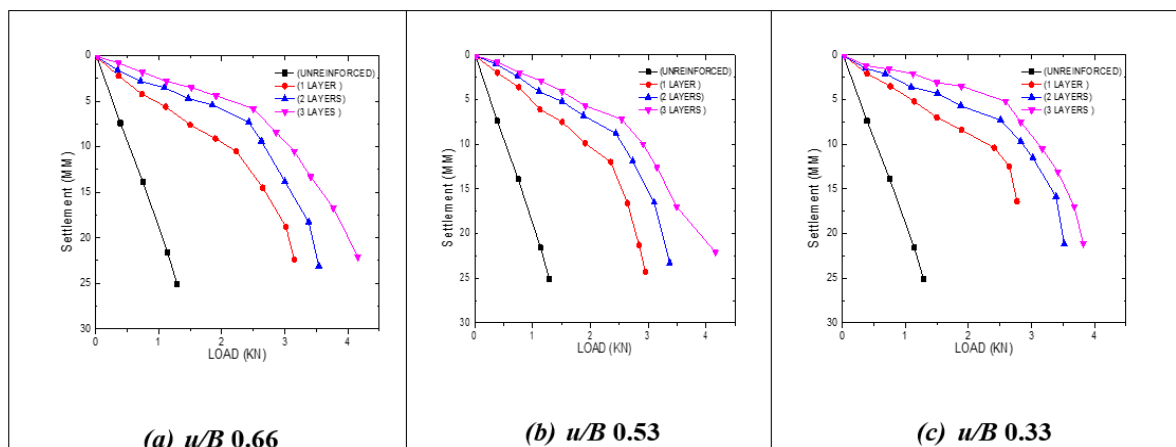


Fig 9: Load Settlement curve for density 14.56kN/m³

Table 5: Ultimate load carrying capacity for density 14.56 kN/m³

Density (kN/m ³)	u/B Ratio	Number of layers	Ultimate Load (kN)
14.56	0.33	Unreinforced	1.28
		1	2.40
		2	2.55
		3	2.60
	0.53	1	2.34
		2	2.45
		3	2.53
	0.66	1	2.25
		2	2.45
		3	2.50

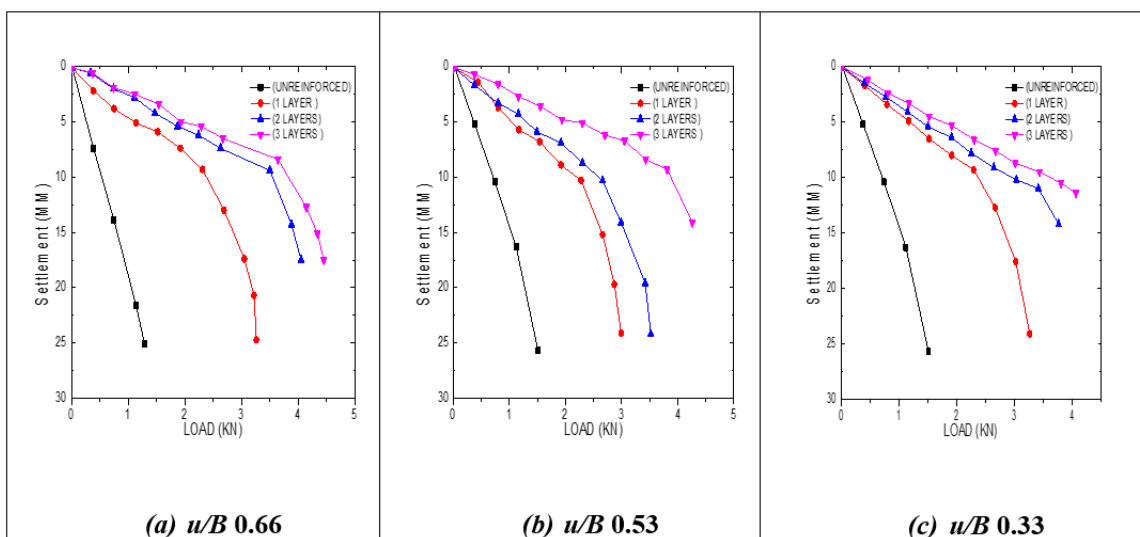


Fig 10: Load Settlement curve for density 14.67kN/m³

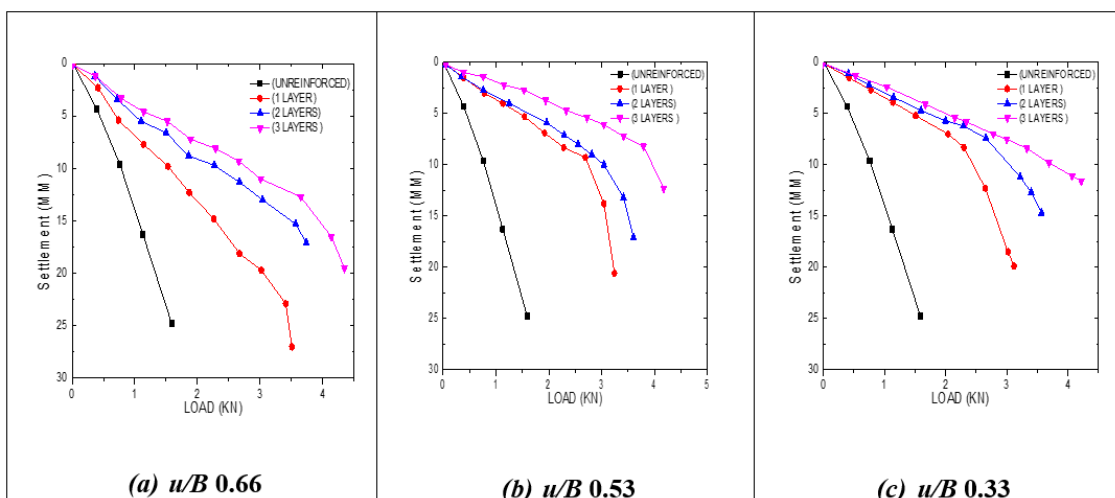


Fig 11: Load Settlement curve for density 14.78 kN/m³

The load-settlement curve for the density of 14.56 kN/m³ with varying u/B ratios of 0.66, 0.53 and 0.33 are presented in Fig. 10 (a) to (c) and Table.6, for all unreinforced and reinforcement conditions. From figures for density 14.56 kN/m³ maximum load carrying capacity is 2.6 kN for u/B ratio 0.33 with 3 layers of reinforcement.

Table 6: Ultimate load carrying capacity for density 14.67 kN/m³

Density (kN/m ³)	u/B Ratio	Number of layers	Ultimate Load (kN)
14.67	Unreinforced	-	1.51
	0.33	1	2.27
		2	3.40
		3	4.05
	0.53	1	2.25
		2	2.65
		3	3.77
	0.66	1	2.30
		2	3.50
		3	3.62

The load-settlement curve for the density of 14.56 kN/m³ with varying u/B ratios of 0.66, 0.53 and 0.33 are presented in Fig. 11 (a) to (c) and Table.7, for all unreinforced and reinforcement conditions. From figures for density 14.78 kN/m³ maximum load carrying capacity is 4.2 kN for u/B ratio 0.33 with 3 layers of reinforcement.

Table 7: Ultimate load carrying capacity for density 14.78 kN/m³

Density (kN/m ³)	u/B Ratio	Number of layers	Ultimate Load (kN)
14.78	Unreinforced	-	1.60
	0.33	1	2.30
		2	2.65
		3	4.20
	0.53	1	2.65
		2	3.02
		3	3.77
	0.66	1	3.40
		2	3.60
		3	3.65

From these experimental investigations, it can be observed that the load carrying capacity of soil has increased due to increasing the density of soil from 14.36 kN/m³ to 14.78 kN/m³ the load carrying capacity has increased from 1.06 kN to 1.60 kN. Increase of 51% in load carrying capacity is observed due to density increase which is self-confinement of soil particles.

Further the introduction of reinforcement layers and number of reinforcement layers has increased the load carrying capacity from 1.51 kN to 3.65 kN for u/B ratio of 0.66, the load carrying capacity increased from 1.85 kN to 3.77 kN for u/B ratio of 0.53, and for u/B ratio of 0.33 the load carrying capacity increased from 1.89 kN to 4.20 kN.

The soil bearing capacity declines as the depth of the reinforcement layer increases, until there is no gain in soil carrying capacity (for $u/B > 0.75$). This can happen when the depth of the reinforcement layer increases excessively, causing a failure between the foundation's base and the reinforcement layer (Chen 2007); as a result, the tensile force in the reinforcement is not developed.

The load carrying capacity of soil is mainly influenced by the introduction of reinforcement layer along with the increasing the number of layers since the confinement increases inside and surrounding the geocell. Influencing parameter was observed that ratio of depth of first reinforcement layer to width of the footing and lastly the increase in the density of soil.

The soil's potential tensile strain or lateral deformation can be constrained by reinforcements (confinement effect). Deformed reinforcements may further provide an upward push (membrane effect). The bearing capacity will rise as a result of these factors. Maintaining the top layer spacing (u) and the vertical spacing between the reinforcement layers (h) within an acceptable/reasonable range will help to prevent failure above the top layer of the reinforcement and failure between the reinforcement layers [23, 24].

6. CONCLUSION

The experimental studies showed that model circular footing behaviour on the reinforced sand with plastic geocell are affected by the number of reinforcement layers, the distance of separation between the first layer of reinforcement and base of the footing (u/B ratio), and density of soil.

The increase in load carrying capacity may be due to the additional confinement of soil inside the geocell in the vicinity of footing and as a load transmission platform, the reinforced soil mass provides a composite structure that distributes loads more uniformly over soft foundation soils, minimizing stress concentration and thereby reducing settlement of the underlying weak soil.

This will result in a reduced foundation size and/or a reduction in the depth of excavation required, which will have an economic impact by lowering material and labor costs. The placement of the reinforcement will increase the load carrying capacity of soil to large extent and also the number of the reinforcement layers up to 3 will increase the load carrying capacity as per observation of the present study.

As u/B ratio decreases from 0.66 to 0.33 and increase in density of soil from 14.36 kN/m³ to 14.78 kN/m³, the load carrying capacity of soil increase significantly. It is also noted that the parameter considered in the present study has increased the load carrying capacity up to 262.5% compared with unreinforced soil.

Further the increase of number layers needs further investigation to optimise the number layers required. Commonly, HDPE geocells are used for construction whereas in plastic bottles PET material is used. May be plastic waste bottles collected, recycled, and made in HDPE geocells of advantageous shapes (e.g., honeycomb instead of only circular) before being used as geocells.

Conflicts of interest

The authors declared that they have no conflict of interest.

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