An Experimental Study on Behaviour of Footings Resting on Sand Reinforced with Combigrid

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Abstract. Due to the scarcity of soils having high bearing capacity, the need for ground improvement posed major challenges to the geotechnical engineering professionals. Amongst the many ground improvement techniques, the use of geosynthetics is always a preferred choice in the field of soil improvement. Geogrids are polymeric products formed by joining intersecting ribs. It has been recognized as a good alternative material to geosynthetics for reinforcement applications, due to its large spaces and good engineering behavior. The aim of present study is to determine the effect of Combigrid reinforcement on bearing capacity of sand. For this, three model footings of rectangular, square, and circular shape having the same equivalent area of 100 cm^2 are taken and the comparison of results are made. In all the tests, the placement density is maintained by rainfall method, equivalent to relative density of 30 % which indicate loose state of sand behavior. The model test tank of size 500 mm x 500 mm x 600 mm is used. The ultimate bearing capacity of footing on sand is determined from the load-settlement curve. The tests are performed by placing the first layer of reinforcement at different depths. Parametric studies have also been made with different number of reinforcing layers and some significant observation have identified.

Keywords: Footings on Sand, Soil Improvement, Soil Reinforcement, Combigrid

1 Introduction

Construction of any form shallow foundation poses major challenges when the soil at shallow depth have very low bearing capacity. More specifically, for a foundation to be placed, the ground should have a capacity to resist the loads impending from the superstructure and transmit directly to the ground soil system. It indicates that the soil plays a key role to decide whether the construction is to be done or not, if not what methods has to be adopted in order to make construction to proceed.

When the construction is to be done on a weak soil, it is generally recommended that before the construction to be initiated, the condition of the soil should be improved in such a way that it can bear the loads. For the same purpose, replacing a weak soil by a good strong soil sometimes not feasible to be adopted because of the too much cost involvement. Therefore, the most commonly adopted alternative technique is the ground improvement technique for improving the soil [5, 8].

Over the years, thus, geotechnical practitioners are in a search of an alternative method for improving the bearing capacity and reducing the settlement of footing resting on the soil. Although a variety of methods of soil stabilization are already known and well developed, sometimes, these could be very expensive and thus, restricted by the site conditions. In some situations, they are also very difficult to apply to existing foundations. Soils have capacity to resist compressive and shear forces but are weak in tension. However, with the use of geosynthetics as reinforcing elements, soil structures can be built to carry tensile forces [1-2, 4, 6-7]. Therefore, the placement of different types of geosynthetics have now popularly been used as an alternative method of improving the bearing capacity and reducing the settlement of footing resting on the soil.

Nomenclature

B = Width of footing	s = Footing Settlement
b = Width of combigrid	IF = Improvement factor
h = Vertical spacing between layers	D = Diameter of circular footing
q_u = Ultimate bearing capacity	N = Number of reinforcement layers
c = Cohesion	Ø= Friction angle

u = Distance from bottom of footing to 1st layer of reinforcement

2 Materials Used

2.1 Sand Sample

The sand collected from the nearby river is made free from the foreign matters i.e., roots, organic matters etc. The sand which is then passed through the 4.25 mm sieve and retained on the 75 micron sieve, is taken for the experiment.

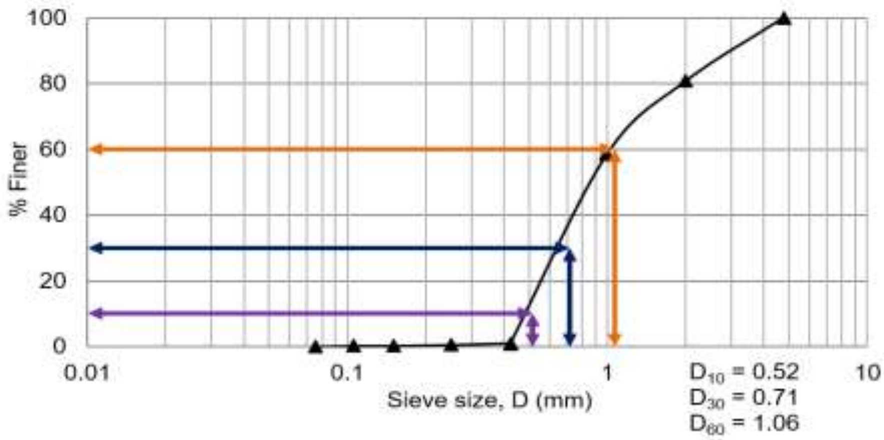

Fig. 1. Grain Size Distribution Curve of Sand

Table 1. Properties of Sand

Sl. No.	Property	Value
1.	Specific Gravity (G_s)	2.58
2.	Relative Density (%)	30
3.	Maximum unit weight, γ_{dmax} (kN/m^3)	16.76
4.	Minimum unit weight, γ_{dmin} (kN/m^3)	14.51
5.	D_{60} (mm)	1.06
6.	D_{30} (mm)	0.71
7.	D_{10} (mm)	0.52
8.	C_u	2.03
9.	C_c	0.91
10.	Type of Sand	SP
11.	Cohesion	0.0
12.	Angle of internal friction	33^o

The results from the grain size distribution curve (Fig. 1) and the other properties of the sand sample used in the experiment are presented in Table 1. From basic properties, it is observed that the soil sample is of SP type (poorly graded sand). All the tests were done at a relative density of 30% to indicate the loose condition.

2.2 Combigrid

Combigrid are one types of geogrids. Combigrid will serve as an important material as a reinforcement. It is manufactured by polypropylene or polyester bar material. This are mainly to achieve a high load carrying capacity at low settlements. They will available at low cost, and it brings cost saving and economical. They didn’t take much process for installation, it can be installed very easily. High resistance against biological and chemical degradation. This is ISO 9001:2001 certified material. The Combigrid used in the experiment is illustrated in Fig. 2 and the properties are in Table 2.

Fig. 2. Combigrid used in the experiment

Table 2. Properties of Combigrid used

Sl. No.	Property	Value
1.	Material/Type	Polypropylene/Bioriented-Biaxial
2.	Aperture Size	32 x 32
3.	Max Tensile Strength MD/CD	30/30
4.	Elongation at Nominal Tensile Strength	8%

3 Laboratory Tests

3.1 Test set up

In this study. three types of model steel footings with different size having the same equivalent area of 100 cm^2 have been used. Sizes of footing are as follows.

1. Square footing of 10 cm x 10 cm
2. Rectangular footing of 12.5 cm x 8 cm
3. Circular footing of diameter 11.3 cm

As already mentioned, the dimension of the tank is 50 cm x 50 cm x 60 cm which is nearly the 5 times of footing size. The two dial gauges having least count of 0.01 mm are placed on the footings, which have arrangements for keeping dial gauges.

3.2 Preparation of Test bed

In all the tests, the placement density is maintained by rainfall method, equivalent to relative density of 30% which indicate loose state of sand behavior. The height at which the raining or pouring of sand corresponding to relative density of 30% can be found by performing a number of trails by changing heights of pouring. The height at which the required relative density of 30% had been achieved is noted. For this experiment by performing a series of trials it is found that 5 cm height of pouring is quite satisfying.

To maintain the constant placement density, it should be checked always for a certain depth of rainfall by keeping steel box of known volume at different positions inside the tank and then sand pouring is to be carried out. For reinforcing tests bed, the location of footing as well as the location of geogrid layer were marked on the inner faces of the tank. The sand was then rained into the tank from the prescribed height. On reaching the geogrid position, the pouring of sand was temporarily stopped, and the geogrid layer was then placed. The top of geogrid was then again filled with sand using raining technique which continued up to the footing level.

3.3 Testing procedure

The model footing is to be placed on the top surface of the sand at center position, so that the loads applied by the hydraulic jack will be transferred to the footing and then to the sand. The proving ring is fitted to the hydraulic jack. In between hydraulic jack proving ring and footing a ball is kept. For this requirement, a groove is made on the top surface of footing. After reaching every loading position, the settlement readings are noted for the zero-time interval, and every 5 minutes the settlements are noted. This process is to be continued till the rate of settlement gets a value of less than or equal to 0.02 mm/min.

All the experiments have been performed as stress-controlled manner keeping the load fixed. At each load interval, the settlements are noted from the two dial gauges readings. By doing the average of the two settlement readings, the average settlement has been determined. The testing program is to be continues till the settlement of 25 mm is reached under normal conditions or 50 mm in case sand mixtures or gravels or till the failure mechanism achieved, whichever occurs earlier.

After completion of each test, the test tank is to be emptied fully or up to a 2.5 to 3B depth considering the usual depth of the pressure bulb influence. Again, the test tank is refilled and repeat the same procedure for next set of tests. After the completion of each test, applied pressure vs footing settlement curve has been plotted. By drawing the tangents from initial point of the curve and the final point of the curve, the ultimate bearing capacity of the footing has been estimated.

4 Results and Discussions

As already mentioned, the objective of this study is to investigate the improvements in settlement behaviour as well as the load bearing capacity of combigrid reinforced foundation. For this, a number of experiments have been conducted by changing the depth of first layer of reinforcement (Figs. 3-6) and the number of reinforcement layers (Figs. 7-10) and the results are thus obtained are reported in the following sections.

The variation of settlement with applied pressure of the three model footings tests are graphically shown below and observation are as follows

4.1 Effect of vertical spacing between layers

To study the effect of vertical spacing between reinforcing layers, at first, the effect of variation of the depth of first layer of reinforcement has studied (Figs. 3-5). From these three figures, it is observed that for circular footing, the maximum load carrying capacity has been achieved when the first layer of reinforcement is at u/D = 0.25, for rectangular footing, when the first layer of reinforcement is at u/B = 0.5 and for square footing, when the first layer of reinforcement is at u/B = 0.35.

Also, in this study, different heights of vertical spacing have been placed only for one footing which has attained highest bearing capacity for the depth ‘u’. Once this depth ‘u’ has been determined from Fig. 6, that ‘u’ depth is kept equal to the vertical spacing between layers. Therefore, for square footing, the vertical spacing is kept as 0.35, for rectangular footing, the vertical spacing is kept as 0.5, and for circular footing, the vertical spacing is kept as 0.25.

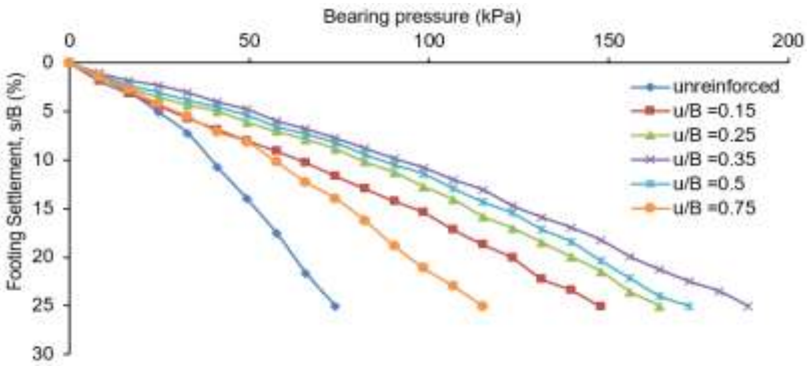

Fig. 3. Variation of settlement with applied pressure for different (u/B) ratio (square footing)

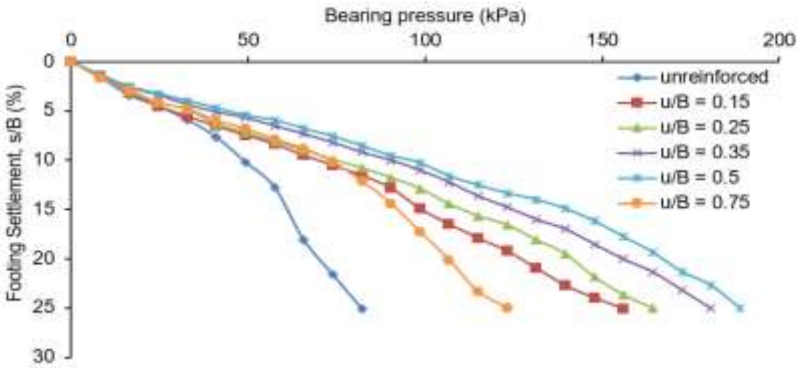

Fig. 4. Variation of settlement with applied pressure for different (u/B) ratio (rectangular footing)

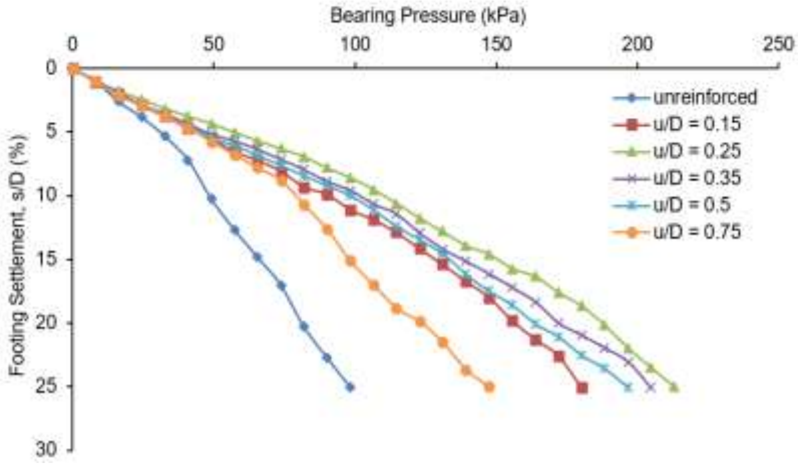

Fig. 5. Variation of settlement with applied pressure for different (u/B) ratio (circular footing)

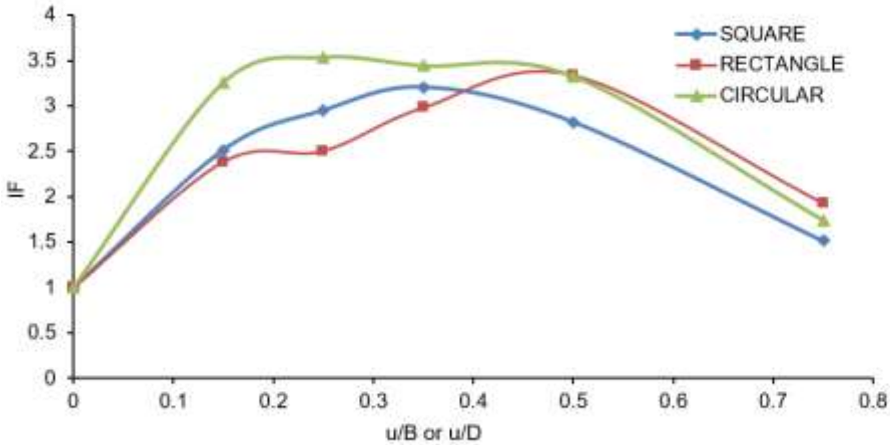

Fig. 6. Variation of improvement factor (IF) with u/B or u/D ratio

4.2 Effect of number of reinforcement layers

It is obvious that with the increase of number of reinforcement layers, settlement of the footing will be reduced, and ultimate bearing capacity will be increased. However, with the aim of determining the optimum number of reinforcement layers, the effect of number of reinforcement layers have been studied in this paper (Figs 7-9). From these three figures, it is observed that the maximum improvement is up to N = 4, the increment from N = 4 to N = 5 is very less for all the three footings and in rectangular footing it is decreasing (Figs. 10-11). This is due to the fact that the N = 5 depth is more than the stress distribution depth corresponding to pressure bulb influence. Therefore, after N = 5, virtually there are no more improvement.

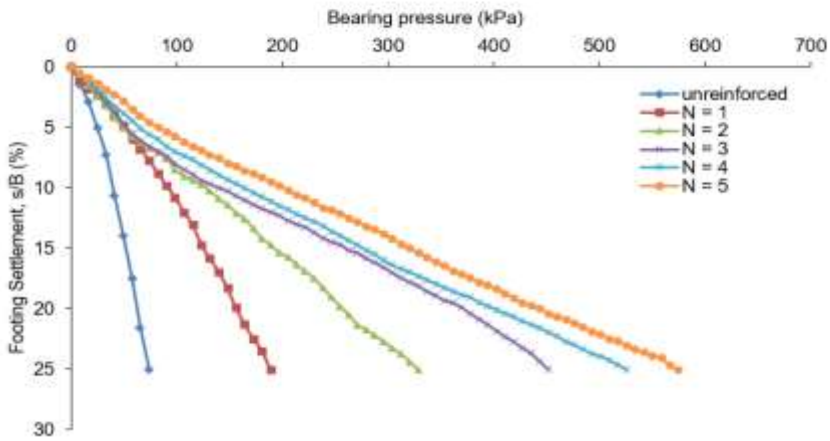

Fig. 7. Variation of settlement with applied pressure for different numbers of reinforcement layers (N) (square footing)

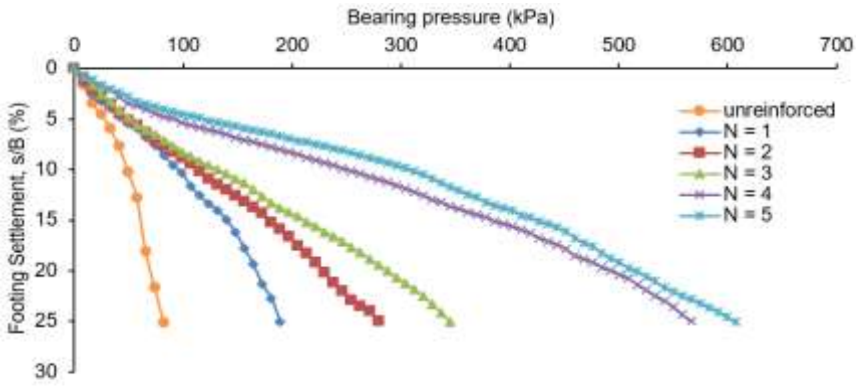

Fig. 8. Variation of settlement with applied pressure for different numbers of reinforcement layers (N) (rectangular footing)

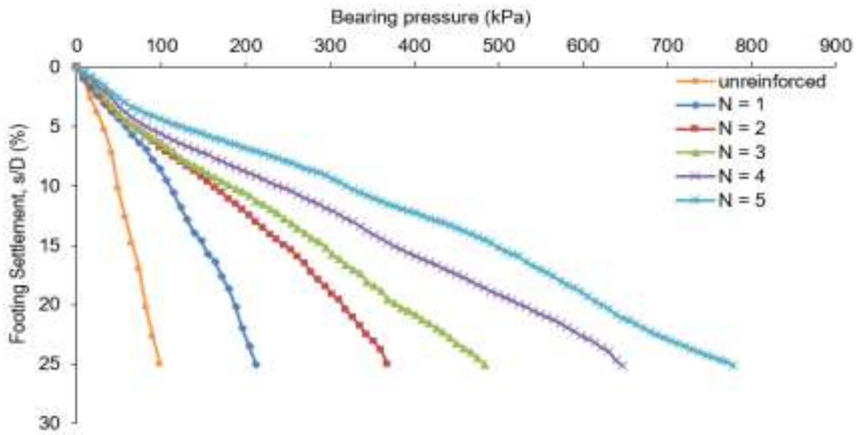

Fig. 9. Variation of settlement with applied pressure for different numbers of reinforcement layers (N) (circular footing)

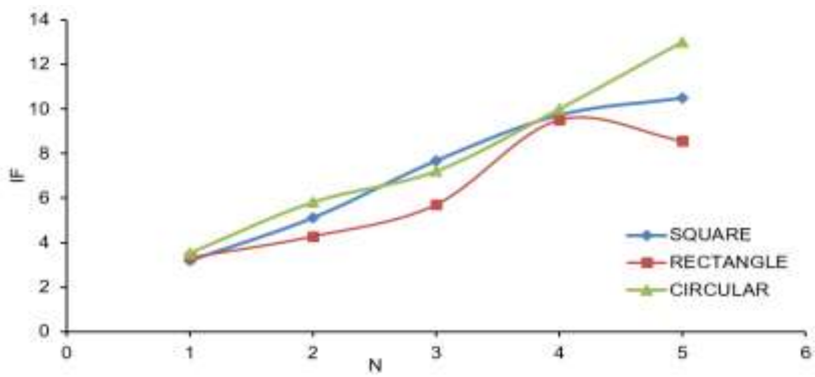

Fig. 10. Variation of improvement factor (IF) with the number of reinforcement layers (N)

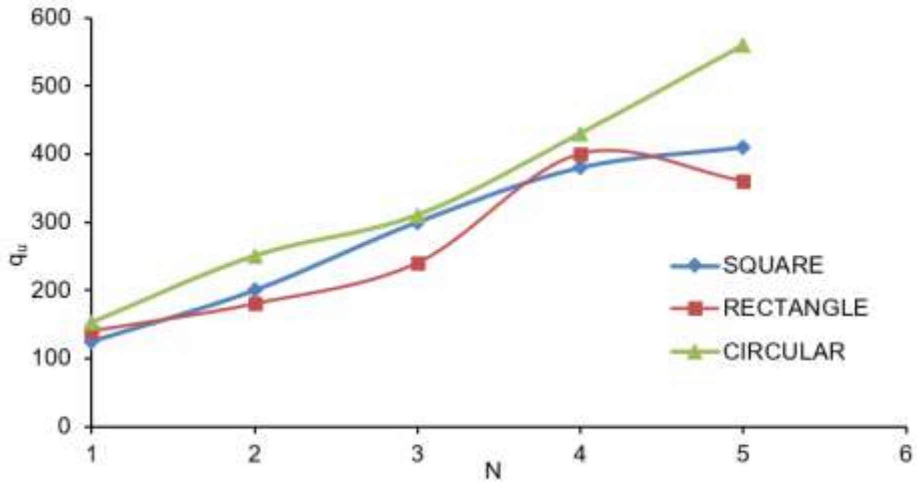

Fig. 11. Variation of ultimate bearing capacity (q_u) with the number of reinforcement layers (N)

It is also observed from Fig. 11 that for the condition on one reinforcement layer, similar to the without reinforcement case, the all three footings have achieved nearly the equal value of the ultimate bearing capacity.

5 Conclusions

From the experimental study conducted in this paper, the following concluding remarks can be made.

1. It is generally found that load carrying capacity of footings is increased with the use of combigrid as a soil reinforcement.
2. The maximum load carrying capacity for different footing shape are observed as follows:
   For circular footing, the maximum load carrying capacity is observed when the first layer of reinforcement is at u/D = 0.25, for rectangular footing, when the first layer of reinforcement is at u/B = 0.5 and for square footing, when the first layer of reinforcement is at u/B = 0.35.
3. The value of the optimum numbers of reinforcement layers (N) corresponds to the maximum improvement in ultimate bearing capacity due to use of combigrid reinforcement has also been determined. For rectangular footing, the maximum improvement is observed when the reinforcement layers are 4 while for other two footing shape, it is 5.
4. The improvement factor is also been measured for the different footing shape. It is observed that all the three footings, the improvement factor is showing nearly equal at N = 1 and 4. At N = 5, the circular footing has achieved more improvement factor among three footings.

5. The ultimate bearing capacity of circular footing is always observed to be in the higher side with the variation of numbers of reinforcement layers. It is also observed that circular footing and the square footing have nearly same ultimate bearing capacity at N = 3.
6. In all aspects, the circular footings have more load carrying capacity among them and it is thus the best footing shape than the other two.
7. A best fit curve analysis for the applied pressure vs settlement relationship has also been studied for different footing shape combined with reinforcement layers by the first author [3] and in most cases it is observed the polynomial with order 3 is best fitted curve.

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