Influence of Mesh Size on Bearing Capacity and Settlement Resistance of Coir Geotextile-Reinforced Sand

***R. Sridhar* [1] *and M.T. Prathapkumar* [2]**

[1] Research Scholar, VTU and Professor, Dept. of Civil Engg., Nagarjuna College of Engg. and Technology, Bengaluru, India. E-Mail: sridharrajagopalg@gmail.com
[2] Professor and HoD, Dept. of Civil Engg., RNS Institute of Technology, Bengaluru, India.
E-Mail: drmtprathap@gmail.com

ABSTRACT

The present investigation was undertaken to study the behaviour of reinforced sand in improving the bearing capacity and settlement resistance under circular footing. Comparison was carried out between reinforced condition and unreinforced condition under circular footing in sand bed. Comparison was made between bearing capacity of sand bed and coir geotextile layer reinforced in sand bed under footings. Locally available river sand was used along with 'coir geotextile' as a reinforcing material. The parameters selected were: depth of the top layer of reinforcement and different mesh sizes of coir geotextile below the footing. Relationships between intensity of loading and settlement have been presented to determine the influence of the above parameters on bearing capacity and settlement resistance. It can be concluded that by a suitable arrangement of the reinforcing coir geotextile, the bearing capacity and settlement resistance of sand are improved as compared to unreinforced sand.

KEYWORDS: Coir geotextile, Reinforcement, Bearing capacity, Settlement resistance, Reinforced and unreinforced sand.

INTRODUCTION

Soil is the integral part of civil engineering practices. It can be used as a construction material in building construction practices. Construction of every structure may need the analysis of soil before starting construction. Foundation is the lowermost part of the superstructure, which is resting on soil surface at different depths. It receives the overall load from the superstructure and distributes it uniformly to the ground. The total performance of a structure depends on the performance of a foundation. So, it should be strong enough to resist the load from superstructure. The performance of the foundation depends on the performance of the soil below the foundation. The performance of the soil below the foundation depends upon strength of the soil. It means that the soil should have enough ultimate bearing capacity to resist the load from the foundation and to distribute the load to the ground. Design of foundation depends upon the ultimate bearing capacity and the settlement of the soil below the foundation. Ultimate bearing capacity means the load that the soil under the foundation can sustain before shear failure. Settlement means the deformation of the soil below the footing under loading. Ultimate bearing capacity and settlement problem can be solved with the help of either analytical solution or experimental study. The theoretical study can be carried out by theory of plasticity and finite element method and the

Received on 30/4/2017.
Accepted for Publication on 22/6/2017.

experimental study can be carried out in laboratory. As we know, the ultimate bearing capacity of the soil may vary from one soil to another. Some soils have good ultimate bearing capacity and some have insufficient bearing capacity, depending upon grain size of the soil, cohesion of the soil and angle of internal friction in the soil particles. Insufficient bearing capacity soils may need to improve their strength by different methods. The strength of the soil can be improved by stabilization, reinforcing, grouting the soil and by other ground improvement techniques. Reinforcing is a type of ground improvement by providing metallic, synthetic fibers in the soil in order to improve the engineering behaviour of the soil (Binquet, 1975; Das, 1994). Reinforcement of the soil is a specified method for improving the mechanical soil properties, such as shear, compression, hydraulic conductivity and density. Ground improvement by providing reinforcement has been in practice since a long time. Babylonians built ziggurats more than three thousand years ago using the principle of soil reinforcement. A part of the Great Wall of China is also an example of reinforced soil construction. Dutch and Romans had used soil reinforcing techniques to reinforce willow animal hides and dikes. Basic principles of underlying reinforced soil construction were completely investigated by Henry Vidal of France who demonstrated its wide applications and developed the rational design procedure. Next modification of soil reinforcement was conceived by Lee (1975). He suggested a set of design parameters for a reinforced soil structure. Due to continuous increase in population and land cost, demand on availability of land in urban areas was created. The scope of ground improvement techniques improved. The use of natural fibers for soil improvement is highly attractive in countries where such materials are locally and economically obtainable, in view of the preservation of natural environment and cost effectiveness. Several investigations have been carried out (Yetimoglu et al., 1994; King et al., 1993) with regard to the bearing capacity of mat type and fiber type of reinforcement and indicated that both synthetic and natural materials when used as reinforcement in soils are beneficial in increasing the bearing capacity of soil and in reducing the settlement of reinforced soil. Guido et al. (1986) performed a series of laboratory model tests on rectangular and square footings. They indicated that bearing capacity ratio (BCR) at a settlement of 0.1B increases rapidly with increasing strip length up to a length of about 0.7B, after which it remains relatively constant (where B is the width of footing). Omar et al. (1993) have conducted laboratory model tests for the ultimate bearing capacity of strip and square foundations on sand reinforced with geo-grid layers. Based on the model test results, the critical depth of reinforcement and the dimensions of the geo-grid layers for mobilizing the maximum bearing capacity ratio have been determined and compared. Dash et al. (2004) have conducted model studies on a circular footing supported on geo-cell-reinforced sand underlain by soft clay. The test beds were subjected to monotonic loading by a rigid circular footing. The influences of width and height of geo-cell mattress as well as that of a planar geo-grid layer at the base of the geo-cell mattress on the overall performance of the system have been systematically studied through a series of tests. The test results indicated that the provision of geo-cell reinforcement in the overlaying sand layer improves the load carrying capacity and reduces substantially the surface heaving of the foundation bed. The performance improvement increases with increase in the width of the geo-cell layer up to $b/D = 5$, beyond which the improvement is negligible. Here, b =width of geo-cell layer, D = diameter of footing. The overall performance improvement is significant up to a geo-cell height of about two times the diameter of the footing and beyond this, the improvement is marginal. Das et al. (1998) have conducted laboratory tests to find out the effect of transient loading over a foundation supported by geo-grid-reinforced sand. In the test, a square foundation was used and throughout the test, relative density was maintained. In all the tests, the peak value of the transient load per unit area of the foundation exceeded the ultimate static bearing capacity of foundation supported by unreinforced sand. The conclusion drawn from this test is that geo-grid reinforcement reduces the settlement due to transient loading. Madhavi Latha and Amit Somwanshi (2007) presented the results of a laboratory model test on a square footing resting on sand. Laboratory model test and numerical simulation on a square footing supported by sand bed with or without geo-synthetic reinforcement were discussed. Madhavi Latha and Vidya (2006) presented the effect of reinforcement form on strength improvement of geo-synthetic-reinforced sand through tri-axial compression tests. Samples of sand reinforced with geo-synthetics in three different forms, *viz*. horizontal layers, geo-cells and randomly distributed discrete fibers were tested in tri-axial compression and results were analyzed to understand strength improvement in sand due to reinforcement in different forms. In all these investigations, it has been observed that the layout and configuration of reinforcement play a vital role in bearing capacity improvement rather than the tensile strength of the material. Interaction between soil and grid/mat basically depends on mechanical properties of soil (density, grain size distribution, particle size, shape and orientation) as well as on geometrical and mechanical properties of the reinforcement. When grids/mats are used, aperture size of the grid, thickness and shape of rib cross-section, extensibility of longitudinal ribs, flexibility and shear stiffness of transversal ribs and strength of knots matter. Degree of interaction is influenced by interrelation of soil particles and structure of the grid: ratio between particles. Very few investigations are available on the mesh size assessment of behaviour of mat/grid form of reinforcement, as essentially there exists a completely different mechanism involved in different parameters of reinforcement. The objective of the present study is thus to understand the influence of mesh size of mat reinforcement on the bearing capacity. For this study, locally available coir-based materials have been used as reinforcement.

MATERIALS AND METHODS

Sand Used

Sand, a naturally occurring granular material composed of finely divided rock and mineral particles, was used. It was obtained locally at Bangalore. Properties of sand used in the present experimental study are shown in Table 1.

Coir Geotextile

Coir geotextile of mesh sizes (10x10) mm, (20x20) mm and (30x30) mm, procured from Karnataka Coir Industry, Bangalore, was used. Properties of coir geotextile are tabulated in Table 2.

Table 1. Properties of sand used

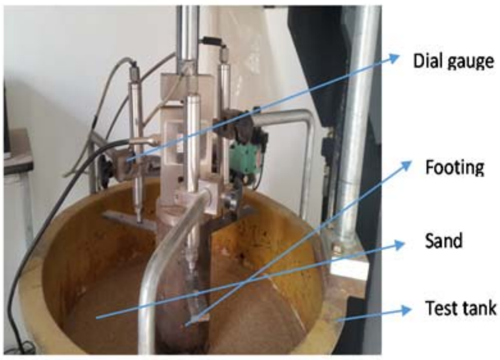
Property	Value
Coefficient of uniformity, (C_u)	4.48
Coefficient of curvature, C_c	0.960
Specific gravity, G	2.66
Maximum density, Υ_d (max.), kN/m^3	16.7
Minimum density, Υ_d (min.), kN/m^3	14.0
Classification of sand	SP

Table 2. Typical properties of coir geotextile

Property	Value
Mass/unit area (g/m^2)	835
Thickness (mm)	6.81
Yarn count Direction A (Ne) Direction B (Ne)	 2/ 0.24^5 2/ 0.22^5
No. of yarns/dm Direction A/dm Direction B/dm	 7 9
Yarn twist (Turns/m) Direction A Direction B	 73 63
Cover factor	10.8
Breaking load (kgf)	25.2
Elongation (%)	31

Methodology for Load Testing

The load cell configuration and coir geotextile used in this study were as shown in Fig. 1(a) and (b). Sand bed was prepared up to the height of 30 cm by compaction in three layers and a relative density of 60% was maintained for all the tests. Coir mats of openings (10x10) mm, (20x20) mm and (30x 30) mm and of a diameter slightly less than the inner diameter of the tank, to avoid side friction, were used and placed at specific depths while preparing the sand bed for each model test. The depth of layer of reinforcement in case of coir mat was labelled as u and model footing tests for various depths of reinforcement to width of footing (u/B ratio) 0.3, 0.6, 1.0 and 2.0 were conducted. Tests with reinforced sand beds were carried out by placing the coir mat at the predetermined depth while preparing the sand bed. After preparing the bed, surface was levelled and footing was placed exactly at the center to avoid eccentric loading. The footing was loaded and the load was applied at a rate of 1.25mm/min, measuring the corresponding footing settlements through the dial gauges D1, D2 and D3.Average of the three readings was considered as final settlement for a given load intensity. Model footings resting on unreinforced sand bed were conducted to compare the results in terms of Bearing Capacity Ratio (BCR). Experiments were repeated with unreinforced sand for comparison purposes.



(a) Coir mat used **(b) Load cell arrangement**

Figure (1): Typical coir geotextile used and load cell arrangement

RESULTS AND DISCUSSION

Effect of Coir Geotextile Reinforcement on Peak Stress at Failure

Results of load settlement measurement were plotted in terms of load intensity *versus* percentage strain for model footings resting on unreinforced and reinforced sand beds. Typical curves at u/B ratios of 0.3,0.6,1 and 2 for coir mat-reinforced sand with different mesh sizes of (10x10) mm, (20x20) mm and (30x30) mm are shown in Fig 2. Peak stress was obtained from these plots. The peak stresses of sand reinforced with various mesh-sized geotextiles are shown in Table 3. It was observed from Table 3 that coir geotextile of (10x10) mm mesh size shows optimum peak stress. Strain corresponding to peak stress was considered as peak strain. In the case of unreinforced sand bed, it is apparent that bearing capacity failure (defined by the peak stress condition) has taken place at a settlement equal to 12% of the footing width. Sand reinforced with coir geotextile of (10x10) mm mesh size bears more load intensity than sand reinforced with coir geotextile of the other two mesh sizes.

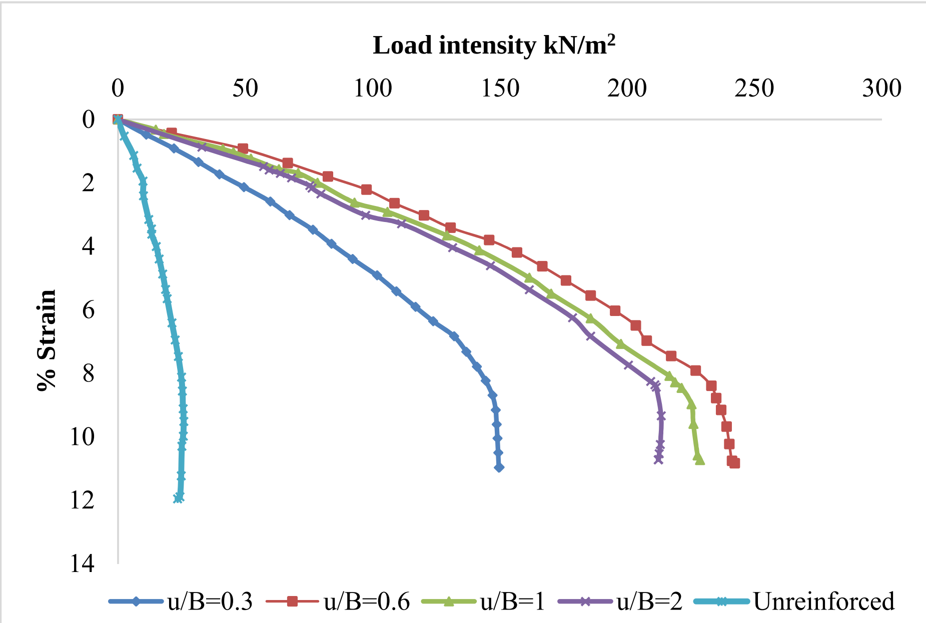


Figure (2): Variation of load intensity *versus* % strain for sand reinforced with coir geotextile of (10x10) mm mesh size

A soil mass with coir reinforcement has higher stiffness and strength than an unreinforced soil mass. Also, at a given imposed stress level, a footing on a reinforced bed has a significantly smaller settlement than one on an unreinforced bed. The increase in bearing capacity with addition of coir geotextile is due to the fact that reinforcing elements interact with soil particles mechanically through surface tension and by interlocking. The function of the interlock or bond is to transfer the load from soil to the reinforcing element by mobilizing the tensile strength of reinforcing elements, which results into an improvement in bearing capacity. Similar trend has been observed by earlier researchers. Sridhar et al. (2011) reported that reinforced soil medium gives more bearing capacity than unreinforced soil bed for square footing and concluded that as reinforcement layer increases, bearing capacity of the soil medium also increases. Reinforced sand carried load as high as eight times the ultimate capacity of footings on unreinforced soil. This behaviour is probably the result of two factors. First, due to its mesh structure, the coir geotextile contains and confines sand more effectively.

Table 3. Peak stress of sand reinforced with different mesh-sized coir geotextiles

u/B ratio	Peak stress (kN/m^2) for (10x10) mm mesh-sized mat	Peak stress (kN/m^2) for (20x20) mm mesh-sized mat	Peak stress (kN/m^2) for (30x30) mm mesh-sized mat
0.3	149.028	134.88	81.588
0.6	241.53	213.58	132.12
1	227.656	204.78	124.668
2	213.334	192.18	116.364

As a result, a better composite material is formed, which helps redistribute the footing load over a wider area. Second, the geotextile reinforcement acts as an interconnected cage and is anchored from both sides of the loading area, due to friction and passive resistance developed at the soil/reinforcement interfaces. Further, because of shear and bending rigidity of the reinforcement layer, the footing load is carried even after shear failure of the sand inside the pockets beneath the footing.

Using these plots, peak stress, corresponding peak strain and BCR were calculated. BCR is defined as the ratio of peak stress for reinforced sand to that of unreinforced sand. For peak strains of 2%, 4%, 6% and 8%, corresponding peak stress and BCR values were calculated for different mesh sizes. The results are tabulated in Tables 4, 5 and 6. It is observed that the ultimate bearing capacity decreases with increase in u/B ratio. BCR value decreased from 9.336 to 8.246 when the u/B ratio was increased from 0.6 to 2 irrespective of mesh size of the coir geotextile. It is clear that placing the reinforcement beyond a depth of 0.6 B beneath the footing in sand will not contribute to increase the ultimate bearing capacity of the footing. This is due to the reason that for higher u/B ratios, the failure surface in sand at ultimate load will be located fully above the first layer of reinforcement beneath the footing.

Table 4. Variation of peak strain with peak stress for various depth ratios for coir geotextile of (10x10) mm mesh

Depth ratio	Peak stress (kN/m^2)	Corresponding peak strain (%)	BCR
Unreinforced sand	25.87	9.51	-
0.3	149.028	10.975	5.76
0.6	241.53	10.76	9.336
1	227.656	10.59	8.8
2	213.334	9.34	8.246

Table 5. Variation of peak strain with peak stress for various depth ratios for coir geotextile of (20x20) mm mesh

Depth ratio	Peak stress (kN/m^2)	Corresponding peak strain (%)	BCR
Unreinforced sand	25.87	9.51	-
0.3	134.88	9.64	5.213
0.6	213.58	9.25	8.255
1	204.78	9.45	7.915
2	192.18	8.88	7.428

Table 6. Variation of peak strain with peak stress for various depth ratios for coir geotextile of (30x30) mm mesh

Depth ratio	Peak stress (kN/m^2)	Corresponding peak strain (%)	BCR
Unreinforced sand	25.87	9.51	-
0.3	81.588	12.131	3.153
0.6	132.12	11.98	5.107
1	124.668	11.865	4.819
2	116.364	10.321	4.498

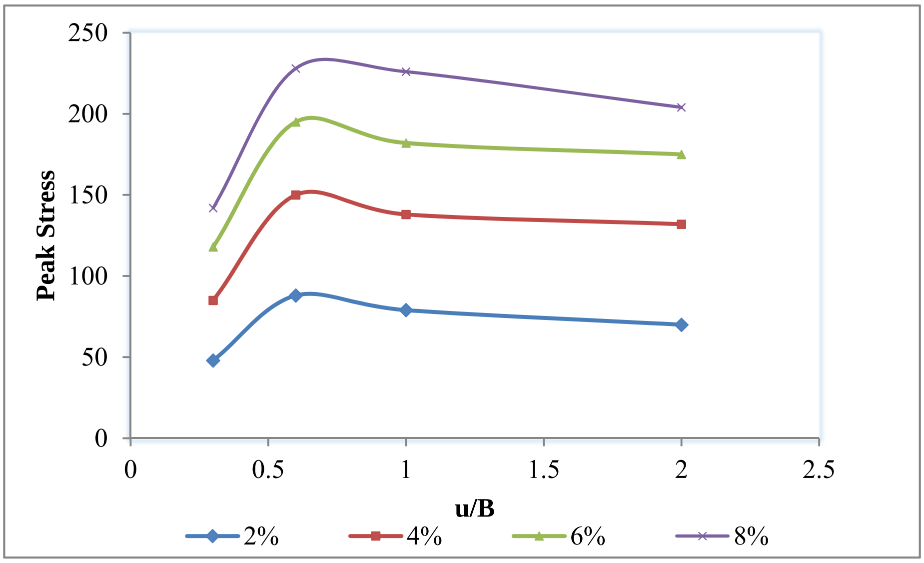


Figure (3): Typical variation of peak stress with u/B ratio for various values of settlement to width (S/B) ratio for coir geotextile of mesh size (10x10) mm

Fig. 3 shows the typical variation of peak stress with u/B ratio for settlement to width (S/B) ratios of 2%, 4%, 6% and 8% for coir geotextile of mesh size (10x10) mm. It was observed that peak stress increases from the reinforcement depth 0.3B to 0.6B irrespective of various values of settlement to width (S/B). Then, peak stress decreases with reinforcement depth from 0.6B to 2B.

Fig.4 shows the variation of bearing capacity ratio with u/B ratio for coir geotextile of different mesh sizes. It was observed that coir geotextile of (10x10) mm mesh size shows more efficiency than the other two mesh sizes in terms of BCR. It can be concluded that the increase in mesh size leads to a decrease in BCR. Also, there was no much variation observed between coir geotextile of (10x10) mm and (20x20) mm mesh size. On the durability of geotextile, few researchers worked and found out that the performance was good for a number of years. Colin et al. (1986) found no degradation for geotextiles buried for seven years in moist organic rich soil. Finally, it can be concluded that coir geotextile will modify mode deformation, improving the overall stability of structure and limiting failure to localized areas.

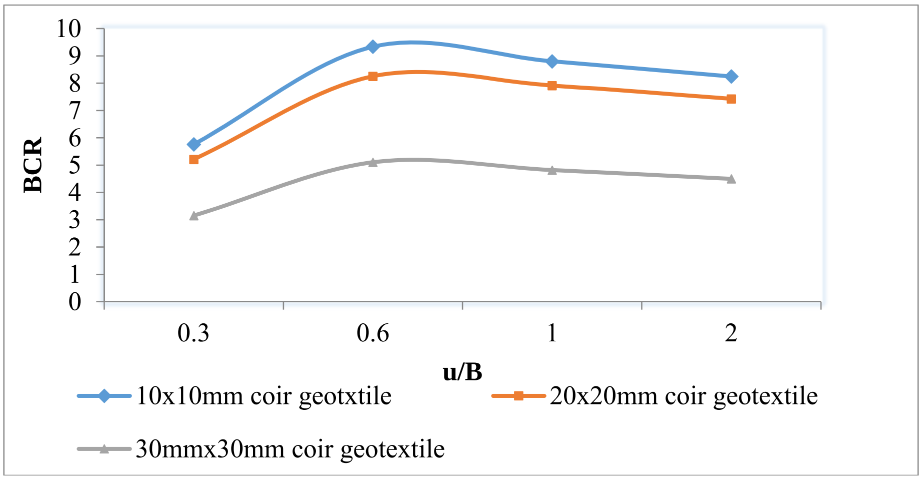


Figure (4): Variation of bearing capacity ratio with u/B ratio for coir geotextile of different mesh sizes

CONCLUSIONS

On the basis of the present experimental study, the following conclusions have been drawn:

The forms of reinforcement mat/grid have considerable influence on strength of reinforced sand. Peak stress, and hence BCR, decreases with increases in u/B ratio, for mat-reinforced sand. The size of the mat opening has a significant influence on BCR of coir mat-reinforced sand. The smaller the opening size of mat, the greater the interlocking effect, which increases the BCR of mat form of reinforcement. Due to inclusion of reinforcement, bearing capacity of footing increases as settlement to width (S/B) ratio increases, when compared to unreinforced sand.

Reinforced sand carries load as high as eight times the ultimate capacity of footings on unreinforced soil. At a given imposed stress level, the footing on a reinforced bed has a significantly smaller settlement than one on an unreinforced bed. The peak stress increases from the reinforcement depth 0.3B to 0.6B irrespective of various values of settlement to width ratio (S/B). Sand reinforced with coir geotextile of (10x10) mm mesh size bears more load intensity than sand reinforced wit coir geotextile of the other two mesh-sized mats.

REFERENCES

A1-Refeai, T.O. (1991). "Behaviour of granular soils reinforced with discrete randomly oriented inclusions". Journal of Geotextiles and Geomembranes, 10, 319-333.

Binquet, J., and Lee, K.L. (1975). "Bearing capacity tests on reinforced earth slabs". Journal of Geotechnical Engineering Division, 101, 1241-1255.

Collin, J.G. (1986). "Earth wall design". Ph.D. Thesis, University of California, Berkeley, California, USA, 440 p.

Collin, J.G., Editor. (1997). "Design manual for segmental retaining walls". Second Edition, National Concrete Masonry Association, Herndon, Virginia, USA, 289 p.

Das, B.M., Shin, E.C., and Omar, M.T. (1994). "The bearing capacity of surface strip foundations on geogrid-reinforced sand and clay: a comparative study". Geotech. Geol. Eng., 12, 1-14.

Dash, S.K., Rajagopal, K., and Krishnaswamy, N.R. (2007). "Behaviour of geo-cell-reinforced sand beds under strip loading". Canadian Geotechnical Journal, 44, 905-916.

Guido, V.A., Chang, D.K., and Sweeney, M.A. (1986). "Comparison of geogrid- and geotextile-reinforced earth slabs". Canadian Geotechnical Journal, 23, 435-440.

Huang, C.C., and Tatsuoka, F. (1990). "Bearing capacity of reinforced horizontal sandy ground". Journal of Geotextiles and Geomembranes, 9, 51-82.

Kaur, A., and Kumar, A. (2014). "Bearing capacity of eccentrically-obliquely loaded footings resting on fiber-reinforced sand". Geotechnical and Geological Engineering, 32, 151-166.

Khing, K.H., Das, B.M., Puri, V.K., Cook, E.E., and Yen, S.C. (1993). "Bearing capacity of strip footing on geogrid-reinforced sand". Journal of Geotexttiles and Geomembranes, 12, 351-361.

Kumar, A., Walia, B.S., and Saran, S. (2005). "Pressure-settlement characteristics of rectangular footings on reinforced sand". Geotechnical and Geological Engineering, 23, 469-481.

Kumar, A., and Saran, S. (2004). "Closely spaced rectangular footings on reinforced sand". Geotechnical and Geological Engineering, 22, 497-524.

Kumar, A., and Walia, B.S. (2006). "Bearing capacity of square footings on reinforced layered soil". Geotechnical and Geological Engineering, 24, 1001-1008.

Madhavi Latha, G., and Murthy, V.S. (2007). "Effects of reinforcement form on the behavior of geosynthetic-reinforced sand". Journal of Geotextiles and Geo-membranes, 25, 23-32.

Madhavi, L., and Amit, S. (2009). "Bearing capacity of square footing on geosynthetic-reinforced sand". Journal of Geotextiles and Geomembranes, 27, 281-294.

Omar, M.T., Das, B.M., Puri, V.K., and Yen, S.C. (1993). "Ultimate bearing capacity of shallow foundations on sand with geogrid reinforcement," Canadian Geotechnical Journal, 30, 545-549.

Pothal, G.K., and Rao, G.V. (2007). "Behaviour of a strip footing on compacted pond ash reinforced with coir geotextiles". International Journal of Advanced Technology in Civil Engineering, 7-13.

Saran, S., Kumar, S., Garg, K.G., and Kumar, A. (2007). "Analysis of square and rectangular footings subjected to eccentric inclined load resting on reinforced sand". Geotechnical and Geological Engineering, 25, 123-137.

Sreedhar, M.V.S., Rao, G.V., and Reddy, R.R. (2011). "Bearing capacity of pond ash reinforced with non-woven geotextile". In: Proc. of Indian Geotechnical Conference, 545-548.

Yetimoglu, T., Wu, J.T.H., and Saglamer, A. (1994). "Bearing capacity of rectangular footings on geogrid-reinforced sand". Journal of Geotechnical Engineering, 120, 2083-2099.