

A Review on “Parametric Study of Geosynthetic Material below Strip Footing”

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ABSTRACT: The use of geosynthetic materials to improve the bearing capacity and settlement performance of shallow foundation has gained attention in the field of geotechnical engineering. For the last three decades, several studies have been conducted based on the laboratory model and field tests, related to the beneficial effects of the geosynthetic materials, on the load bearing capacity of soils in the road pavements, shallow foundations, and slope stabilizations. Several researchers have demonstrated that the ultimate bearing capacity and the settlement characteristics of the foundation can be improved by the inclusion of reinforcements in the ground. Out of several studies, very few studies are available on the two-layer soil systems. Generally, all the studies are ultimately related to improvement in the bearing capacity of soil using reinforcing materials and related to the effect of various parameters (e.g. u/B , h/B , b/B , and D_f/B) on bearing capacity. In this paper, review is taken to know the work carried out by different researchers on the effect of providing geosynthetic material as reinforcement and other parameters (e.g. u/B , h/B , b/B , and D_f/B), on the bearing capacity and settlement behaviour of unreinforced and reinforced soil systems.

KEYWORDS: Soil system, geogrid, geocomposite, bearing capacity, settlement.

I. INTRODUCTION

Construction of building and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements. Various soil improvement techniques have been used to enhance the engineering properties of soil. Soil reinforcement by Geosynthetic material is considered an effective ground improvement method because of its cost effectiveness, easy adaptability, and reproducibility. Geosynthetics are particularly suitable for soil reinforcement. Geosynthetic products typically used as reinforcement elements are nonwoven geotextiles, woven geotextiles, geogrids, and geocells. Geosynthetic inclusions within a soil mass can provide a reinforcement function by developing tensile forces which contribute to the stability of the reinforced soil structure.

Reinforced soil vertical walls generally provide vertical grade separations at a lower cost than traditional concrete walls. Reinforced wall systems involve the use of shotcrete facing protection or of facing elements such as precast or cast-in-place concrete panels. Alternatively, steepened reinforced slopes may eliminate the use of facing elements, thus saving material costs and construction time in relation to vertical reinforced walls.

The main objective of this research is to focus on the strength behaviour of soil reinforced with geosynthetic material. Soil reinforcement technology is given the utmost importance in present days to adapt weak soil into the competent stable ground for different civil engineering applications.

II. LITURATURE REVIEWS

ElifCiceka et.al.(2015) [1] carried out laboratory tests to investigate and present the result of effect of reinforcement length with laboratory model tests of a surface strip footing on unreinforced and reinforced sand beds. Multiples of footing width B was employed in the tests, namely B , $2B$, $3B$, $5B$ and, in some tests, even $7B$. The type and number of

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reinforcements were also varied to determine whether these parameters had an influence on the optimum reinforcement length. The comprehensive results from laboratory model tests on strip footings supported on a woven geotextile and different Geogrids are presented. The load–settlement and Bearing Ratio values obtained from the model test program were compared.

S. A. Naeini et al. [2] studied the effect of geosynthetic reinforcing on bearing capacity of a strip footing resting on geo-reinforced clayey slopes. The results of a series of numerical study using finite element analyses on strip footing upon both reinforced and unreinforced clayey slopes were presented.

C.R. Patraet al.[3] Performed the laboratory model test results for the ultimate bearing capacity of a strip foundation supported by multi-layered geogrid-reinforced sand. The depth of embedment of the model foundation, d_f , was varied from zero to B (width of foundation). Only one type of geogrid and one variety of sand at one relative density were used. The ultimate bearing capacity obtained from the model test program has been compared with the theory proposed by Huang and Menq, [1977, Journal of Geotechnical and Geo environmental Engineering ASCE 123(1), 30–36]. Based on the present tests, it appears that the theory provides a conservative prediction of the ultimate bearing capacity.

Guido et al. [4] performed a series of laboratory model tests on rectangular and square footing. 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. They also found similar conclusions using square sheets of geogrid to reinforced sand.

Omar et al. [5] have conducted laboratory model test results for the ultimate bearing capacity of strip and square foundations on sand reinforced with geogrid layers. Based on the model test results, the critical depth of reinforcement and the dimensions of the geogrid layers for mobilizing the maximum bearing capacity ratio have been determined and compared. From this experiment, they have drawn conclusions that for development of maximum bearing capacity, the effective depth of reinforcement are $2B$ for strip footings and $1.4B$ for square footings. Further they have observed that maximum width of reinforcement layers for optimum mobilization of maximum bearing capacity ratio is $8B$ for strip footings and $4.5B$ for square footings

Dash et al. [6] presented the results from laboratory model tests on a strip footing supported by sand reinforced with a geocell mattress. The parameters varied in the testing program include pattern of geocell formation, pocket size, height and width of geocell mattress, depth of the top of geocell mattress, tensile stiffness of the geogrids used to fabricate geocell and the relative density of sand. With the provisions of geocell reinforcement, failure is not observed even at a settlement equal to 50% of the footing width and a load as high as 8 times the ultimate bearing capacity of the unreinforced sand. The performance improvement is significant up to a geocell height equal to 2 times the width of the footing. Beyond that height, the improvement is marginal. The optimum width of the geocell layer is around 4 times the footing width at which stage the geocell would intercept all the potential rupture planes formed in the foundation soil.

Mandal and Manjunath [7] have conducted an extensive program of monotonically loaded footings. The study is aimed at investigating the effects of a single layer of geosynthetic reinforcing material on the improvement of bearing capacity and settlement characteristics of strip footings under plane strain conditions supported by compacted sand and also to study the effectiveness of placing the reinforcing layer horizontally and vertically. The bearing capacity increase due to the use of a geosynthetic layer has been expressed in terms of a non-dimensional bearing capacity ratio (BCR). The study shows that the BCR could be improved up to 1.8 times when reinforcement is suitably located relative to the footing. The horizontal reinforcement is found to be more effective in improving the bearing capacity as compared to the vertical reinforcement.

Shin et al. [8] have done laboratory test to determine the bearing capacity of strip footing supported by sand reinforced with multiple layers of geogrid of one type. The results show that the ratio of the critical depth of reinforcement below

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the footing w.r.t the width of footing is about 2. For a given reinforcements depth ratio, the BCR w.r.t ultimate load increases with the embedment ratio of the foundation.

Dash et al. [9] presented the results from laboratory model tests on a strip footing supported by sand reinforced with a geocell mattress. The parameters varied in the testing program include pattern of geocell formation, pocket size, height and width of geocell mattress, depth of the top of geocell mattress, tensile stiffness of the geogrids used to fabricate geocell and the relative density of sand. With the provisions of geocell reinforcement, failure is not observed even at a settlement equal to 50% of the footing width and a load as high as 8 times the ultimate bearing capacity of the unreinforced sand.

Busehehrian and Hataf [10] have performed tests to investigate the bearing capacity of circular and ring footings on reinforced sand along with numerical analysis. The effects of the depth of the first layer of reinforcement, vertical spacing and number of reinforcement layers on bearing capacity of the footings are investigated. Both the experimental and numerical studies have indicated that when a single layer of reinforcement layer is used, there is an optimum reinforcement embedment depth for which the bearing capacity is greatest. There is also an optimum vertical spacing of vertical layers for multilayer reinforced sand. The bearing capacity also increases with increasing number of reinforcement layers, if they are placed within a range of effective depths. They have drawn the conclusions that for circular footings on reinforced sand, the maximum bearing capacity occurs at different values of u/D and z/D depending on the number of reinforcement layers and are not unique as reported by some researchers, where u = depth of first layer of reinforcement, z = vertical distance between layers, D = circular footing diameter or outer diameter of ring footing. For ring footings, however it has been concluded that increasing the number of reinforcement layers leads to the decrease of the optimum values of z . Also it is concluded that a maximum threshold exists for the effect of the rigidity of reinforcement and therefore choosing a more rigid reinforcement does not always lead to better results in terms of BCR for circular and ring footings on reinforced sand.

Dash et al. [11] have done model studies on circular footing supported on geocell reinforced sand underlain by soft clay. The test beds are subjected to monotonic loading by a rigid circular footing. The influence of width and height of geocell mattress as well as that of a planar geogrid layer at the base of the geocell mattress on the overall performance of the system has been systematically studied through a series of tests. The test results indicate that the provision of geocell reinforcement in the overlaying sand layer improves the load carrying capacity and reduces the surface heaving of the foundation bed substantially. The performance improvement increases with increase in the width of the geocell layer up to $b/D = 5$, beyond which it is negligible. (Here, b = width of geocell layer, D = diameter of footing). The overall performance improvement is significant up to a geocell height of about two times the diameter of the footing and beyond this, the improvement is marginal.

Benrabah et al. [12] have done analytical work and undertaken experiments to explore the changes in stress distribution for a sand medium reinforced by geomembrane layers. The three results i.e. 1. from experiments; 2. using the Boussinesq method and 3. using the fast lagrangian analysis of continua calculation program (FLAC) are established. They have found that even in the case of loaded reinforced soil, the vertical stress distribution follows Boussinesq's formula, especially for high loads and despite the discrete nature of the experimental medium being used. This may be due to the fact that in the foundation zone, the soil grains are structured in such a way that they closely approximate a continuous medium. In the case of loaded reinforced soil, the presence of reinforcing layers has no bearing on the vertical stress, while the horizontal stress shows a large increase. The use of FLAC program leads to slightly lower calculated stress values, however the increase of the horizontal stress can be predicted by FLAC.

Aigen Zhao [13] has presented the failure criterion for a reinforced soil composite. The failure criterion of reinforced soil presented here is anisotropic due to inclusion of geosynthetic reinforcement with preferred direction. The slip line method in relation with the derived failure criteria can be used for calculating the failure loads of geosynthetic reinforced soil structures. The stress characteristics of reinforced slopes, retaining walls and foundations are presented

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and compared with those without reinforcement. The inclusion of geosynthetic reinforcement enlarges the plastic failure region in a reinforced soil structure and significantly increases the load bearing capacity.

Palmeira et al. [14] have stated that geosynthetic reinforcement can be used to increase the factor of safety of embankments on soft soils, particularly for shallow foundation layers. They have presented back analysis of some reinforced embankments that can be found in literature using stability methods commonly employed. The results obtained suggest that these simple methods are useful tools for predicting factor of safety of reinforced embankments when the required input data are available and accurate.

Lopes and Ladeira [15] have studied the interaction between well graded gravelly sand and a uniaxial geogrid. The influence of the confinement pressure, soil density and displacement rate on the pull out resistance of the geogrid is discussed by analyzing the results of the pull out tests.

The major conclusions of this analysis:

1. An increase in the confinement stress, soil density or displacement rate increases the pull out resistance of the geogrid.
2. The increase in the pull out resistance when the confinement stress increases, is not in proportion to the increase in the normal stress because there is reduction in the adherence factor.

Chunsikyoo [16] has presented the results of laboratory model tests on the bearing capacity behavior of a strip footing supported by a geogrid reinforced earth slope. A wide range of boundary conditions including unreinforced conditions, are tested by varying parameters such as geogrid length, number of geogrid layers, vertical spacing and depth of top most layer of geogrid. He results are then analyzed to establish both qualitative and quantitative relationships between the bearing capacity and the geogrid parameters. He has found that for reinforced slope loaded with a footing, the failure zone tends to become wider and deeper than that for the unreinforced slope. The bearing capacity of a footing situated on the crest of sloping ground can be significantly increased by the inclusion of the layers of geogrid as in the level ground.

Zhao et al. [17] have shown the utility of geogrid reinforcement in stabilizing the weak subgrade of a liquid retention pond in Nebraska. The results of the field tests indicates that the multilayer geogrid is capable of providing the subgrade support needed to achieve the required placement and compaction of a 0.6m thick lagoon clay liner over a weak subgrade. The test also confirms that without the geogrid, the required compaction cannot be achieved. The use of multi layer geogrid in this project has eliminated a 0.3m crushed stone layer which resulted in a significant savings in material and excavation cost.

Manjunath and Diwakar [18] have conducted experimental investigation to determine the influence on the performance of a strip footing located at and near the crest of a granular slope fill with the inclusion of reinforcing layer within the body of the fill. The investigations have been carried out by varying edge distances of the footing for three different slope angles and for two types of geogrids. Both load settlement behavior and the ultimate bearing capacity of the footing show considerable improvement by the inclusion of a reinforcing layer at appropriate location in the body of the sloped fill. The conclusion drawn from the tests are:

1. The insertion of a geogrid reinforcement layer at suitable location of the sloped fill will considerably increase the load carrying capacity as well as stability of footing on slopes.
2. At an edge distance of 5.0B, the ultimate bearing capacity of footing becomes independent of the slopes.
3. At any given slope angle, the footing on reinforced slope exhibits much higher load bearing capacity than that of unreinforced slope.

Andrzej Sawicki [19] has proposed a simple model of the elasto-plastic soil reinforced with the visco-elastic geosynthetics. Two modes of reinforced soil behavior are considered within the framework of mechanics of composite materials. The first mode corresponds to the elastic soil (E-V mode) and the second one to plastic soil (P-V mode). During the E-V mode, the initial stress in reinforcement decreases, causing the regrouping of micro stresses in the soil down to the stage when a yield condition in the soil is reached. Then the P-V mode begins during which the stress in

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reinforcement remains constant but the macro strains increase due to creep. Here a method of estimating the initial stresses in rheological soil has been presented.

Gurung [20] has done a laboratory study on the tensile response of unbound granular base road pavement model using geosynthetics. He also explained the structural response of a pavement base layer under applied tensile forces in a laboratory set up. Experimental results show higher tensile resistance of geosynthetics included in the pavement base and such high tensile responses will significantly influence the behavior of the pavement surfaces. The tensile peak strength of a pavement reinforced with geogrid is higher than pavement reinforced with geotextile. The high tensile strength of a reinforced pavement will have significant increase on the behavior of the pavement surfaces under traffic loading and environmental movements.

III. SUMMARY

Various types of Geosynthetic material such as geogrid, Geocell, Geocomposite, woven & non-woven geotextile, etc. can be used as a reinforcement material in different soil types for strengthening the bearing capacity of soil. Following table summarizes several previous researches about the effect of geosynthetic material & optimum parameters of soil reinforcement.

Table 1. Summary of Previous Research Studies on Geosynthetic Reinforcement

SR.NO.	NAME OF AUTHER	TYPE OF GEOSYNTHETIC USED	CONCLUSION
1.	S. K. Dash et al. (2004)	Geocell reinforcement	Failure is not observed even at a settlement equal to 45% of the footing width & a load as high as 8 times the ultimate bearing capacity of the unreinforced soil.
2.	Elif Ciceka et al. (2015)	Woven Geotextile And Different Geogrids	Improvement in subgrade
3.	S. A. Naeini et al.	Geogrid	Bearing capacity increased
4.	C. R. Patra et al.	One Type Of Geogrid & One Type Of Sand	Ultimate bearing capacity increased
5.	Guido et al. (1980)	Square Sheets Of Geogrid	Bearing capacity ratio increased
6.	Dash et al. (2001)	Geocell Mattress	Enhances the load carrying capacity and the stability against rotation
7.	Mandal and Manjunath (1994)	Single Layer Of Geosynthetics	The BCR improved up to 1.8 times
8.	Dash et al. (1994)	Geocell Mattress & Planar Geogrid Layer	Improves the load carrying capacity and reduces the surface heaving of the foundation bed
9.	Benrabah et al. (1996)	Geomembrane Layers	Gives the effect of vertical stress on foundation bed.
10.	Palmeira et al. (1998)	Geosynthetic Reinforcement	Increases the factor of safety of embankments on soft soils, particularly for shallow foundation layers
11.	Lopes and Ladeira (1996)	A Uniaxial Geogrid	An increase in the confinement stress
12.	Zhao et al. (1997)	Multi-layer Geogrid	Stabilizes the weak subgrade & significant savings in material and

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			excavation cost
13.	Andrzej Sawicki (1998)	Visco-elastic Geosynthetics	The initial stress in reinforcement decreases
14.	Gurung (2003)	Geotextile & Geogrid	Increases tensile strength
15.	Dash et al. (1994)	Geocell Mattress & Planar Geogrid Layer	Improves the load carrying capacity and reduces the surface heaving of the foundation bed
16.	Aminaton Marto et al. (2017)	Geosynthetic geogrid	Improvement in ultimate bearing capacity increases with increased no. of reinforcement layers. With an increase in no. of planar reinforcement layers & reinforcing width, the bearing capacity of the foundation increases & the shallow foundation settlement decreases.
17.	P. K. Kolay et al. (2013)	Geogrid at different depths (Silty clay soil & sand layer)	The bearing capacity of soil increases with an average of 16.67% using one geogrid layer.
18.	S. N. Moghaddas Tafreshi (2012)	Geotextile reinforced sand bed under a combination of static & repeated loads	The rate of footing settlement decreases significantly as the no. of loading cycles increases.
19.	Radhey Sharma et al. (2008)	Geogrid	Linear increase of BCR with increase of no. of reinforcement layers.
20.	Dash et al. (2001)	Geocell Mattress	Failure is not observed even at a settlement equal to 50% of the footing width & a load as high as 8 times the ultimate bearing capacity of the unreinforced sand.
21.	Madhavi Latha & Amit Somawanshi (2009)	Strong & weak biaxial geogrid, uniaxial geogrid & geonet.	Optimum width of reinforcement is about 4 times the width of the square footing.

IV. CONCLUSION

From the above research work done by different researchers, following conclusions are drawn:

1. The type, width & depth of Geosynthetic material below foundation is decided by considering the different properties of soil.
2. The bearing capacity increases by the use of a geosynthetic layer, has been expressed in terms of a non-dimensional bearing capacity ratio (BCR).
3. The study shows that the BCR could be improved when reinforcement is suitably located relative to the footing.
4. The horizontal reinforcement is found to be more effective in improving the bearing capacity as compared to the vertical reinforcement.
5. With the provisions of geocell reinforcement, failure is not observed even at a settlement equal to 50% of the footing width and a load as high as 8 times the ultimate bearing capacity of the unreinforced sand.
6. The inclusion of geosynthetic reinforcement enlarges the plastic failure region in a reinforced soil structure and significantly increases the load bearing capacity.

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