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Settlement in Geosynthetic Reinforced Square Footing over Plastic Soil

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Abstract. Construction over Plastic soil can cause adverse effects on the performance of the earth structures, due to the low load carrying capacities of such soils. Many civil engineering structures like buildings, Major and Minor bridges, Under passes, and Flyovers collapse and undergo crack formation in areas where Plastic soil with poor load carrying capacity is present. Geosynthetic reinforcements have successfully been used in recent times as a low cost method for reinforcing such soils to improve their stability and bearing capacity. However, to recover significant benefit from the geosynthetics, the materials need to be placed at optimum locations within the foundation. Hence, in this paper, small scale laboratory footing tests have been performed to study the effect of depth of the first layer of reinforcement (u), Number of reinforcement layers (N), width of reinforcement (b) and the vertical spacing between reinforcements (h). The results obtained demonstrated that the placement and the loading condition of the geosynthetics greatly influences the bearing capacity of the foundation. The results obtained from the experimental analysis were used for the computation of a regression model in R Studio, for the determining the load carrying capacity of reinforced Soil foundation. The model presented obtained a confidence level of more than 95%, when parameters significant for the computation of load carrying capacity of square footing were included, thus showing great convergence with the experimental results

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Keywords: Plastic soil; Square footing; Geogrid; Geotextile.

1. Introduction

In Geotechnical engineering, failure of a foundation constructed over Plastic soil is a very prevalent issue. The foundation may lose its stability due to poor load carrying capacity of the surrounding soil, which results in higher settlements than the acceptable values and deterioration in the load carrying capacity of the soil. Many researchers have proffered many solutions to mitigate these problems, through different soil improvement techniques. The first comprehensive study on soil reinforcement was conducted by [1], wherein aluminium strips were used to reinforce the sand beds. [2] examined the performance of strip footings on geogrid reinforced sand bed over a soft clay slope. The study showed that the use of geogrid layers in the replaced sand not only significantly improves the performance of footing but also leads to high reduction in the depth of reinforced sand layer required to achieve the allowable settlement. [3] carried out the laboratory model footing tests on reinforced soil bed and reported their results as a comparative study of effectiveness of geogrid and geotextile as soil reinforcement. The results showed that the geogrid is more efficient than the geotextile in respect of bearing capacity of foundation on reinforced sand. In in this paper, small scale laboratory tests have been performed and obtained results are presented.

2. Material used:

2.1 Soil: The geotechnical properties of the soil were determined as per Indian standards listed in Table 1. The soil was classified as a low compressible soil.

2.2 Geosynthetics: A single type of geogrid, and geotextile were used in this study. The geogrid used was bi-oriented and was made of polypropylene thermoplastic, whereas, the Geotextile used was woven type also made of polypropylene material. The material testing certificate of geosynthetics as provided by the manufacturer is tabulated in Table 2. The geogrid and geotextile in the study have been represented by GGR and GTX respectively, throughout the study.

Table 1. Geotechnical properties of soil

Properties	Values	Protocols/Standards
Specific Gravity	2.67	IS 2720 (Part III)
Liquid limit (%)	29	IS 2720 (Part V)
Plastic limit (%)	20	IS 2720 (PartV)
Plasticity index (%)	9	IS 2720 (Part V)
Maximum dry Unit Weight (kN/m^3)	17.6	IS 2720(Part VII)

Optimum Moisture Content (%)	15	IS 2720(Part VII)
Angle of Friction	22˚	IS 2720 (Part XI)

Table 2. Technical characteristics of geosynthetics (Courtesy: Supplier's Data)

Geosynthetic	Property	Data	Unit	Test Method
Geogrid	Mesh Type	Quadrangular apertures	-	-
	Polymer Type	Polypropylene	-	-
	Aperture Size	30 × 30 (MD × CMD)	mm	-
	Stiffness at 0.5% Strain	550 × 350 (MD × CMD)	kN/m	ISO-10319
Geotextile	Tensile Strength	475 × 384 (MD × CMD)	kN/m	IS 1969
	Opening Size	0.075	mm	ASTM D4751
	Weight of fabric	200	g/m^2	ASTM D5261
	Elongation at break	30 × 28 (MD × CMD)	(%)	IS 1969

3. Experimental Setup

3.1 Preparation of test bed

Test bed was prepared with dimensions of 750 mm × 450 mm × 600 mm (L × B × H). Initially the soil was air dried and pulverized and then it was compacted at its maximum dry unit weight of 17.6 kN/m^3. Predetermined water content was thoroughly mixed to soil to achieve the optimum moisture content, i.e. 15%. In case of unreinforced condition, soil was compacted in three lifts, whereas for the reinforced case, the thickness of each lift was decided according to the spacing between the reinforcements. The soil was then poured into the tank and compacted using a rammer with a base of 150 mm diameter up to a marked height. During the test, the height of fall of the rammer, number of blows to be given, and the required amount of soil sample was determined to maintain the condition of uniformity of soil sample in the tank. At the end of compaction, a spirit level was used to check the alignment of the horizontal surface of prepared test bed.

3.2 Layout of Geosynthetics

The geosynthetic configurations were decided according to testing procedure described in the testing programme i.e. at the respective u/B, b/B, h/B, ratios, and number of reinforcement layers N. All the Five different dimensionless parameters (i.e. u/B, b/B, d/B, N and h/B) were varied to ascertain the optimums in geosynthetic placements. Geometry of geosynthetics reinforced bed is shown in Fig 1.

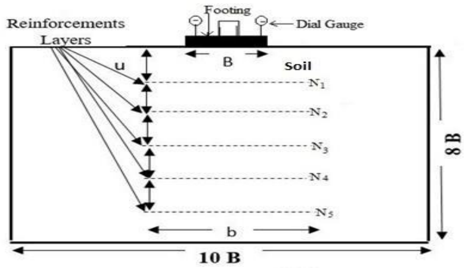


Fig. 1 Geometry of geosynthetics reinforced bed

3.3 Test Setup

A number of laboratory footing tests were conducted on unreinforced and reinforced soil by using testing facilities developed at laboratory. The dimensions of the test set up are as follows: Length = 750 mm, width = 450 mm and height = 600 mm. The back and sides of the tank was fabricated from 20 mm thick steel sheet braced with structural steel member whereas front side of the tank consisted of acrylic sheet of 20mm thickness for visual observation. An angle was fixed on the face of acrylic sheet to prevent its buckling during the compaction and loading. Inner surface of tank was greased to prevent the adverse effect of friction on the test results. A steel plate of size 75 mm × 75 mm was used as a model footing and the dimensioning of the tank were done in accordance with the footing width, so as to avert the boundary effect. Hence, dimensions of 10B, 6B, and 8B were chosen as the length, width and height of the tank respectively, where B is the model footing width, i.e. 75 mm. The base of the footing was kept rough by gluing the sand with epoxy glue. The tank was tested in loading frame consisting of two rigid and heavy steel plate columns of thickness 150mm attached to top head of the loading frame. A load cell of 25kN capacity was placed at centre between the footing plate and upper platen to avoid the eccentric loading. The output of the load cell was logged using a data logger in the form of pressure. Two dial gauges with accuracy of 0.001mm were used at points diametrically opposite to the footing. Average reading obtained by both the dial gauges was considered for settlement analysis. The test bed was tested as per the provision of (ASTM 1997) up to a settlement of 20 mm. where the load increments were applied and maintained at the obtained value until the rate of settlement was less than 0.03 mm/min over three consecutive minutes. Sitting load was applied initially over the footing to fix the footing over the soil base, so as to obtain planar strain conditions.

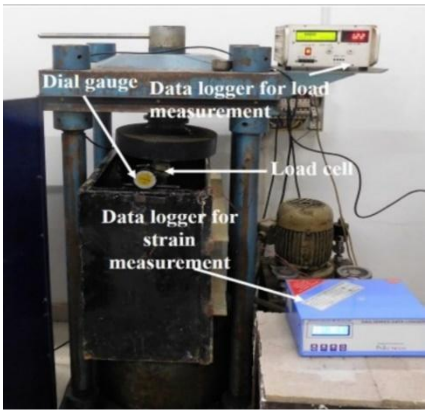


Fig. 2 General arrangements of testing setup

3.4 Testing Procedure

The aim of the study was to investigate the effect of reinforcements in bearing capacity of reinforced soil foundation. The model tests were conducted with both the reinforcements i.e. GGR, and GTX. The detailed experimental programme is shown in Table 3. Test series"A" was carried out on unreinforced soil footing bed to compare the results obtained by tests conducted on reinforced soil bed. Two series of tests (B and C) were conducted for both the reinforcements i.e. GGR and GTX. Initially, at reinforcement width equal to 5B, the u/B values were varied form 0.17, 0.34, 0.51, 0.68 and 0.85 respectively. Effect of number of reinforcement layers was estimated by fixing the top layer at maxima obtained from the previous test and varying the number of reinforcements until the effect of the reinforcement becomes diminished, or becomes considerably insignificant for any further extensions in number of reinforcement layers. The vertical spacing between the reinforcement layers was also fixed at optimum u/B value. Similar testing procedure were adopted for different reinforcement widths i.e. 4B and 6B. The effect of spacing between two corresponding reinforcements was analysed by varying the distance between two reinforcements by a factor of 0.08 B, 0.16 B, 0.24 B, 0.32 B and 0.4 B respectively and fixing the top layer at the optimum obtained from the previous tests.

Table 3 Experimental programme

Test Series	**Reinforcement**	***N***	***u/B***	***b/B***	**h/B**	**No. of test**	**Remarks**
A	Unreinforced soil	-	-	-	-	3	To estimate the improvements due to reinforcement
B	GGR	1	0.17,	5B	-	5	To find out the

Test Series	**Reinforcement**	***N***	***u/B***	***b/B***	**h/B**	**No. of test**	**Remarks**
			0.34,0.51,0.68,0.85				optimum *u/B* value
		1,2,3,4,5	Optimum depth	5B	0.34B	5	To find the effect of number of layers of geogrid
		Optimum depth	0.34	4B, 5B, 6B		15	To check the optimum values of geogrid width and number of geogrid layers.
		2	0.34	5B	0.08 B, 0.16 B, 0.24B, 0.32 B and 0.4 B	5	To check the effect of vertical spacing between reinforcements
C	GTX	1	0.17, 0.34, 0.51, 0.68,0.85	5B		5	To find out the optimum *u/B* value
		1,2,3,4,5	Optimum depth	5B	0.34B	5	To find the effect of number of layers of geogrid
		Optimum depth	0.34	4B, 5B, 6B		15	To check the optimum values of geotextile width and number of geotextile layers.
		2	0.34	5B	0.08 B,0.16 B, 0.24 B, 0.32 B and 0.4 B	5	To check the effect of vertical spacing between reinforcements

4. Results and Discussion

4.1 Determination of optimum depth of first layer of reinforcement

The settlement measured from the dial gauges is considered as footing settlement and denoted as (s). The Ratio of footing settlement (s) to the width of footing (B) is defined as settlement ratio (SR), indicated in percentage. A non-dimensional parameter bearing capacity ratio (BCR) was calculated at each settlement ratio to give an incisive account of the improvement in load carrying capacity due to inclusion of reinforcement in the Plastic soil bed. The BCR is defined as the ratio of the bearing pressure of a reinforced soil to that of an unreinforced soil, when evaluated at the same settlement ratio. In this study, BCR was calculated at four different settlement ratios i.e., UBC, 4%, 8%, 12% and 16%. It should be noted that the BCR is similar to an improvement factor used by many researchers in their studies [4-5]. Another parameter Settlement reduction factor (SRF) being also used in the study, SRF can be calculated as

SRF = $1 - \frac{(S)r}{(S)ur} \times 100$ for s/B= UBC, 4%, 8%, 12% and 16%

Where $(S)_{ur}$ = Settlement of unreinforced soil and $(S)_{r}$ = the settlement of reinforced soil bed at bearing pressure with respect to $(S)_{ur}$. This Settlement reduction factor (SRF) is similar to percentage reduction settlement (PRS) used by [6-7] in their studies to quantify the performance improvement in settlement in terms of percentage. Many researchers have also considered settlement ratio (SR) as a parameter to compare the settlement reduction with the application of geosynthetics. Foundations are designed in accordance to the allowable bearing pressure of the soil. Thus, computation of ultimate bearing capacity (UBC) becomes substantial to correctly assess the increase in construction viability of the soil with applications of geosynthetics. To determine the optimum value of first depth of reinforcement layer, initially five tests were conducted on square model footing, supported by single layer of each geosynthetic. Fig. 3 (a-b) shows the pressure settlement curves for GGR and GTX respectively. As can be deciphered from the curves that bearing pressure of soil increases as the ratio of u/B increases. However the rate of increases in the bearing pressure is significant until a value of u/B = 0.34 after which bearing pressure rapidly decreases with increasing the u/B value. Fig 4 (a-b) depict the improvement factor versus u/B for GGR and GTX respectively. It can be observed from the graph that the BCR gradually increases as u/B value increase from 0.17 to 0.34, afterwards a decrease in BCR can be observed with increases in u/B. [8] reported somewhat similar findings that the bearing capacity of a square footing on a geogrid reinforced Soil bed improved significantly to a depth of placement of u/B =0.33. The probable reason of these optimum values of u/B is that when u/B<

0.34, the surcharge pressure was not sufficient to generate the friction at soil - reinforcement interface.

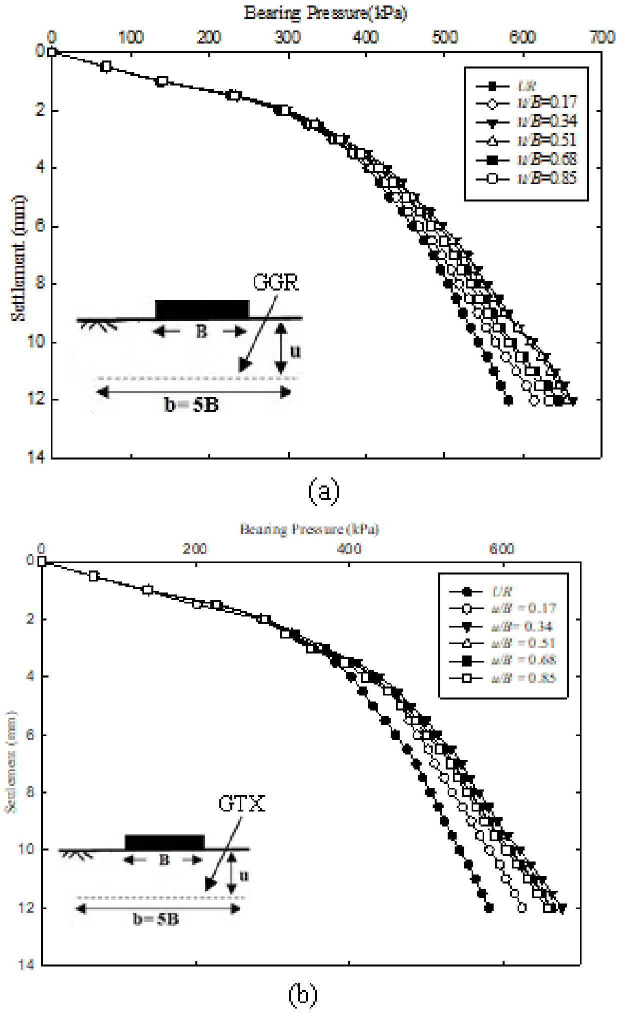


Fig.3 Pressure- settlement curves for (a) Geogrid (b) Geotextile at different u/B ratios

GGR

(a)

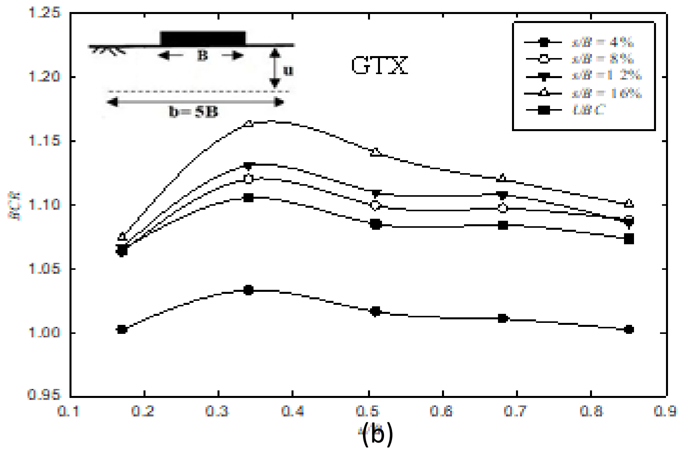


Fig. 4 Bearing Capacity Ratio (BCR) for (a) Geogrid (b) Geotextile at different u/B ratio

4.2 Effect of number of reinforcement layers and effective depth:

For ascertaining the effect of increasing number of reinforcements on the bearing capacity of the soil, the top layer of reinforcement was fixed at 25.5 mm (i.e. u/B =0.34) and then reinforcement layer was varied by fixing the vertical spacing of 25.5 mm till the effect of reinforcement becomes insignificant. The reinforcement ratio (d), which is defined as the ratio of the total depth of the reinforcement and the width of the footing was ascertained for each reinforcement case. The reinforcement depth below the base of the footing can be expressed as

$$d = u + (N - 1) \times h \quad (1)$$

Where u= first reinforcement depth below the base of footing, h = vertical spacing between two consecutive layers of reinforcement, N= Number of reinforcement layers. The pressure-settlement curves were plotted for each number of reinforcement layer to compare with unreinforced one. Fig.5 (a-b) show the pressure settlement for geogrid and geotextile respectively. As expected, the value of bearing pressure increases with increment in number of reinforcement layers. However, improvement in bearing capacity becomes almost insignificant after the addition of fourth layer and third layer which are located at a depths of 1.36B and 1.02B for geogrid and geotextile respectively. The probable reason of bearing capacity improvement is that the increase in friction at the soil reinforcement interface, which increases with the increase in reinforcement layers. Also, better interlocking between the soil and geogrids and passive earth resistance can be attributed as the reason for the development of the bearing capacity. Better interlocking between the geogrid and the soil prevented the lateral deformation of the soil. As a result of applied load, tension is mobilized in the geosynthetics which resist the shear stresses developed in the soil below the loading area and transfer them to the stable soil, thus eventually increasing the depth of the failure zone thus, results in higher bearing capacity and settlement reduction. Similar findings were also observed by [8], they reported that the inclusion of geogrid reinforcements became insignificant after a 1.33B depth of reinforcement. On the basis of their findings, they reported a maximum of four geogrid layers as optimum reinforcement in case of a strip footing.

(b)

Fig. 5 **Pressure- settlement curves for (a) Geogrid (b) Geotextile at different reinforcement depth**

4.3 Effect of type of reinforcement

Geogrid and geotextile of different stiffness are used in the present study. Technical characteristics of geosynthetics are presented in Table. 3. Reinforcements used in the study were made of same material but the tensile properties of geotextile is higher than the geogrid. In order to investigate the effect of tensile properties of reinforcement in reduction in the development of bearing capacity of soil foundation bed, the values of BCR were estimated at different settlement ratios i.e. (4, 8, 12, and 16% and UBC). Fig. 6 (a-b) depict the variation of BCR with reinforcement depth i.e. d/B for geogrid and geotextile respectively. The nature of the curve may be classified in to two groups; one for settlement level s/B< 4% (lower settlement level) in which ultimate bearing capacity lies and other for s/B>4% (higher settlement level). For the first group, geogrid impart much substantial improvement in bearing capacity than geotextile. The reason for the same can be explained that at lower settlement level, geogrid efficiently mobilized the lateral stress resistance capacity due to the confinement effect which plays a vital role in reinforcement mechanism. However for higher settlement (s/B> 4%), performance of geotextile is much better and gives more improvement than the geogrid. The reason behind this can be explained as, at certain settlement, geotextile requires higher deformation to perform on its full capacity due to its higher tensile strength. Generally, foundation constructions require to be constructed for the ultimate bearing capacity of the soil. Geogrid is better performing material than geotextile for limited settlement requirements or settlement upto ultimate bearing capacity. However, geotextiles primary function is to act as a filter or in drainage system behind retaining walls, adjacent to roads, and within slopes etc. thus can be considered as reinforcement material where small tensile strength is required. [9] presented the similar findings when they compared the geogrids with geotextile at a certain settlement level.

GGR

(a)

GTX

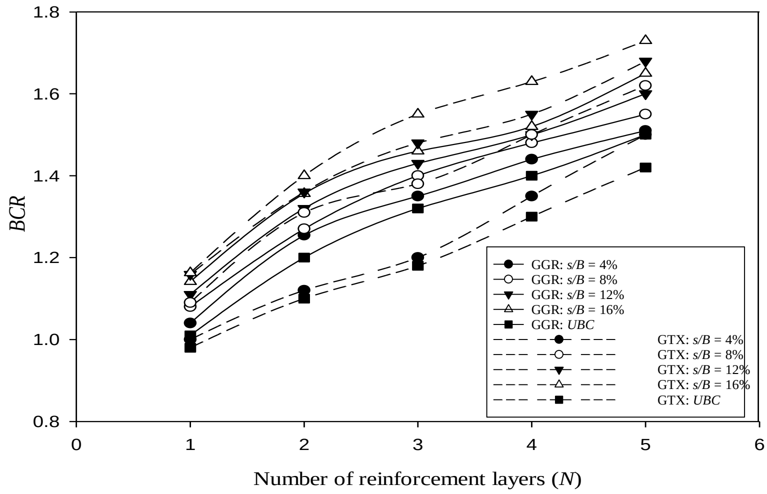
(b)

Fig. 6 Variation of BCR vs reinforcement depth (d) for (a) Geogrid (b) Geotextile

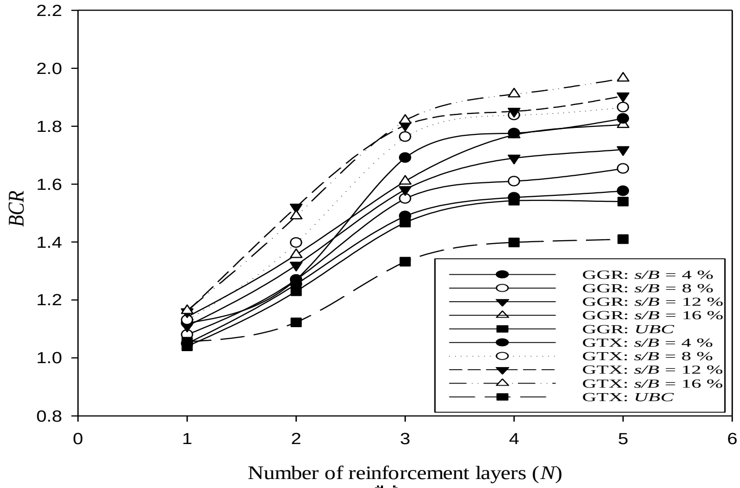
4.4 Influence of reinforcement width:

The effect of reinforcement width was analysed by the variation of reinforcement width as 4B, 5B, and 6B. When comparing the values of BCR from Fig.7 (a-c) for the same number of reinforcement layers at a different reinforcement width, it is clear that the footing performance in terms of bearing capacity improvement for both the reinforcement geogrid and geotextile are significantly improved with an increase in reinforcement width. This significant improvement continues at around five times of width of footing for both the reinforcements. Consider, for example for the geogrid case

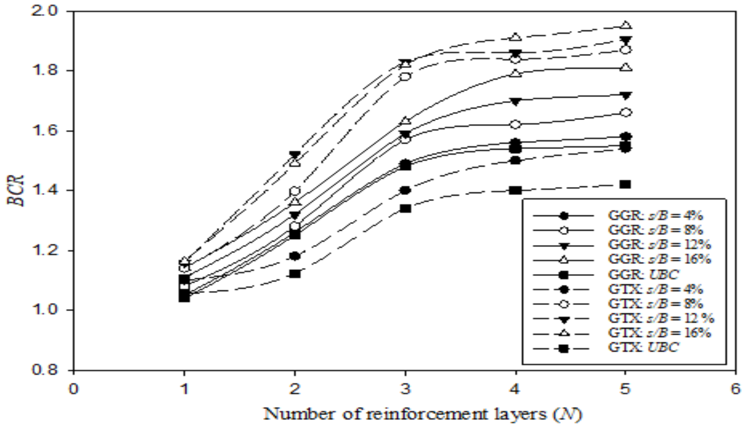
with N= 4 at UBC. The BCR increased from 1.44 to 1.56 when b/B ratio varied from 4 to 5. Further increment in b/B ratio from 5 to 6, the BCR was increased from 1.56 to 1.58. It is observed that a maximum rise in BCR values was observed for b/B ratio between 4 to 5 than those between 5 to 6. It is clear that satisfactory results may not be expected with increment in reinforcement width beyond 6B. Similar to this finding, [5] reported that the optimum width of geogrid to reinforce the square footing resting over the sand observed at b/B = 5 - 5.93. They explained that the concept of optimum width of reinforcement comes from the fact that only those portion of reinforcement is mobilized the tensile strength effectively, which lies in the shear zone below the footing. Beyond the shear zone, some more length is required as anchorage to impart pull-out resistance to the reinforcement thus, the optimum width of reinforcement is sum of length of reinforcement in anchorage zone and shear zone on the both sides. Further increment in reinforcement width beyond the optimum value will not be effective and satisfactory results cannot be expected. [8] considers the similar findings, they suggested the optimum reinforcement width equal to five times of the footing when they used the different planer geosynthetics in reinforced soil foundation. The similar results can be observed in case of geotextile.



(a)



(b)



(c)

Fig. 7 Bearing capacity ratio (BCR) for (a) width of reinforcement = 4B (b) width of reinforcement = 5B (c) width of reinforcement = 6B

4.5 Effect of vertical spacing between reinforcements

Fig.8 shows the pressure settlement curves with variations of vertical spacing between two reinforcements. It can be seen that 0.16B is the optimum vertical spacing for all reinforcements. Considering, for example, GGR case at settlement ratio of s/B = 4%, the bearing capacity increases to 25.0% and then the improvement decreases to 24%, 23.0, 21.4 and 19.8 % (Bearing pressure = 445.3, 441.7, 438.2, 432.5 and 426.8kPa) for h/B ratios 0.08, 0.16, 0.0.24, 0.32 and 0.4 respectively. The optimum value of vertical spacing was obtained at 0.16B for both the geosynthetics under central loading. Similar results were suggested by [8]&[10].

(a)

Fig 8. Variation of Improvement Factor versus h/B for (a) GGR (b) GTX

5. Regression Analysis

Regression analysis was carried out on the results obtained from the experimental analysis. The analysis was carried out on a R Integrated Development Environment (IDE) RStudio. The analysis was carried out by considering five dimensionless parameters, viz. via. u/B, h/B, N, Normalized stiffness and Normalized tensile strength and estimating the degree of significance of each parameter with the improvement factor, computed at ultimate bearing capacity of soil.

For the purpose of analysis, data set was created using the results obtained from the experimental analysis, and imported into the RStudio framework. Bearing Capacity Ratio was kept as the Y intercept for the purpose of analysis and functioned as the dependent variable, and all the other parameters were analyzed for their influence on the improvement factor at the ultimate bearing capacity for all the reinforcements and their corresponding configurations. The relative importance of each independent parameter for computation of ultimate bearing capacity of a reinforced foundation was assessed by computing the individual t values for each of the variable. The higher the value of |t|, the greater is the variable significance. Table 4. shows the fittings obtained with different parameters.

From Table 4. it can be observed that linear model including all dimensionless parameters is the best fitted for computation. Conducting linear regression including all parameters yields the following results as reported in Table 5.

From the analysis, it can be observed that N is the most significant factor when computing the ultimate bearing capacity of reinforced foundation, with an overall t value of 23.911. Also, from the analysis of the obtained results, it can be concluded that spacing between reinforcements is more significant that the tensile modulus of the reinforcement for a range of

$$0.08 \leq h/B \leq 0.4$$

which is a critical observation, as the project cost is usually associated with the spacing between reinforcements. From Table 4. it can be observed that the highest adjusted R^2 value is obtained when u/B, N and Norm. Tensile Strength are taken as the parameters for computation of the ultimate bearing capacity, even though the multiple R^2 value reduces (confidence level still greater than 95%).

Table 4. Various possible linear models and their fittings

Multiple R^2	R^2 adjusted	Parameters
0.9685	0.9524	*u/B, h/B, N,* N_s and N_t
0.9657	0.9516	*u/B, h/B, N* and N_t
0.9644	0.9537	*u/B, N* and N_t
0.9599	0.9508	*u/B, h/B, N* and N_s
0.9547	0.9499	*u/B, N* and N_s
0.9511	0.9433	*h/B, N,* N_s and N_t
0.5197	0.4416	*u/B, h/B,* N_s, N_t
0.4785	0.4315	N
0.2996	0.2277	*h/B,* N_s and N_t
0.2768	0.2226	*u/B* and *h/B*
0.2323	0.2141	*h/B*
0.1884	0.1448	N_s and N_t
0.1871	0.1678	N_t
0.1796	0.1601	*u/B*
0.1117	0.1107	N_s

Table 5. Linear regression computations with all dependent variables

Parameters	Coefficients	t Value
u/B	*-0.1187*	*-3.009*
N	*0.1948*	*23.911*
h/B	*0.0159*	*2.175*
Ns	*0.01956*	*0.678*
Nt	*-0.4798*	*-1.51*

Conclusions

On the basis of obtained results following conclusions were drawn.

1. The optimum depth of top most layer was found to be 0.34B times the width of square footing for both the reinforcements i.e. geogrid and geotextile whereas optimum depth of reinforcement (d) was obtained at d/B ratio of 1.36B and 1.02B for geogrid and geotextile respectively.
2. The soil reinforced with geotextile behave differently from the geogrid. The improvement in bearing capacity increases with increasing in reinforcement layers. Optimum number of reinforcement layers was obtained at N=4 for geogrid reinforced soil

and N=3 for geotextile reinforced soil.

3. The width of reinforcement also played a crucial role in amassing maximum benefit from reinforcements. A substantial improvement in performance of reinforcement was found when the width of reinforcements was equal to 5 times the width of footing for geogrid and geotextile.
4. For the foundation construction point of view, Geogrid was the best performing material. Although, geotextile performed better at higher settlement ratios, geogrid provided better reinforcement for lower settlement ratios for which the structures are usually designed for.
5. Regression analysis showed that the most significant parameter for computation of the ultimate bearing capacity of the soil foundation is number of layers of reinforcements.
6. The vertical spacing between reinforcements is a more significant parameter than the Normalized Stiffness and the Normalized Tensile Strength of the geosynthetic.
7. The numerical model for computation of the ultimate bearing capacity includes number of layers of geosynthetics, Initial layer spacing and the normalized Tensile Strength.

References:

1. Binquet, J., and Lee, K. L.: Bearing capacity tests on reinforced earth slabs. Journal of Ge-otechnical and Geoenvironmental Engineering (101), (1975(b)).
2. El Sawwaf, M. A.: Behavior of strip footing on geogrid-reinforced sand over a soft clay slope. Geotextiles and Geomembranes 25(1), 50-60 (2007).
3. Rowe, R. K., and Soderman, K. L.: Stabilization of very soft soils using high strength geosynthetics: the role of finite element analyses. Geotextiles and Geomembranes 6(1-3), 53-80 (1987).
4. Mandal and Sah: Beating Capacity Tests on Geogrid-Reinforced Clay, Geotextiles and Geomembranes 327-333 (1992).
5. Latha G. M., and Somwanshi A.: Bearing capacity of square footings on geosynthetic reinforced sand (27), 281–294 (2009).
6. Thallak, S., G., Saride, S., and Dash, S., K.: Performance of surface footing on geocell-reinforced soft clay beds, GeotechGeolEng (25), 509–524 (2007).
7. Tafreshi, M. S. N, and Dawson, A.: Comparison of bearing capacity of a strip footing on sand with geocell and with planar forms of geotextile reinforcement (28), 72–84 (2010).

8. Chen, Q., Abu-Farsakh, M., Sharma, R., and Zhang, X.: Laboratory investigation of behavior of foundations on geosynthetic-reinforced clayey soil, Transportation Research Record: Journal of the Transportation Research Board 28-38. (2007).
9. Biswas, A., Krishna, A.M., and Das, S.K.: Behavior of Geosynthetic Reinforced Soil Foundation Systems Supported on Stiff Clay Subgrade, Int. J. Geomech 1532-3641 (2016).
10. Guido, V. A., Chang, D. K., & Sweeney, M. A.: Comparison of geogrid and geotextile reinforced earth slabs. Canadian Geotechnical Journal, 23(4), 435-440 (1986).