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Bearing Capacity Behaviour of Geosynthetics Reinforced Soil

Ankur Mudgal, Raju Sarkar, Amit Kumar Shrivastava

Abstract* —The study shows small scale footing test results of silty clay reinforced with geosynthetics, where load is passed in the soil through a surface square footing having dimensions 75mm×75mm. In the research two types of planar reinforcements i.e. glasgrid and geotextile have been used. The results obtained from laboratory model footing tests reinforced with geosynthetics are presented and compared. The parameters analysed in the study includes the vertical spacing of first reinforcement layer from footing base (u), optimum depth of effective reinforcement (d), number of geogrid layers (N). Scanning electron microscopic (SEM) study also performed to observe the failure behavior of geosynthetic during the testing. The experimental results indicate that soil reinforced with geosynthetic increases the load carrying capacity of footing and the performance of glasgrid at lower settlement is better than geotextile in development of bearing capacity of foundation soil. Optimum spacing between base of footing and first reinforcement layer (u) is found to be 0.34B for both the reinforcements. Depth of effective reinforcement (d) was observed at 1.36B and 1.02 B for glasgrid and geotextile, respectively.

***Keywords*—Silty clay; Geotextile; Glasgrid; Bearing Capacity; SEM.**

I. INTRODUCTION

In geotechnical engineering, construction of structure over clay with low to medium plasticity may cause the reduction in the durability of structure and leading to damage in near future due to poor bearing capacity and higher footing settlement. Earlier, to stabilize these types of soil for carrying out construction activity, many techniques were used such as replacing the topmost weak soil with much stronger granular fill, increasing the footing size, incorporating natural fibers in the soil. However, these conventional methods were not economical. Hence the soil reinforcement technique using geosynthetic materials emerged rapidly. These geosynthtetics like geogrid, geocell, geotextile, and composite are now successfully used in many engineering works as a reinforcement in mechanically stabilized earth wall, pavements, reinforced foundation, and slopes. The past studies show that geosynthetic material improves the geotechnical properties of soil having low shear strength. One of the noticeable work in the area was done by [1] who proposed a term. Bearing Capacity Ratio (BCR) to estimate improvement in the bearing capacity due to inclusion of geogrid in foundation soil. [2] studied the behavior of reinforced clay foundation reinforced with geogrid. The results showed that when soil is reinforced with geogrid, bearing capacity increases, which results in reduction in settlement of footing. It was also observed that settlement was reduced upto 50% when three or more reinforcement layers were provided in foundation soil. [3] Investigated the improvement of load carrying capacity of clay subgrade reinforced with geogrid. They observed the optimum distance between footing base and first reinforcement as 0.175B. [5] observed the behavior on geosynthetic reinforced sandy soil. The study indicates that if two or more geosynthetic layers are provided in soil, settlement can reduce upto 20%. In the present study model footing tests on unreinforced and reinforced soil bed have been conducted to check the effect of all the parameters used in the study for the improvement of bearing capacity of silty clay using glasgrid and geotextile. The experimental results obtained are presented and discussed in results section.

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II. MATERIALS USED

A silty clay with low plasticity was used to prepare the foundation bed. The soil has silt and clay in proportion of 63% and 21% respectively. The geotechnical properties of soil are shown in Table 1. A single type of glasgrid and woven geotextile were used as a planar reinforcement. The material testing certificate of glasgrid and geotextile as provided by the manufacturer are tabulated in Table 2 and 3, respectively. Tensile strength of geotextile was obtained as 475 kN/m in machine direction and 384 kN/m in transverse direction. Whereas for glasgrid it was obtained as 90 kN/m in both the directions. In the present study, the glasgrid, and geotextile have been represented as GGR, GTX respectively.

Table.1 Geotechnical properties of soil

Properties	Value
Coefficient of university (C_u)	18
Coefficient of curvature (C_c)	0.060
Maximum Dry Unit weight (kN/ m^3)	17
Optimum moisture content (%)	15
Liquid limit (%)	34
Plastic limit (%)	24
Plasticity index (%)	10

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Table. 2 Mechanical properties of glasgrid

Properties	MD	TD
Tensile Strength (kN/m)	90	90
Secant Stiffness EA @ 1% Strain	4.6	4.6
Aperture Size (mm)	12.5×12.5	
Material	Glasfiber	

Table 3. Mechanical properties of geotextile

Tensile Strength	475 × 384 (MD × TD)	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 × TD)	(%)	IS 1969

III. TESTING PROCEDURE

The aim of the study is to check the influence of geosynthetics on the load carrying capacity of silty clay foundation. The parameters considered in the study were vertical spacing of first geogrid layer from footing base (u), effective depth reinforcement (d) and number of geogrid layers (N). These dimensionless parameters (i.e. *N*, *d/B* and *u/B*) were considered to ascertain the optimums in geosynthetic placements. Geometry of geosynthetics reinforced soil bed is presented in Fig.1. The geosynthetic configurations were decided according to testing program i.e. at the respective *u/B, d/B* ratios, and number of reinforcement layers *N*. Initially, tests on soil bed were performed with unreinforced condition to compare the result with reinforced soil and then optimum vertical spacing between first reinforcement layer and footing base, ‘u’ was determined. The ratio of first reinforcement depth to width i.e. u/B value was varied form 0.17 to 0.34, 0.51, 0.68 and 0.85 respectively. Likewise, number of geogrid layers were varied from N =1 to 5 (i.e. d/B = 0.34, 0.68, 1.02, 1.36, and 1.7) by considering the topmost layer of reinforcement at optimum value of u/B.

IV. PREPARATION OF SOIL FOUNDATION BED

A steel tank of dimension 75 cm × 45 cm × 60 cm was used to conduct the experimental work. Initially, soil was mixed with predetermined water i.e. OMC = 15% and it was poured into the tank then compacted at its maximum dry unit weight with the help of rammer having base of 150 mm, falling freely from a height between 25mm to 102mm depending upon reinforcement spacing. The soil bed was prepared in three lifts for unreinforced case while it depends on the reinforcement layers for reinforced soil bed. At the end of compaction, a spirit level was used to check horizontal surface of bed. Figs. 2(a-b) show the first compacted layer of soil and final prepared foundation bed respectively.

V. TEST SETUP

Test were performed in steel tank; three sides of the box was made of steel and front longitudinal side of tank made of acrylic sheet for the purpose of the visual observation. A square footing of dimension 75mm × 75mm was used as surface footing placed at the center of clay bed. The footing base was kept rough by gluing sand with epoxy. The sides of the tank were fabricated with steel sheet to counter the bulging of the steel tank. Load was applied through compression frame and the settlement was recorded with the help of dial gauge and LVDT attached to it and having accuracy of 0.001 mm. A Load cell of 25 kN capacity was placed at the center model footing. Fig. 3 shows the schematic view of testing arrangement in laboratory.

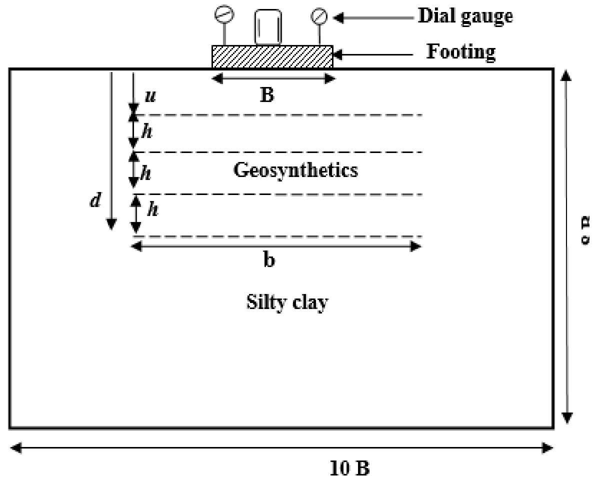

Fig. 1 Geometry of reinforced soil bed

(a)

(b)

Fig. 2 (a) first layer of soil bed (b) Prepared test bed of silty clay

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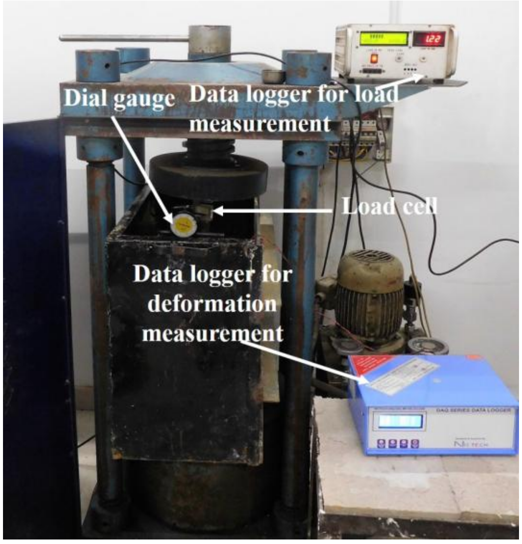


Fig. 3 Testing setup

VI. RESULTS AND DISCUSSION

A. General

A bearing capacity improvement factor (*IF*) was estimated for each geosynthetic case to give an incisive account of the bearing capacity improvement due to inclusion of reinforcement in the foundation soil. It is noted that the bearing capacity factor is similar as bearing capacity ratio (*BCR*) used by many researchers in their study [1,2]. The improvement factor was calculated at different settlement width ratios i.e. *s/B* = 4%, 8%, 12% and 16%. As foundation is designed for allowable bearing pressure so improvement factor also calculated for ultimate bearing capacity (*UBC*). *UBC* of soil was estimated by double tangent method. Two tangents were drawn, one from the start of the curve and another from the end of the curve. The projection of interception on x-axis is the observed bearing capacity.

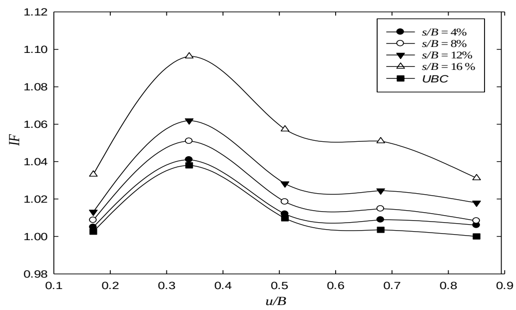
B. Effect of reinforcement configurations

The effect of first reinforcement depth i.e. *u* was investigated using a single layer of reinforcements located below footing base. Fig. 4 shows the improvement factor curves of reinforced soil foundation for GGR and GTX. From the curves it can be observed that value of improvement factor increases with *u/B* ratio and after reaching the u/B value equal to 0.34, a decrease in improvement factor can be seen for both the reinforcements. Hence, optimum value of '*u*' was found to be 0.34*B*. The feasible reason of this optimum value of u/B is that when the u/B ratio was placed below 0.35, the overburden was not enough to mobilize enough frictional resistance at the soil and reinforcement interface. A significant reduction in bearing pressure occurs when u/B > 0.34 because the first reinforcement depth was situated out of most influence zone. [11] indicated that the location of first reinforcement below the strip footing was found at a depth of u/B=0.40 when they performed the laboratory model strip footing tests on geogrid reinforced sand and clay. The reason for different values could be different test conditions and soil properties. The study on influence of effective depth of reinforcement was analyzed by placing the reinforcement layers in different locations as described in testing procedure.

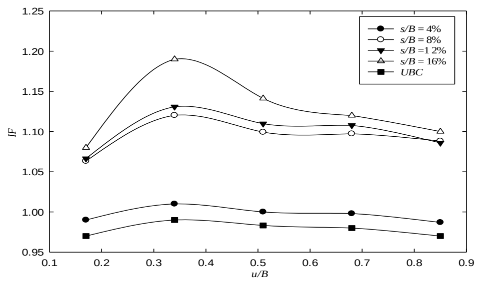
Effective depth of reinforcement is the depth beyond which the influence of reinforcement in the development of bearing capacity becomes insignificant. In the study, effective reinforcement depth is denoted as '*d*'. The past studies indicate that, 'd' is equivalent to number of reinforcement layers. The relation between d and N proposed by [11] is shown as in (1)

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

Where, 'u' is the first reinforcement depth, '*h'* is the vertical spacing between two reinforcing layers, and *N* is the number of reinforcing layers. Figs. 5 (a-b) show the pressure settlement curves for GGR and GTX, respectively. It was observed from the curves that the improvement in bearing pressure increases with increasing in the number of reinforcement layers. This significant improvement was observed upto the number of reinforcement layers 3 and 4 for GTX and GGR, respectively. Further addition in number of reinforcement layers resulted in insignificant improvement in bearing capacity improvement of foundation soil. Hence, N= 4 or d = 1.36*B* and N = 3 or d = 1.02 *B* are the optimum number of reinforcement layers and reinforcement depth in the case of GGR and GTX respectively. [2] also reported that the optimum depth for geogrid and geotextile reinforced square foundation clay bed was observed at 1.5B and 1.25B respectively. The deviation in results could be due to the variation in footing size, properties of soil and geosynthetics used for the respective studies.



(a)



(b)

Fig.4 Improvement factor curves for (a) GGR (b) GTX for *u/B*

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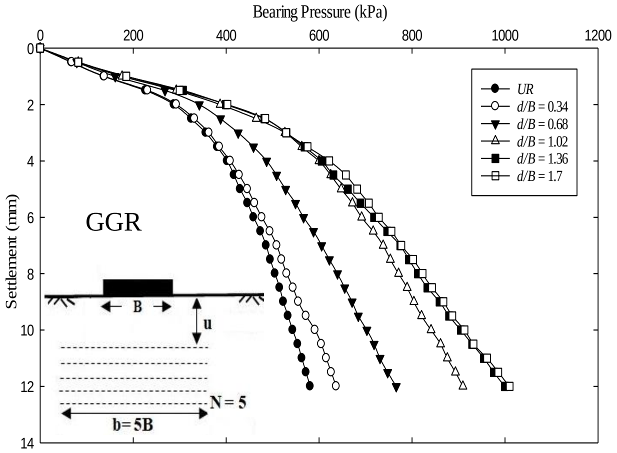
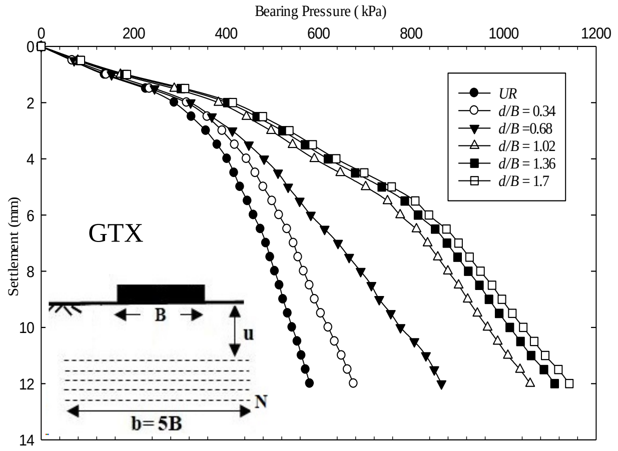


(a)

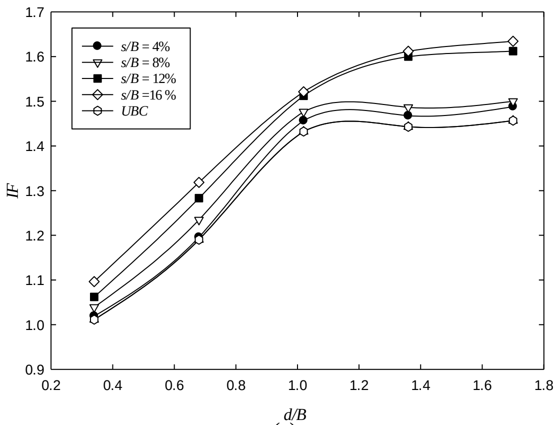


(b)

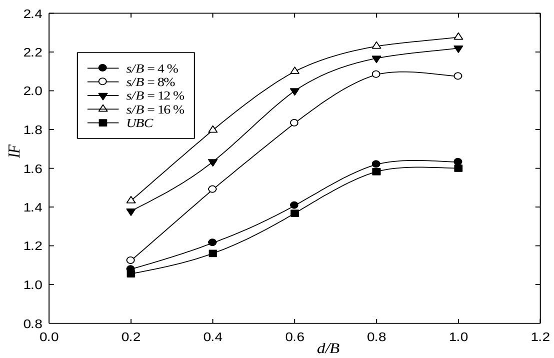
Fig. 5 Pressure settlement curves for (a) GGR (b) GTX

C. Comparative performance of glasgrid and geotextile

A glasgrid made of fiber glass, and woven geotextile were used in the study. The tensile strength of the geotextile is higher than the glasgrid but the aperture size of the glasgrid is bigger than the geotextile. The properties of both the reinforcements are discussed earlier in material used section. Figs. 6(a-b) show the improvement curves for GGR and GTX with variation of reinforcement depths. This again confirmed that optimum depth of reinforcement was observed at N = 4 and 3 for GGR and GTX, respectively. Interestingly one more fact can be noticed here that GGR performed better than GTX at lower settlement. The reason for the same can be explained that at lower settlement level, GGR efficiently mobilized the lateral stress resistance capacity due to the confinement effect which plays a vital role in reinforcement mechanism. However for higher settlement, the performance of GTX is much better and imparts more improvement than GGR. The probable reason behind this can be attributed by the fact that GTX require higher deformation to perform on its full capacity. As settlement increases to higher values, GTX initiate to deform and bear the vertical loading due to the membrane effects. Two samples of GGR and GTX were taken for SEM analysis shown in Fig. 7 (a-b). Samples were taken from the edge of deformed geosynthetics where highest tension effect can be observed. As GGR perform better at lower settlement than GTX, sample of GGR was taken at lower settlement and for GTX sampling was done at higher settlement. Fig. 8 shows the SEM images of GGR and GTX before and after the testing. As can be observed from the SEM images of GTX post testing, the yarns of the geotextile begin to open up, due to the applied load over the reinforced soil. This observation can explain the results obtained during the experimental procedure, which showed that GTX performed better after a certain deformation. As the yarns opened, the soil could bond more efficiently with individual yarn fibers, unlike during the initial phase of testing. This promoted higher bonding efficiency between the geotextile and the soil layer as the testing procedure carried on and due to the higher tensile strength of the GTX with respect to the GGR, the mobilization of higher tensile resistance could be achieved. However, in case of GGR, the glass structure of the reinforcement deformed at higher loads, thus not mobilizing lateral resistance at higher displacements. Geogrids however, can efficiently mobilize its lateral stress resistance capacity at lower settlement ratios, due to the confinement effect, which is the major reinforcement mechanism in geogrids, and thus performs better than geotextile for smaller s/B ratios.



(a)



(b)

Fig. 6 Improvement factor versus *d/B* for (a) GGR (b)) GTX

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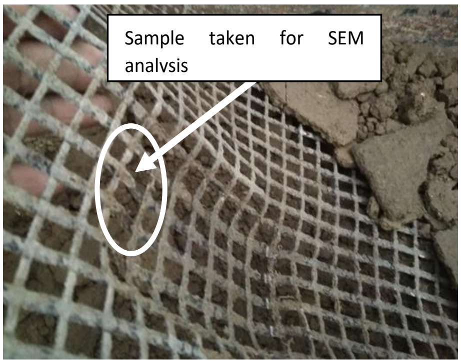
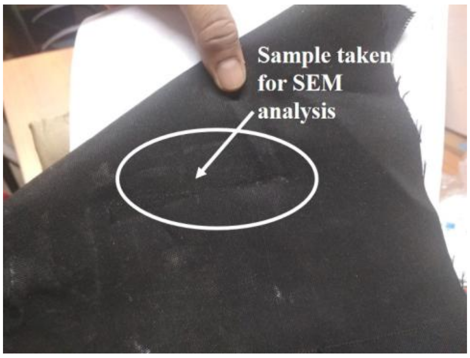
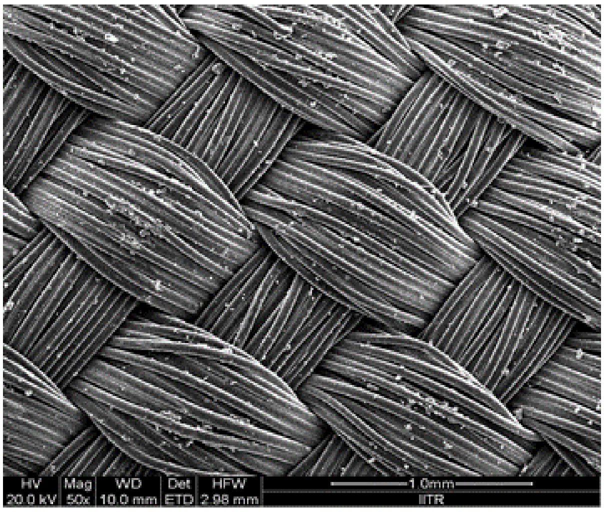


(a)

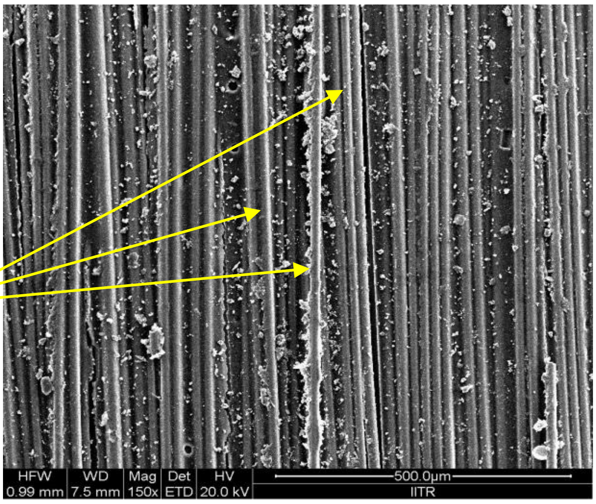


(b)

Fig. 7 (a-b) Sample taken for SEM analysis of (a) GGR (b) GTX



(a)



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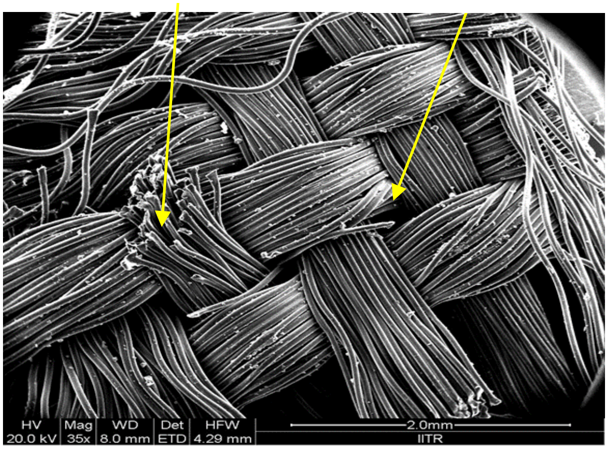

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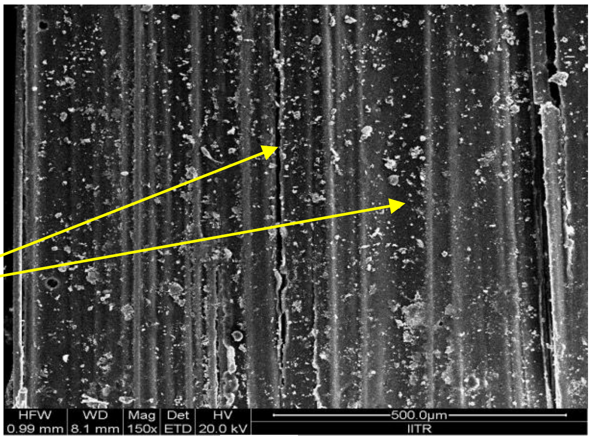

(d)

Fig.8 SEM micrographs of (a) and (b) of Geotextile before and after testing, Fig. 8 (c) and (d) of Geogrid befor after testing

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VII. CONCLUSION

In the present study, experimental results on model footing tests on square footing supported by silty clay reinforced with glasgrid and geotextile were compared and reported. The study indicates that the layout and configuration of reinforcements are very important parameters in the development of bearing capacity of reinforced soil foundation. On the basis of the obtained results following conclusions were drawn.

1. Maximum improvement in bearing capacity was observed when first reinforcement layer was located at 25.5 mm from the base of the footing. It means optimum/ optimum value of u/B = 0.34 for both GGR and GTX.
2. The soil reinforced with geotextile behave differently from the glasgrid. The improvement in bearing capacity rises with increasing in reinforcement layers. Optimum number of reinforcement layers was obtained at N = 4 for geogrid reinforced clayey soil and N = 3 for geotextile reinforced clayey soil.
3. As foundation is designed for allowable bearing pressure of soil, ultimate bearing capacity estimation is very important for this purpose. In the study the ultimate bearing capacity of soil usually found below 4% of settlement ratio, GGR is giving excellent performance at lower settlement ratio. Although, geotextile performed better at higher settlement ratios and its 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.

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