Numerical Studies on Ground Improvement Using Geosynthetic Reinforced Sand Layer

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Abstract. Clayey soils exhibit high shrinkage and compressibility characteristics as well as low shear strength. Engineering projects in clayey soils requires construction of deep foundations or use of ground improvement techniques. Soil reinforcement is a popular and widely used ground improvement technique. Shallow foundations resting on geosynthetics reinforced sand layer is a cost effective and feasible construction technique. Since the geosynthetics are placed in sand or granular layer compaction can be easily performed to achieve the design density and adequate friction between sand and the geosynthetics. The performance of strip footings resting on geosynthetics reinforced sand layer overlying clay layer is investigated using finite element software MIDAS GTS NX. A number of numerical models were analyzed and the effect of various parameters such as type of geosynthetic material, depth of sand layer, critical depth of reinforcement below base of footing, number of reinforcement layers, spacing between multiple layer of reinforcement and width of reinforcement layer on the load-settlement behavior of strip footings was studied. The optimum values of these parameters were also determined. Laboratory models of clay underlying sand layer with and without geosynthetics reinforcement were prepared in a steel tank of size 84 * 25 * 50 cm and monotonic load was applied through a steel plate of width 8 cm up to failure. The model test results were compared with the finite element analysis results. Design charts were developed which can be used to determine the depth of sand layer and number of reinforcement layers for a target bearing capacity.

1 Introduction

Naturally occurring clayey soils exhibit high compressibility and low shear strength. Construction of heavy structures on such soils requires erection of deep foundations or implementation of ground improvement techniques such as soil reinforcement. Soil reinforcement or strengthening of soils using geosynthetics or metallic strips have been developed as viable alternative for projects such as retaining walls and embankments for simple and fast construction techniques, better economy, aesthetics, reliability and easily adaptable in variety of environments. Geosynthetics can be classified into categories such as geogrids, geotextiles, geonets and geomembranes based on the methods of manufacturing. Geogrids have an open grid-like appearance and have been used

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efficiently to reinforce the soil structures such as embankments, slopes, retaining walls and foundations.

Laman and Yildiz (2003) stated that geogrids generally mobilize a higher soil reinforcement bond stress than geotextiles and have a higher stiffness per weight. Numerous laboratory model test results are currently available in the literature, related to improvement in the load-bearing capacity of shallow foundations supported by sand reinforced with various materials, such as metal strips, metal bars, rope fibres, geotextiles, and geogrids. The results of these investigations clearly showed that the bearing capacity of the foundation can be significantly improved by the inclusion of reinforcement in the ground. Construction of geogrid reinforcement incorporated at the base of a layer of granular fill placed on a soft clay subgrade is commonly used for unpaved roads, embankments, large stabilized areas such as car parks or working platforms for oil drilling and retaining walls Abedi et al. (2009). The use of a geogrid embedded in lightweight granular fill appears to be the most satisfactory means of improving the performance of embankments on very poor foundations. It was shown that reinforcement can significantly reduce the maximum lateral displacements, vertical displacements, and foundation soil heave during embankment construction. Fannin and Sigurdsson (1996) investigated the stabilization of unpaved roads on soft ground with geosynthetics. It was shown that the combination of geosynthetic reinforcement and fill helps to spread the concentrated vertical loads and to inhibit large deformations and local failures. Geosynthetics reinforcing unpaved roads on soft subgrade have been shown to reduce the necessary fill thickness by approximately 30%. Ling and Liu (2001) investigated the performance of geosynthetic-reinforced asphalt pavement under monotonic, cyclic, and dynamic loading conditions. This study showed that geosynthetic reinforcement increased the stiffness and bearing capacity of the asphalt concrete pavement. Under dynamic loading, the life of the asphalt concrete layer was prolonged in the presence of geosynthetic reinforcement. The stiffness of the geogrid and its interlocking with the asphalt concrete contributed to the restraining effect. Zidan (2012) studied the behaviour of circular footing on geogrid-reinforced sand.

In the present study, the bearing capacity and settlement behaviour of strip footings on a sand layer overlaying clayey stratum reinforced with geogrid layers were investigated using finite element software MIDAS GTS NX. The main objectives of this study includes studying the effect of sand layer with and without geosynthetic reinforcement on the settlement behaviour of soft soils, determination of the optimum thickness of sand layer to be provided above clayey soils, determination of the optimum number of geosynthetic layers (geotextiles and geogrids) and the optimum spacing between layers, preparation of design charts to find out required thickness of sand layer and number of geosynthetic layers for a required Safe Bearing Capacity.

2 FEM Modelling

MIDAS GTS NX (version 1.1) is a simulation program developed for the evaluation of soil-structure interaction based on the finite element method. GTS NX helps engineers to perform step-by-step analysis of excavation, banking, structure placement, loading and other factors that directly affect design and construction. The program supports various conditions (soil characteristics, water level etc.) and analytical methodologies to simulate real phenomena. Settings for all types of field conditions can be simulated using non-linear analysis methods (such as linear/non-linear static analysis, linear/non-linear dynamic analysis, seepage and consolidation analysis, slope safety analysis) and various coupled analysis (such as seepage-stress, stress-slope, seepage-slope and nonlinear dynamic-slope coupled analysis).

The first step of modeling involves fixing the dimensions of the test model. The two main factors to be considered for this step is the minimum width of geosynthetics layer required for soil reinforcement and the depth of pressure bulb when the footing is under load. In this study we are considering three various size of footings: 100 cm, 150 cm and 200 cm. So the width of model should be large enough to accommodate the geosynthetics layer for 200 cm footing. The reinforcement effect of geosynthetics is effective in sand layer and very less in cohesive soils. Therefore, a number of models were created and analyzed in GTS NX with sand layer on top and clay at bottom. Geosynthetics of different widths were embedded in the clay layer to find out the minimum width of reinforcement required. Medium clay with properties similar to the clay found at SVNIT Campus was created in GTS NX. Table 1 illustrates the properties of clay and sand bed used in the numerical modeling.

Table 1. Properties of soil

Property	Clay	Sand
Cohesion, *C*	0	0
Angle of internal friction, *Ø*	200	360
Dilatancy angle, ψ	0	100
Unit weight, Υ	1.6 kN/m^3	1.8 kN/m^3
Poisson's ratio, v	0.35	0.3
Modulus of elasticity, *E*	30 MPa	80 MPa
Soil classification	CL	SP

Bearing Capacity Ratio (BCR) is the ratio of bearing capacity of unreinforced soil to the reinforced soil. Width ratio is the ratio of width of geosynthetics to the width of footing. Since BCR depends on width of reinforcement, it is increased till it reaches such a point that there is no further increase in BCR with increase in width. From Fig. 1, BCR reaches maximum at width ratio of geosynthetics layer equal to 6. Therefore, the minimum width of reinforcement required for 200 cm footing is 12 m. Hence clay model with dimensions 14 m * 14 m * 14 m was created in GTS NX with medium Hybrid mesher. Mohr – Coulomb model was chosen for the model. Load was applied similar to the plate load test used in model testing in laboratory. Figure 2 shows a general schematic representation of the clay-sand-geosynthetic model used for analysis and the parameters that are studied and Fig. 3 shows 3D stress contour in MIDAS GTS NX.

Since the dimensions of geosynthetics, footing and soil model is fixed, parametric studies are conducted using GTS NX. Firstly, model consisting of only clay is analysed and then top layer of clay is replaced with varying thickness of sand till the optimum

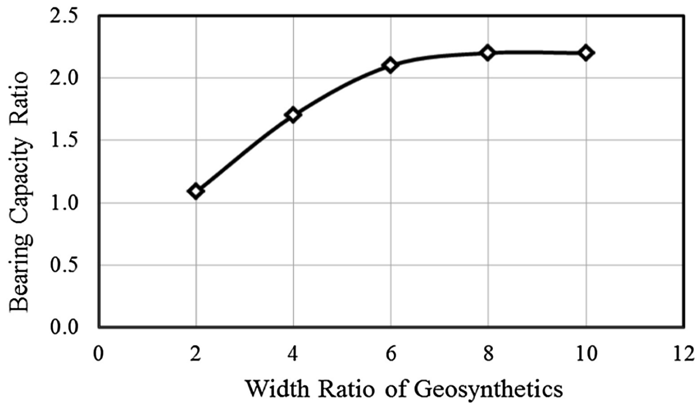

Fig. 1. Relationship between BCR and width ratio (b/B) of geosynthetic layer

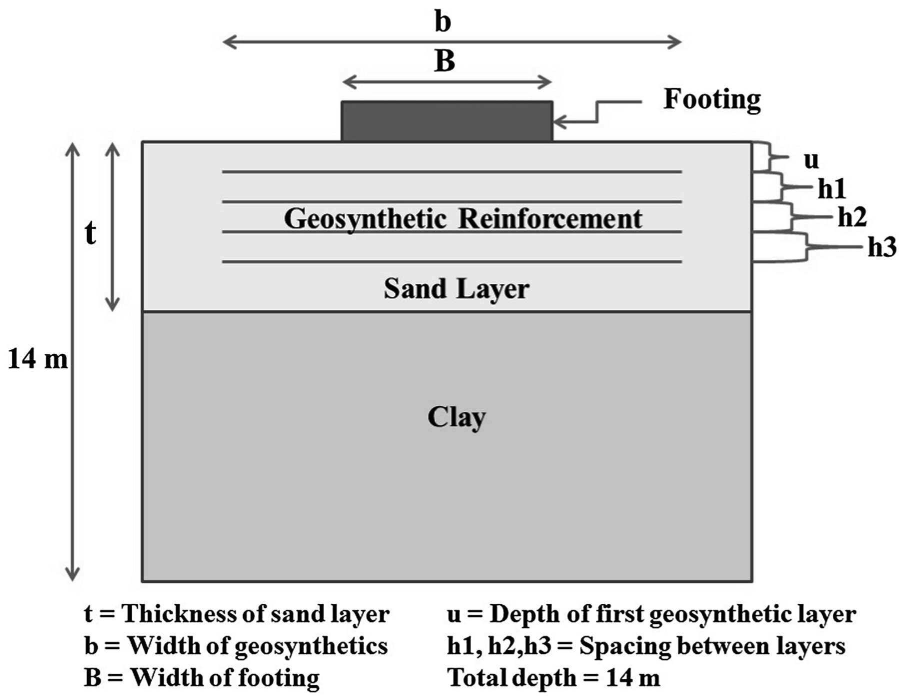

Fig. 2. Schematic representation of test model

thickness of sand is reached. After determining the optimum thickness of sand layer, the depth of first layer of geosynthetics is finalised by varying the depth of geosynthetics layer with respect to the width of footing. When depth of first layer is fixed, same procedure is repeated for second layer. This procedure is carried out for multiple

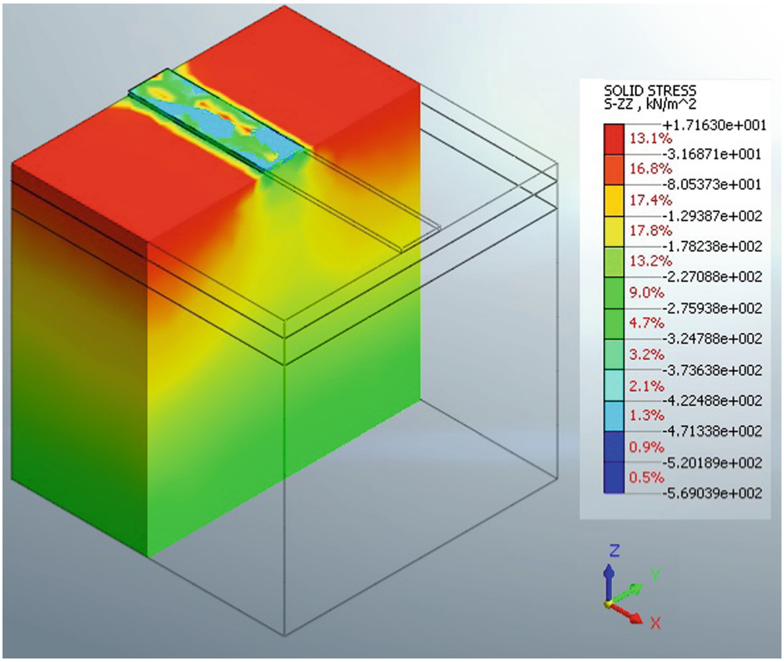

Fig. 3. 3D stress contour in MIDAS GTS NX

layers of geosynthetics till there is no improvement in bearing capacity when an additional layer of geosynthetics is added.

3 Experimental Work

The main aim of this study was determining the load settlement behaviour of soft clays, sand bed overlying soft clay, clay improved with geogrid and geotextile reinforced sand layer, and there by evaluating the bearing capacity of the improved soft soil. A total of four model tests has been planned, namely, only clay, clay with sand bed, clay + sand + geogrid, clay + sand + geotextile. The Finite Element Analysis results from MIDAS GTS NX were validated using laboratory results. Various laboratory tests such as compaction test, particle size analysis, liquid limit test, plastic limit test and direct shear test were performed to determine the properties of soil used for model test.

Plate load tests were carried out in a mild steel tank of dimensions 84 * 25 * 50 cm. A mild steel loading plate of dimensions 25 * 8 * 2 cm was used as footing to transfer load to soil mass. Load was applied using hydraulic jack. To simulate ground condition of overlying soil above footing, surcharge load equal to 20 cm deep soil mass was applied on the soil surface. Two dial gauges were attached to the loading plate to measure deflections of plate while loading.

4 Results and Discussion

4.1 Experimental Work

A total of four sets of plate load tests were carried out in laboratory and the Applied pressure vs Settlement relationships were obtained. Mild steel plate of dimensions 8 * 25 * 2 cm was used as the strip footing to transfer load from hydraulic jack to the surface of soil. Surcharge load equal to 20 cm of soil layer was applied on the exposed surface of soil. Clay failed at 320 kPa stress, unreinforced soil failed at 400 kPa, whereas geogrid and geotextile reinforced soils achieved bearing capacity of 730 kPa and 940 kPa respectively. That is, the Bearing Capacity Ratio (BCR) of geotextile reinforcement is 1.825 and that of geogrid reinforcement is 2.35.

The results obtained from laboratory experiments were validated in FEM using GTS NX software. Figure 4 shows the results of FEM validation of laboratory results. The results are nearly matching for all three cases with a slight deviation. The applied pressure is lesser for same settlements in case of FEM results till elastic limits. This may be due to various reasons. Reinforcement by geogrid is mainly from lateral constraint provided by interlocking between aggregates and geogrid. But geotextile functions through a number of ways, including reinforcement through interaction friction, separation between subgrade soil and base course material, filtration, and drainage. In FEM analysis using software, these factors may not be considered for the reinforcement mechanism of geosynthetics. However, the results obtained from the experiment and the FEM analysis match to a great extent and therefore results are acceptable.

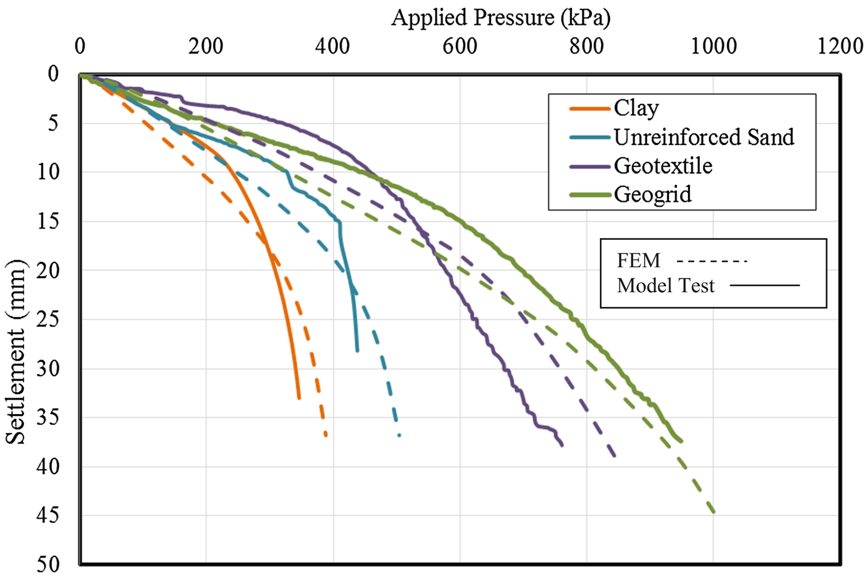

Fig. 4. Comparison of FEM and experimental results for geosynthetic-reinforced soils

4.2 FEM Analysis

A series of numerical analyses were carried out in medium clay models with and without ground improvement using geosynthetics reinforced sand layer. Models with only clay, sand overlying clay bed, and sand overlying clay reinforced with multiple number of geogrids and geotextiles were analysed in FEM software MIDAS GTS NX. Parameters varied in this study are thickness of sand layer, number of geosynthetics layers, spacing between layers and depth of first layer of reinforcement below base of footing. Parameters kept unchanged in this study are total depth of soil model and properties of clay and sand.

Three footing sizes, namely 100 cm, 150 cm and 200 cm were selected for both geogrid reinforced soils and geotextile reinforced soils. Figures 5 and 6 shows the stress vs settlement relationship for 100 cm footings with geogrids and geotextiles respectively.

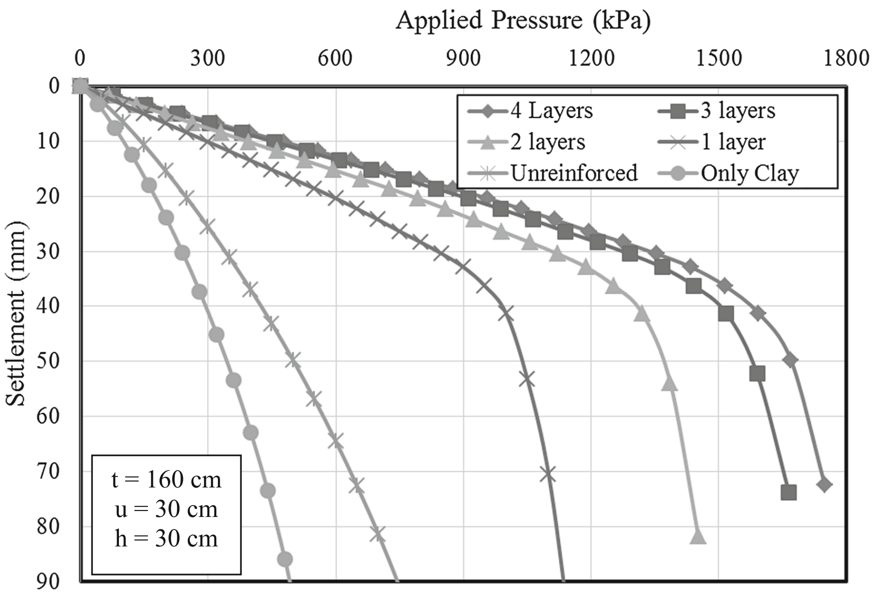

Fig. 5. Stress vs settlement chart for 100 cm wide footing with/without geogrid reinforced sand layer

Thickness of Sand Layer 't'

Results were obtained for thickness '*t*' of sand layer varying from 0.25*B* to 1.5*B*. The optimum thickness of sand layer for varying footing sizes was nearly equal to *B*. However, *t* can be reduced by inclusion of geosynthetics reinforcement.

Depth of First Layer 'u'

The most important parameter in this study was found out to be the depth of 1st layer of reinforcement layer. To get best results, depth '*u*' should be taken as 30 cm for 100 cm footing, 40 cm for 150 cm footing and 45 cm for 200 cm footing.

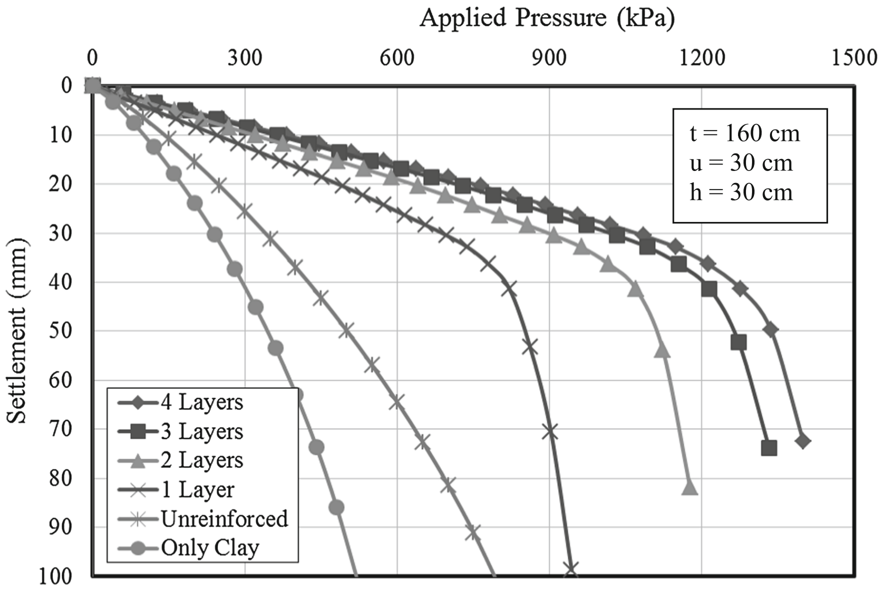

Fig. 6. Stress vs settlement chart for 100 cm wide footing with/without geotextile reinforced sand layer

Spacing Between Layers 'h'

Spacing between 1st to *n*th layer of geosynthetics can vary between 30 cm to 50 cm, but best results are obtained by selecting '*h*' as 30 cm.

Number of Reinforcement Layers 'N'

Maximum improvement in bearing capacity was obtained when the first layer of reinforcement is added. With addition of each layer of reinforcement, bearing capacity increases and settlements are reduced. However, there was no improvement observed after 4 layers of geosynthetics layers.

4.3 Behaviour of Geogrids

Clay model loaded with 100 cm wide footing was analyzed with varying thickness of sand layer below base of the footing. Thickness of sand layer was varied from 40 cm to 160 cm. It was observed that the bearing capacity of model increases with increase in value of '*t*', but the difference in bearing capacity was reduced when '*t*' is increased beyond 120 cm. Therefore 160 cm thick sand layer is selected for the addition of geogrid reinforcement. Thickness of sand bed was taken as 160 cm and the depth '*u*' was varied between 30 cm and 90 cm. For values of '*u*' between 30 cm and 60 cm, the difference in stress vs settlement behaviour is low. But on further increase of '*u*', higher settlements are observed for the same loading. First layer of geogrid was placed at 30 cm from bottom face of footing for analysis of multiple layers of geogrids. Sand bed '*t*' was taken as 160 cm and '*u*' equal to 30 cm. Second layer of geogrid was placed at spacing 30 cm to 90 cm. The load- settlement characteristics are not significantly affected for 30 cm and 60 cm spacing, but settlements are increased for 90 cm spacing. However, the variation in stress vs settlement curve is significantly reduced for second layer compared to the first layer. Keeping optimum values of '*t*', '*u*' and '*h1*' = 30 cm, effect of spacing was studied for the addition 3rd and 4th layer of geogrid reinforcement. For third layer of geogrid, the difference in behaviour of footing with respect to spacing of reinforcement layers is negligible. However, a minimum of 30 cm thick sand layer is required to be provided between geosynthetic reinforcements. Figure 5 represents stress – settlement characteristics of clay model, clay model with unreinforced sand, sand bed reinforced with 1, 2, 3 and 4 layers of geogrids for 100 cm wide footing. Parameters were taken as follows: *t* = 160 cm, *u* = 30 cm, *h1* = *h2* = *h3* = 30 cm. Similar studies were conducted using 150 cm and 200 cm wide footings for varying parameters as discussed above.

4.4 Behaviour of Geotextiles

Woven geotextiles were used in the experimental work to reinforce sand layer. 2D geotextile element with properties similar to the geotextile used in experimental work was modeled in GTS NX using the built in option provided in the software. The thickness of geotextile was taken as 1.5 mm. The performance of woven geotextiles in FEM analysis is slightly lesser compared to experimental work. This may be due to the assumptions in FEM which fails to model the interaction friction of geotextile layer accurately. The effect of first layer of geotextiles and the spacing between multiple layers were found similar to that of geogrids, that is, '*u*' equal to 0.3*B* to 0.6*B* and '*h*' equal to 0.3*B* to 0.4*B*. Figure 6 represents stress – settlement characteristics of clay model, clay model with unreinforced sand, sand bed reinforced with 1, 2, 3 and 4 layers of geogrids for 100 cm wide footing. We got optimum thickness of sand layer for 100 cm footing as 120 cm. Similar to geogrids depth '*u*' and spacings '*h1*', *h2*' and '*h3*' was varied by placing geotextiles at various depths and they were analyzed in GTS NX. Parameters were taken as follows: *t* = 120 cm, *u* = 300 cm, *h1* = *h2* = *h3* = 30 cm. Similar studies were conducted using 150 cm and 200 cm wide footings for varying parameters as discussed above.

4.5 Bearing Capacity Ratio

Bearing Capacity Ratio is defined as the ratio of ultimate bearing capacity of unreinforced soils to that of reinforced soils, as described in Eq. (1). Figure 7 shows relationship of BCR and number of reinforcement layers for geogrids. On addition of first layer of geogrid, BCR of 2.2 was achieved and the maximum BCR achieved was 3.6, by adding 4 layers of geogrid. Addition of geogrid layer after 4th layer does not show any significant increase in bearing capacity or reduction in settlement.

$$\mathrm{BCR} = \mathrm{q_r}/\mathrm{q_u} \tag{1}$$

where
q_r = Bearing capacity of reinforced sand,
q_u = Bearing capacity of unreinforced sand.

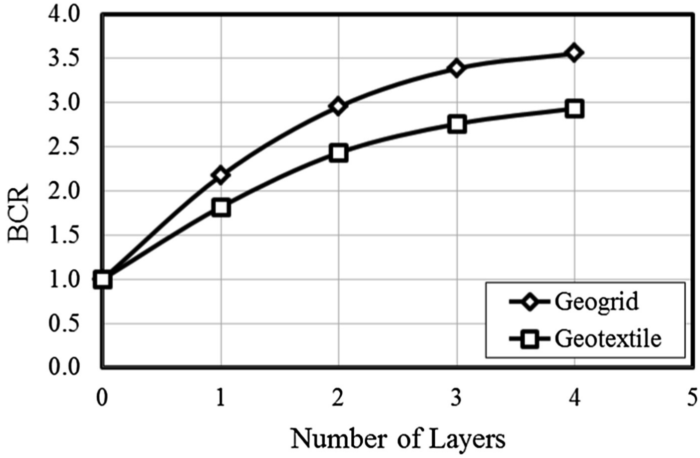

Fig. 7. Comparison of BCR of geogrids and geotextiles for 150 cm wide footing

On addition of first layer of geotextiles, BCR of 1.8 was achieved and the maximum BCR achieved was 2.9, by adding 4 layers of geogrid. Optimum number of layers was found to be 4 for geotextiles. Figure 7 compares the performance of geogrids and geotextiles in improving bearing capacity under similar conditions.

From Fig. 7, it is observed that geogrids exhibit superior performance compared with geotextile when it is used for soil reinforcement. Although expensive, geogrids give higher bearing capacity when used for foundation purposes. But in field conditions, geotextiles have versatile uses in addition to soil reinforcement such as separation, filtration, drainage etc. These factors also indirectly affect bearing capacity of soils. For example, preventing subgrade soil mixing with base material is crucial for the strength of pavements. Therefore, selection of reinforcing material not only depends on target bearing capacity, but also the site conditions and purpose of construction. Table 4 shows the percentage increase in Bearing Capacity for different number of geogrids and geotextiles.

Table 2. Properties of geogrid

Property	Value
Structure	Uniaxial
Aperture shape	Rectangular
Aperture size	51 mm × 31 mm
Mass per unit area	500 g/m^2
Raw material	Polypropylene
Elastic modulus	2 GPa
Poisson’s ratio	0.3
Thickness	0.003 m
Elongation at nominal strength	8%
Tensile strength	80 kN/m

Table 3. Properties of geotextile

Property	Value
Type	Woven
Mass per unit area	300 g/m^2
Raw material	Polypropylene
Elastic modulus	1.5 GPa
Poisson's ratio	0.3
Thickness	0.0015 m
Tensile strength	45 kN/m

Table 4. Percentage increase in Bearing Capacity w.r.t only clay layer

Reinforcement	Geogrid	Geotextile
Only clay	-	-
Unreinforced sand	5.76%	5.76%
1 Layer	129.5%	92.3%
2 Layers	212.5%	157.2%
3 Layers	258.2%	191.8%
4 Layers	276.2%	210.3%

4.6 Design Charts

Studies were conducted on different parameters such as number of reinforcement layers '*N*', thickness of strip footing '*B*', thickness of sand layer '*t*', spacing between layers '*h*' and depth of reinforcement below base of footing '*u*' with respect to Bearing Capacity. Based on the findings from these studies, we can choose required *u*, *t*, *N* and *h* for target Safe Bearing Capacity and economy. For field applications, design charts are prepared considering thickness of sand layer, number of geosynthetic layers and Safe Bearing Capacity. Since depth of reinforcement layer below footing and spacing between layers can be optimized, optimum '*u*' and '*h*' is chosen for preparation of design charts. Therefore, for a target Safe Bearing Capacity, we can obtain required sand thickness and number of reinforcement layers (under specified depth of reinforcement and spacing between layers). These design charts is valid only for medium clays (clays which can be indented with strong thumb pressure). Figure 8 shows design chart for 100 cm wide footings on geogrid reinforced sand layer. Depth of first geogrid layer below base of footing was taken as 30 cm and the spacing between adjacent geogrid layers was 30 cm. Figure 8 shows the variation of Safe Bearing Capacity (SBC) with respect to thickness of sand bed '*t*'. Five different curves on the graph represents the behaviour of footings on unreinforced soils, soils reinforced with 1 layer, 2 layers, 3 layers and 4 layers of geogrids.

Similar to the design charts for geogrids, the same was prepared for footings resting on geotextile reinforced sand layer. Figure 9 shows design chart for 100 cm wide footings on geotextile reinforced sand layer. Depth of first geogrid layer below base of footing was taken as 30 cm and the spacing between adjacent geogrid layers was

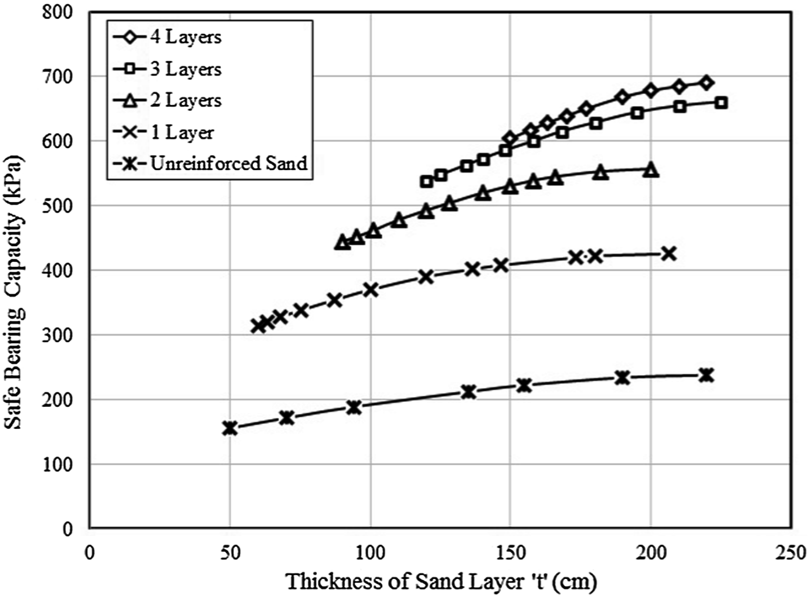

Fig. 8. Design chart for geogrid - reinforced sand layer for 100 cm wide footing

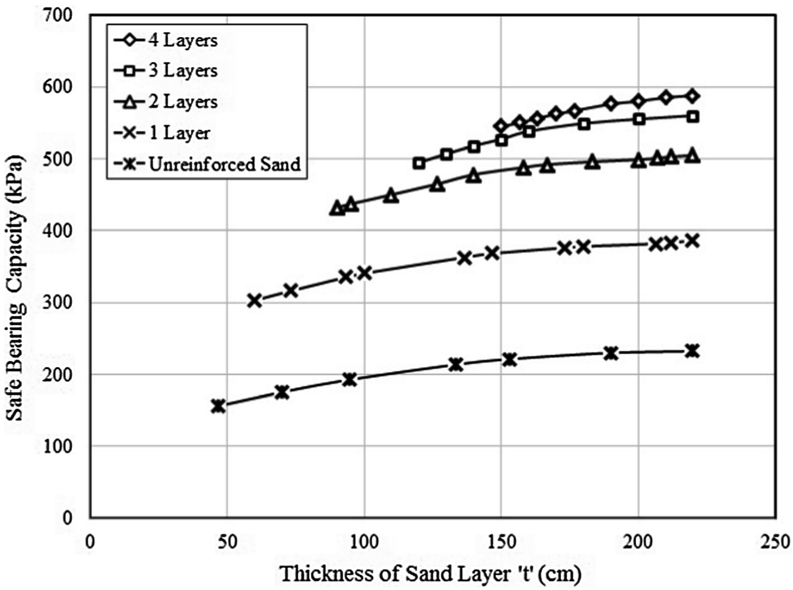

Fig. 9. Design chart for geotextile - reinforced sand layer for 100 cm wide footing

30 cm. Figure 9 shows the variation of SBC with respect to thickness of sand bed '*t*'. Five different curves on the graph represents the behaviour of footings on unreinforced soils, soils reinforced with 1 layer, 2 layers, 3 layers and 4 layers of geogrids.

5 Conclusions

When the strip footing is subjected to static load, the improvement in ultimate bearing capacity increases with increase of reinforcement layers due to the transfer of footing loads to greater depths through the geogrid layers and interlock between the geogrid and the sand reduce lateral and vertical displacements below the footing.

- The mechanisms of interaction friction of geotextiles reduced settlements and improved the bearing capacity. The addition of more than 4 layers of geogrids as well as geotextiles did not contribute much to the bearing capacity improvement: thus the optimum number of layers of geogrid is found to be 4.
- Depth of first reinforcement layer below base of footing was found to be 30 cm for 100 cm footing, 40 cm for 150 cm footing and 45 cm for 200 cm footings. Optimum spacing between layers was found to be 30 cm in all cases.
- Optimum thickness of sand layer was found out to be 1 to 1.2 times B, which can be reduced by inclusion of geosynthetics layers.

The improvement in bearing capacity using geosynthetic reinforcement is dependent on the relative density of sand. In relatively medium-dense and dense sand conditions, a significant increase is obtained. The effectiveness of geosynthetics in improving the bearing capacity of footings on slopes is attributed to its tensile strength and elastic modulus.

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