Performance of Square Footing on Reinforced Granular Trenches Above Soft Soil

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Abstract— **With the increasing demand for basic infrastructure and the diminishing availability of land for development, it becomes imperative to use land with weak soils for construction of buildings. There are different ground improvement techniques to stabilize the poor ground in which soil reinforcement is an effective and reliable technique. This paper evaluates the bearing capacity of square footing embedded in geogrid reinforced granular trenches above soft soil with various configurations. Numerical analysis using Plaxis 2D have been carried out using a rigid strip footing supported on granular trenches overlaying soft clay with and without a layer of geogrid reinforcement. It was found that the bearing capacity increases with an increase in the ratio of sand thickness to footing width until it reaches a critical value, which can be considered as the optimum limit of settlement of layered soil. The installation of a geo-grid reinforcement at the interface resulted in an appreciable decrease in settlement of the footing.. The influence of configuration of the trenches, thickness of sand layer and position of geogrid were investigated.**

I. INTRODUCTION

One of the primary criteria used to select a site for development is the suitability of the ground for supporting the structure to be built. In most urban areas, the best sites were developed first and as urbanization continues, when a previously undeveloped site is purchased, the engineering properties of the existing near surface materials are often such that the structure cannot be supported by shallow foundation. The traditional solution for these situations is to support the structures on deep foundations typically piles or drilled piers where a small portion of the load is transmitted to poorer near surface materials and a large portion of the load is transmitted to better bearing materials deeper within the ground. There are many field situations where at least a moderate increase in the bearing capacity is desired. To meet this demand numerous soil stabilization and improvement techniques have been developed within the past 30 years or so.

The behaviour of foundations on different types of soil remains a challenging task for the geotechnical engineer. Soft ground, widespread throughout the world possesses poor geotechnical properties such as high natural moisture content, high compressibility and low shear strength. A number of ground improvement techniques have been used in practice. In the case of clay deposits, accelerating consolidation through installation of sand / sand drains and chemical means have gained acceptance. In the case of loose sand deposits, densification through the installation of compaction sand piles is a widely adopted technique. The classical approach to ground improvement is replacement of weak soil by a better soil. However, replacing the entire weak zone is not practical which involves high costs and also due environmental restrictions on mining and reclamation. The reinforced soil may attain a superior behavior as a consequence of load transfer from the soil to reinforcement in the contact area. The advantage of the reinforced soil behavior, compared with the unreinforced soil, is increased shear strength. Without replacing the entire zone of weak soil, partial replacement along with reinforcement results in increased bearing capacity and reduction in settlement.

Many researchers have conducted experimental and numerical studies to understand the behaviour of footings resting on granular reinforced bed above soft soil and the effect of reinforcement to reduce the excessive settlement such as Nael K. Dalaly (2015) [1], Dhathrak A.I. (2014) [2], Aysan Ranjbar (2015) [3], Madhira R Madhav (2015) [4], Rethaliya R P (2009) [4] and K M Lee (1999) [6]. However, Effect of shape of granular trenches on the behaviour of strip footing underlain by reinforced granular trenches above soft soil have not been established yet.

II. METHODOLOGY

Following methodology was adopted for the numerical study using Plaxis version 8.2 software. Three groups were designed to examine the influence of granular trenches on the deformation of the soft soil-granular fill system.

1. Strip footing resting on soft soil alone and compared with the experimental results from previous studies
2. Footing on unreinforced and reinforced granular fill of various thickness
3. Footing on reinforced and unreinforced rectangular trenches of different sizes
4. Footing on reinforced and unreinforced triangular granular trenches of varying sizes

Numerical study was carried out on subgrade of clay of size 50cm×50cm×50cm, granular material with varying pattern and varying thickness was laid. Strip footing of size 7cm wide and 1cm thickness was centrally placed above prepared granular bed and vertical loads were applied in stages at the centre of the model footing test set up. Foundation was modelled as square footing and load increment was applied till the soil model fails.

III. MODELLING

For modelling of soil, reinforcing elements, footing and loading were performed using the commercial FEM package Plaxis version 8.2. The material properties for the numerical analysis were taken from Lee et al [6] and modelled using Plaxis 2D, which is one of the finite element softwares involved in the field of geotechnical engineering. Finite element analysis was carried out using Mohr Coulomb failure criteria to represent two dimensional soil model in plane strain condition. The foundation system was simulated using asymmetric model and the soil was modelled as 15 noded triangular elements. The modelled boundary conditions are assumed such that the vertical boundaries are free vertically and constrained horizontally while the bottom horizontal boundary is fully fixed as shown in the below Fig 1. Settlement of the rigid footing is simulated using vertical prescribed displacements. The results from Plaxis was verified by comparing solutions achieved from it with results taken from actual case histories. In current study, one example of the results of the laboratory and numerical were compared in Fig.

TABLE 1.MATERIAL PROPERTIES USED IN THE FEM ANALYSIS

Parameter	Name	Clay layer	Sand layer
Type of material behaviour	Type	Undrained	Drained
Young's modulus	E_{ref}	725	13000
Dry unit weight (kN/m^3)	γ_{unsat}	16	17
Wet unit weight (kN/m^3)	γ_{sat}	18	20
Poissons ratio	ν	0.35	0.3
Permeability in horizontal direction (m/day)	k_x	0.001	1.00
Permeability in vertical direction (m/day)	k_y	0.001	1.00
Cohesion (kN/m²)	C_{ref}	10.93	1.00
Friction angle (º)	ϕ	0.0	36
Dilatancy angle (º)	ψ	0.0	0.0
Normal stiffness of geogrid (EA) 22.22kN/m			

Initially, a series of tests were performed with various sand (H) thickness to footing width (B) ratios (H/B) without reinforcement to investigate the effect of fill thickness on the settlement characteristics of the unreinforced footing. Typical load-settlement curve for different H/B ratios of zero (clay only), 0.5, 1, 1.5, 1.75, 2, 2.25 and 2.5 were obtained.Fig.1 shows the plaxis model showing load and boundary conditions and Fig 2 and 3 displays the typical mesh generated and deformed mesh.

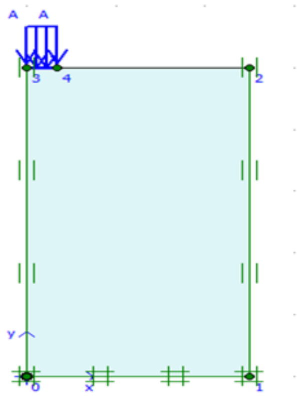

Fig1 Finite element model showing the load and boundary conditions

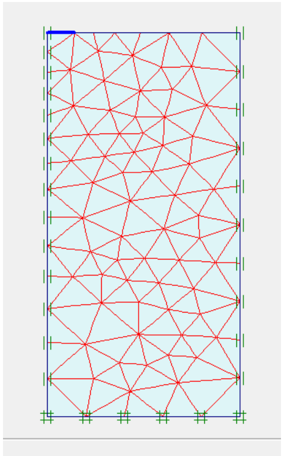

Fig. 2.Mesh generation

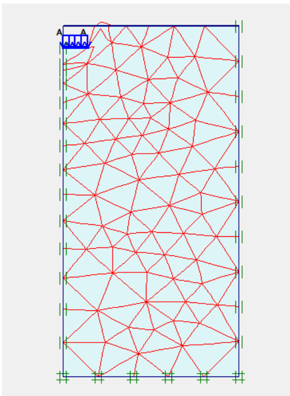

Fig. 3. Deformed mesh

A second series of analysis were performed with various sand thickness - footing width ratios (H/B) with geogrid reinforcement placed at the interface and middle of sand layer to investigate the effect of fill thickness on the settlement characteristics of the reinforced footing.

To investigate the effect of reinforcement width on the performance of the layered soil, analysis were conducted with varying widths of reinforcement layer in relation to footing width (B'/B). However, for all of these analysis the thickness of the sand layer was maintained constant at H/B = 0.8, which was equal to the optimum value, as determined from the earlier series of analysis

Next series of study were conducted for footing on reinforced and unreinforced rectangular trenches provided at an optimum of H/B =1.75 and also reinforced and unreinforced triangular trenches were provided at an optimum H/B =1.75. In both the cases, width of the trench changes from 0.175m (5 times the B) to 0.15

IV. RESULTS AND DISCUSSIONS

A comparison between load displacement response calculated using finite element analysis and the results obtained from the previous experimental studies from literatures for unreinforced soft soil. The finite elements results provide a reasonable fit with the experimental data given in Fig.1.

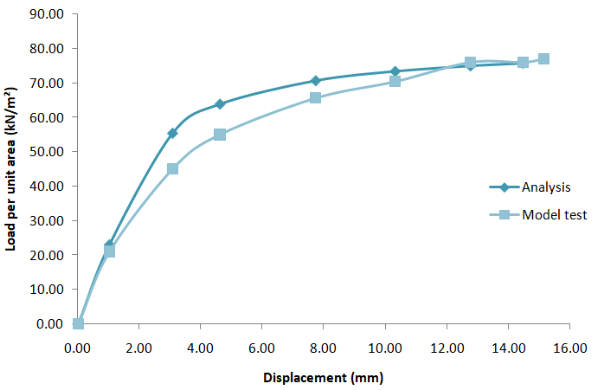

Fig 4 Comparison of results from experimental value and analysis

For an unreinforced sand-soil system, an increase in the thickness of the sand layer resulted in the decrease of the settement of the layered soil upto a value of H/B =1.75. Beyond this value, there was no significant decrease in the settlement with increase in fill thickness.Variation of load settlement curve shown in Fig.2. from which the optimum value of fill thickness at which the maximum benefit in terms of settlement was obtained at H/B =1.75 in unreinforced soil. For this ratio, ultimate bearing capacity obtained was 135kN/m^2. Summary of the results of footing unreinforced granular soil resting on soft soil given in Table 1.

Unlike the unreinforced case, footing on reinforced sand above soft soil showed a decrease with an increase in fill thickness for H / B ratios which increases from zero to the maximum of about 0.8. The settlement was persisted constant after attaining a maximum value, there was a gradual increase in settlementof the reinforced system when the fill thickness is increased beyond H/B = 0.8. In all the cases geogrid reinforcemnt were provided at the interface between granular fill and soft soil.The provision of a granular fill of suitable thickness over the soft subgrade was resulted in improved performance of the footing. The inclusion of geogrid reinforcement resulted in a considerable reduction in fill thickness with a significant improvement in bearing capacity and decrease in the settlement.Summary of the resutts given in Table II.

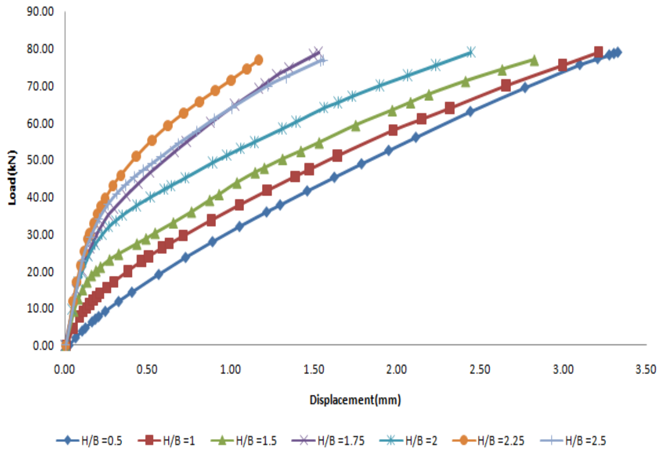

Fig. 5. Varitaion of load settlement curves of sand layers

TABLE 1. SUMMARY OF RESULTS OF UNREINFORCED SAND LAYER FROM FINITE ELEMENT ANALYSIS

H/B	Settlement (mm)
Series 1 - Unreinforced	
0	15.23
0.5	3.33
1.0	3.21
1.5	2.82
1.75	1.53
2	2.44
2.25	1.17
2.5	1.56

TABLE II. SUMMARY OF RESULTS OF REINFORCED SAND LAYER FROM FINITE ELEMENT ANALYSIS

H/B	Settlement (mm)
Series 2 - Reinforced	
0.2	3.97
0.4	3.65
0.6	3.31
0.8	3.06
1.0	3.17
1.2	1.92
1.6	2.68
1.75	1.41
2.0	2.30

To investigate the effect of reinforcement width on the performance of the layered soil, analysis were performed with varying widths of reinforcement layer in relation to footing width (B'/B). However, for all of these analysis the thickness of the sand layer was maintained constant at H/B = 0.8, which was equal to the optimum value as determined from the earlier series of analysis. In all the analysis geogrid reinorcement were placed at the interface between granular material and soft soil.

The settlement showd an decreasing trend with the increase in the width of reinforcement until it reaches a peak value, when the reinforcement width is about two times the width of the footing (B'/B=2.0).This is due to the fact that below the footing there exists a zone of shear deformation of soil, and only the portion of reinforcement which lies within this zone will have its tensile strength effectively mobilized. Portions of the reinforcement on either side of this zone would serve as anchorage to provide pull-out resistance to the geogrid. Therefore, the total required length of the geogrid located within the shear zone underneath the footing and the anchorage zones developed on both sides were considered as the optimum width, B', of the reinforcement. Any additional width of reinforcement beyond this optimum value of B' will be ineffective, and therefore the trend was decrease in the settlement. Table III shows the summary of footing settlement of reinforced sandlayer with geogrid above soft soil.

TABLE III. SUMMARY OF RESULTS OF REINFORCED SAND LAYER WITH GEOGRID

H/B	B/B'	Settlement (mm)
Series 3 – Effect of width of reinforcement		
0.8	3.57	3.06
0.8	3.00	3.29
0.8	2.00	3.44
0.8	1.00	3.19

For the next serries of tests rectangular trenches were provided at an optimum H/B =1.75 in unreinforced and reinforced granular soil. Width of the trench changes from 0.175 m (5 times the B) to 0.15m. In the granular trenches geogrid reinforcement was placed at the interface and at the middle of the trench. The results of these series showed that when the width of the rectangular trenches decreases from 0.175 to 0.15 m , the settlement value increases.Summary of the results presented in Table IV.

TABLE IV. SUMMARY OF RESULTS OF UNREINFORCED AND REINFORCED RECTANGULAR TRENCH

H/B	Width of the trench	Settlement (mm)	
		Unreinforced	Reinforced
Series 3 –Rectangular Trench			
1.75	0.175	1.76	1.59
1.75	0.15	2.02	2.0

Effect of Triangular trenches were also studied and were provided at an optimum H/B =1.75 in unreinforced and reinforced. Width of the trench changes from 0.175 m (5 times the B) to 0.15m. The results of these series showed that when the width of the triangular trenches decreases from 0.175 to 0.15 m , the settlement value increases. Triangular trench with geogrid around the trench with width 5% of the footing width is observed as the lowest settlement, 0.64mm.

TABLE V. SUMMARY OF RESULTS OF UNREINFORCED AND REINFORCED TRIANGULAR TRENCH

H/B	Width of the trench	Settlement (mm)	
		Unreinforced	***Reiinforced***
Series 3 – Triangular Trench			
1.75	0.175	2.78	0.64
1.75	0.15	3.45	0.82

It was found that the settlement increases with an increase in the ratio of sand thickness to footing width until it reaches a critical value, which can be considered as the optimum limit of lowest settlement of the layered soil. The installation of a geogrid reinforcement at the interface resulted in an appreciable decrease in settlement of the footing. The optimum thickness of the sand layer for a geotextile-reinforced foundation was found to be 0.8 times the width of the footing. Settlement of the footing resting on reinforced/unreinforced rectangular and triangular trenches above soft soil found to be decreased compared to settlement of footing on unreinforced soft soil. Fig 6 displays the Summary of the load settlement curves at different H/B ratios and ultimate bearing capacity obtained from numerical study is presented in Table VI.

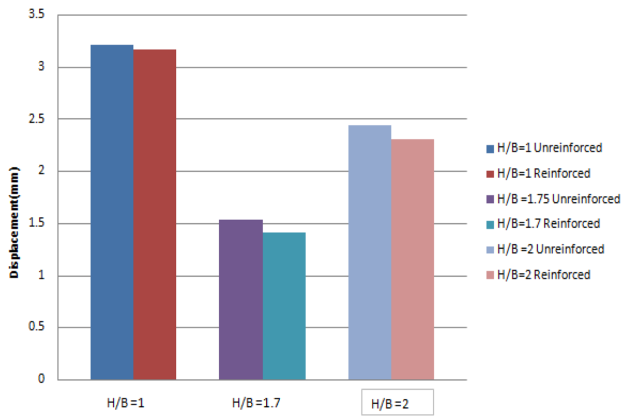

Fig. 6. Summary of load settlement curves at different H/B ratios

TABLE VI ULTIMATE BEARING CAPACITY FROM FINITE ELEMENT ANALYSIS

Material	Ultimate bearing capacity (kN/m^2)
Soft soil	68
Unreinforced sand layer above soft soil	135

V. CONCLUSION

A detailed numerical model study was carried out on a square footing on a geogrid reinforced granular fill-soil soft system. The primary aim of the study was to determine the effect of geo-grid reinforcements and the thickness and pattern of a sand layer on the settlement characteristics of square footing.Based on the results from the various finite analysis, the following conclusions were made:

- Different levels of improvement was gained depending on H/B ratio, reinforcement and position of reinforcement.
- While the provision of a layer of granular fill over the soft clay subgrade leads to an increase in its load carrying capacity, the provision of a reinforced layer at interface and middle of sand layer was resulted in an additional increase in the bearing capacity and a decrease in settlement of the footing.
- The optimum thickness of the sand layer with geo-grid reinforced foundation was found to be about 0.8 times the width of the footing.
- The optimum thickness of the sand layer with unreinforced foundation was found to be about 1.75 times the width of the footing.
- The effective width of reinforcement that resulted in the optimum performance of the footing was found to be about 3.75 times the width of the footing.
- The values of ultimate bearing capacity achieved from plaxis is 135kN/m² for H/B =1.75 in unreinforced, which is 98.53 % of the soft soil.
- Triangular trench with geo-grid around the trench with width 5 times of the footing width is observed as the lowest settlement, 0.64mm.
- Using a reinforced triangular trench of width 5 times B can be considered as the most effective method for problems of high settlement in soft soil.

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