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Numerical Study on Enhance Performance of Granular Pile with Geogrid Layer Reinforcement by PLAXIS 3D

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Abstract. *In India, there is a very long coastline which is covered with thick soft marginal deposits at several locations having very low shear strength and high compressibility. The engineers are very well versed with the applications of ground improvement techniques to lay foundation safely on this type of soft soil. The granular pile (GP) has been generally recognized as a useful technique to reinforce soft cohesive soils and loose silty sand deposits. In the present study, an attempt has been made to study the behaviour of single granular pile (GP) reinforced with layers of geo-grid by numerical model study using PLAXIS 3D software. Influence of spacing of geo-grid layer and depth of reinforcement in GP have been studied. Bulging and settlement behaviour have also been considered here. From the single GP model study, optimum spacing and 'reinforced depth' are concluded. Then group behaviour of GP has been studied with optimum spacing of geo-grid layer and optimum reinforced depth in GP. Increase in load carrying capacity has been observed for both the cases, GP as single and in group. Notable reduction in bulging and settlement have also been observed from the study. The outcome of the study has been compared with available published results*

Keywords— *Soft soil, geo-grid layer reinforcement, granular pile, bearing capacity.*

I. INTRODUCTION

In India, many ground improvement techniques are available which may be employed depending upon soil conditions and nature of projects. The granular pile (GP) has been generally recognized as a useful technique to reinforce soft cohesive soils and loose silty sand deposits. The construction of GP reinforcement involves replacement of 10 to 35 percent of weak soil with coarse granular material. The overall stiffness of the ground increases due to presence of GP. As a result, the load carrying capacity of the ground increases and reduction in settlement takes place.

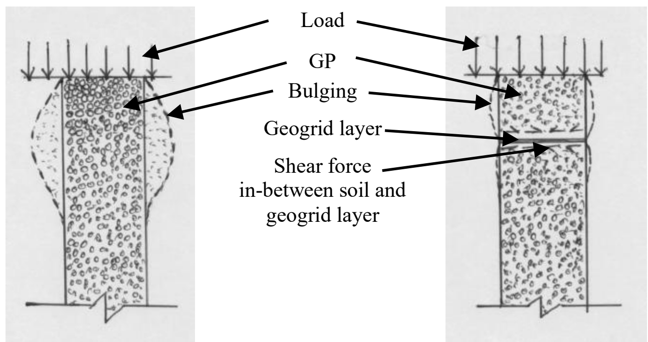

Fig. 1. Mechanism of geodrid layer reinforced GP

Load carrying capacity of granular pile further can be increased and bulging failure of granular pile can be reduced by placing horizontal reinforcement in the upper portion of the granular pile (Fig. 1.). In bulging, the granular material in the top portion of the pile is displaced laterally into the soil while the composite ground settles under compressive load. If geo-grid layer are placed in GP at top portion, friction is generated in between granular soil and geogrid during lateral movement of the granular material. This friction tends to reduce the bulging and increases load-carrying capacity of GP.

Bergado and Lam (1987) conducted experimental studies on granular piles with different densities and different proportions of gravel and sand on soft Bangkok clay. It was observed that gravel was the most efficient material for granular pile compared to gravel-sand combinations. Based on their investigations it was found that the ultimate bearing capacity with granular pile was 3 to 4 times greater than that of the untreated ground. They also observed that the piles acted independently when the spacing was 3 times pile diameter or greater. Al-Refeai (1992) performed triaxial tests on soft clay with randomly fiber mixed sand columns. In the experiment, fibrillated polypropylene fibers in 25 and 50 mm bundles were used as random fiber. It has been found that the column replacement ratio and depth of fiber reinforced sand layer inside column have a significant effect on load carrying capacity and settlement response of the reinforced soft soil. Madhav *et al.* (1994) proposed a method for estimating the contribution of reinforcement in the form of layers to the ultimate capacity and stiffness of a reinforced granular column. The analysis shows that the ultimate capacity and the stiffness of the reinforced column increase with the number of reinforcement layers. Rao and Nayak (1995) performed tests on partially confined sand column using geo-grid tubes. The experimental study was conducted to evaluate the feasibility of geo-grid tube as circumferential reinforcement to a compacted sand column. Uniaxial compression tests have been performed on circumferentially reinforced compacted sand column, with different number of reinforcing layers. The effect of repeated loading was also studied by conducting cyclic loading test. It has been concluded that the strength and stiffness of a circumferentially reinforced sand column can be significantly increased by increasing the number of reinforcing layers. Shroff and Patel (2003) carried out experimental

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studies on full length, floating and composite stone columns in Kaolinite clay. Composite columns include columns with reduced diameter at lower depth and columns with both reduced diameter and stones replaced by sand at lower depth. The results indicated that in all the types of columns the critical length is around 4.25 times diameter of column. Sharma *et al.* (2004) performed a series of laboratory tests to investigate the effect of geo-grid reinforcement on the load-carrying capacity and bulging of granular piles in soft clay. The study revealed an increase in the load-carrying capacity of geo-grid reinforced piles. The improvement in load carrying capacity increases with an increase in the number of geo-grids and a decrease in the spacing between them. The bulge diameter and bulge length decreased due to the incorporation of geo-grid reinforcement. Ambily and Gandhi (2007) have carried out experimental study on behaviour of single column and group of seven columns by varying parameters like spacing between the column, shear strength of soft clay and loading condition. The loading was applied either on equivalent area to estimate the stiffness of improved ground or on column only to estimate the limiting axial capacity. It has been established that columns arranged with spacing more than 3 times the diameter of the column do not give any significant improvement. Design charts have been developed and a design procedure is suggested. Samadhiya *et al.* (2009) studied on the response of a geo-grid reinforced granular pile under a rigid circular footing. The influence of spacing of geo-grid layers and reinforced depth of pile, on the performance of reinforced pile has been investigated. Geo-grid reinforced granular pile has been found to result in significant increase in load carrying capacity. The bulge diameter of pile has been found to reduce due to the incorporation of geo-grid layers as reinforcement.

The present paper shows the results of numerical three-dimensional study using PLAXIS 3D software to investigate the effect of geo-grid reinforcement on bulging and load-carrying capacity of granular piles in a soft clay bed. FEM analyses have been done on unreinforced GP, as well as GP reinforced with geo-grid layer. For analysis, GP with diameter (d) of 500 mm and a length (L) to diameter (d) ratio of 10 is chosen. The effect of spacing of geo-grid layers and its extent along the depth of pile on load carrying capacity, settlement and bulging behaviour of geo-grid reinforced granular pile have been studied. An attempt has been made to compare the results from present numerical study with the experimental results.

II. FINITE-ELEMENT ANALYSIS

FEM analysis has been carried out using package PLAXIS 3D. This is a finite element package intended for three-dimensional analysis of deformation, stability and ground water flow in geotechnical engineering.

A. PLAXIS 3D Model

First, single granular pile of diameter (*d*) 0.5 m and height (*L*) 5 m was made at the centre of the clay bed and loaded with a footing of diameter (*D* = 0.5 m) equal to the diameter of the GP. The model tank size was chosen as 5 m x 5 m and 8 m depth. The model geometry for single GP analysis has been shown in figure 1(a). For GP in group, model tank size was chosen as 10 m x 10 m and 8 m depth. The model geometry for GP in group analysis has been shown in figure 1(b). Four numbers of GP in group with square pattern of spacing 2d were chosen for group behaviour study. Analyses were carried out using Mohr-Coulomb's criterion considering elastoplastic behaviour for soft clay and sand. In the present study, the footing has been represented by a plate element modelled as a linear isotropic material. An undrained behaviour has been assumed for all the materials. The interface between GP material and geo-grid has been considered for the present study. The input parameters for present study for clay bed and GP have been shown in table 1 and for geo-grid in table 2.

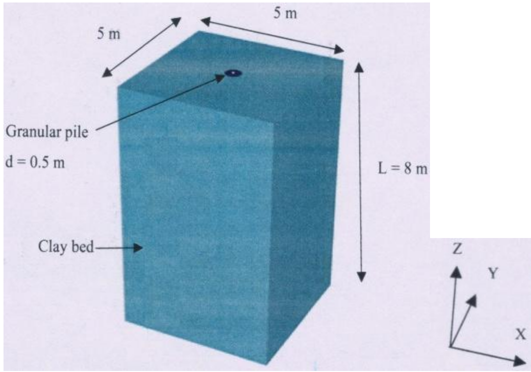

Fig.1. a. Model geometry for single GP analysis.

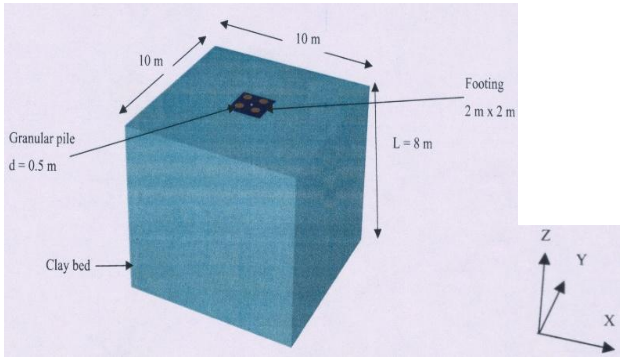

Fig. 1b. Model geometry for single GP analysis and GP in group analysis

The loading in FEM analysis, has been carried out through rigid plate to ensure equal settlement over the loaded area. To ensure equal settlement in FEA prescribed displacement is applied on geometry model over the loaded area. This ensures equal settlement over the loaded area during the progress of loading. For the present study, point prescribed displacement 65 mm (allowable settlement 65 mm for isolated footing on cohesive soil, as per IS: 1904-1986) is applied downwards at CG of the footing. The load-settlement curve at CG of the footing (just below the point prescribed displacement application) is plotted for every condition of base soil. Thus the bearing capacity values obtained from PLAXIS 3D analysis indicate allowable bearing capacity. For single GP, point load has been applied by circular footing of diameter D (= d) and for GP in group, square footing of size 2m x 2m has been considered.

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TABLE 1. Input values of clay bed and GP for FEA

S. No.	Property	Material	
		Clay Bed	Granular Pile (GP)
1	E* (kN/m²)	3000	18000
2	ν *	0.45	0.35
3	c ** (kN/m²)	15	3.5
4	ψ * (degree)	0	2
5	ϕ** (degree)	1	40
6	γ_{unsat} (kN/m³)	14.9	18
7	$\gamma_{sat}/\gamma_{bulk}$ (kN/m³)	19.5	18.9

E: Young's modulus, ν: Poisson's ratio, ϕ: Friction angle,
c: Cohesion, ψ: Dilatancy angle
* assumed value [reference Ambily and Gandhi (2007)],
** from model test data of Basu et al. (2018).

TABLE 2. Input values of geo-grid layer for FEA

Material	Material type	Behaviour	Axial stiffness (kN/m)
Geo-grid layer	Elastic	Isotropic	2000

B. Numerical Study Program

The following cases have been analysed for this study on unreinforced GP and geo-grid layer reinforced GP, which have been indicated in the subsequent table 3a and 3b for single GP and GP in group respectively.

TABLE 3 a. Numerical study programme of single GP

Sl. No.	H_{ig}	S_g	H_g	GP condition
1.	1d	1d	1d	Single GP / Footing diameter D = GP diameter (d)
2.			2d	
3.			3d	
4.			4d	
5.			5d	
6.	0.5d	1d	0.5d	-do-
7.			1.5d	
8.			2.5d	
9.			3.5d	
10.			4.5d	
11.	0.5d	0.5d	1d	-do-
12.			2d	
13.			3d	
14.			4d	
15.			5d	

Note. H_{ig} = distance of 1st geo-grid layer from top of GP,
S_g = spacing between geo-grid layer,
H_g = distance of last geo-grid layer from top of GP.

TABLE 3 b. Numerical study programme of GP in group for PLAXIS 3D analysis

Sl. No.	H_{ig}	S_g	H_g	GP condition
1.	1d	1d	1d	GP in group / Footing size: 2 m x 2 m
2.			2d	
3.			3d	
4.			4d	
5.			5d	
6.	0.5d	1d	0.5d	-do-
7.			1.5d	
8.			2.5d	
9.			3.5d	
10.			4.5d	
11.	0.5d	0.5d	1d	-do-
12.			2d	
13.			3d	
14.			4d	
15.			5d	

C. Results of Numerical Analysis

In this section discussion has been made on the outcome of finite element analysis using PLAXIS 3D for single GP and GP in group for plain GP and geo-grid reinforced GP.

Figure 2 shows the load-settlement curve for single GP with plain and geo-grid layer reinforcement for Hig = 1d and Sg = 1d for Hg = 1d, 2d, 3d, 4d and 5d respectively. Figure 3 shows that the presence of geo-grid layer in GP increases the load carrying capacity of GP.

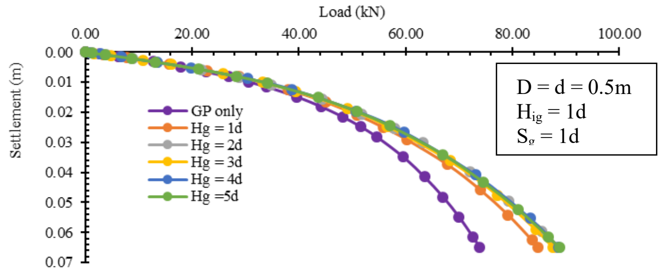

Fig. 2. Load settlement curve for single (plain) GP and geo-grid layer reinforced single GP (H_{ig} = 1d case, S_g = 1d case)

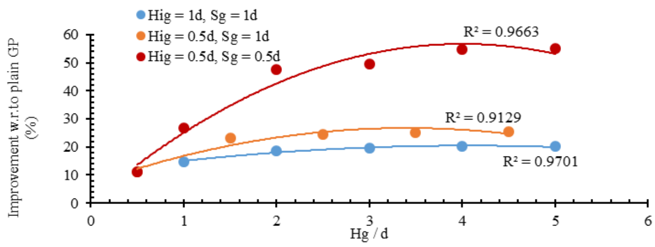

Fig. 3. Improvement in load carrying capacity of geo-grid layer reinforced single GP w.r.to plain single GP

As compared to unreinforced GP, an improvement of 14.76%, 18.59%, 19.67%, 20.11% and 20.18% in load carrying capacity has been observed for Hg = 1d, 2d, 3d, 4d and 5d respectively. It has been observed that for Hig = 1d and Sg = 1d, beyond geo-grid layer depth 3d (Hg = 3d) from top of GP, there is no such effect of geo-grid layer on load carrying capacity. So, in this case Hg = 3d may be considered as optimum position.

Figure 4 shows the load-settlement curve for single GP with plain and geo-grid layer reinforcement for H_{ig} = 0.5d and S_g = 1d for H_g = 0.5d, 1.5d, 2.5d, 3.5d and 4.5d respectively. Fig. 3 shows that the presence of geo-grid layer in GP increases the load carrying capacity of GP. As compared to unreinforced GP, an improvement of 11.02%, 23.29%, 24.39%, 25.24% and 25.59% in load carrying capacity has been observed for H_g = 0.5d, 1.5d, 2.5d, 3.5d and 4.5d respectively. It has been observed that for H_{ig} = 0.5d and S_g = 1d, beyond geo-grid layer depth 3.5d (H_g = 3.5d) from top of GP, there is no such effect of geo-grid layer on load carrying capacity. So, in this case H_g = 3.5d may be considered as optimum position.

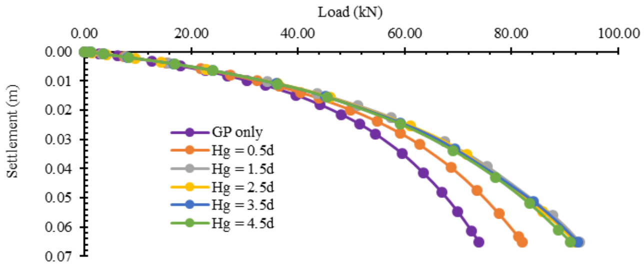

Fig. 4. Load settlement curve for single (plain) GP and geo-grid layer reinforced single GP (Hig = 0.5d, Sg = 1d case)

Figure 5 shows the load-settlement curve for single GP with plain and geo-grid layer reinforcement for H_{ig} = 0.5d and S_g = 0.5d for H_g = 0.5d, 1d, 2d, 3d, 4d and 5d respectively. Fig. 3 shows that the presence of geo-grid layer in GP increases the load carrying capacity of GP. As compared to unreinforced GP, an improvement of 26.70%, 47.53%, 49.61%, 54.65% and 55.05% in load carrying capacity has been observed for H_g = 1d, 2d, 3d, 4d and 5d respectively. It has been observed that for H_{ig} = 0.5d and S_g = 0.5d, beyond geo-grid layer depth 4d (H_g = 4d) from top of GP, there is no such effect of geo-grid layer on load carrying capacity. So, in this case H_g = 4d may be considered as optimum position.

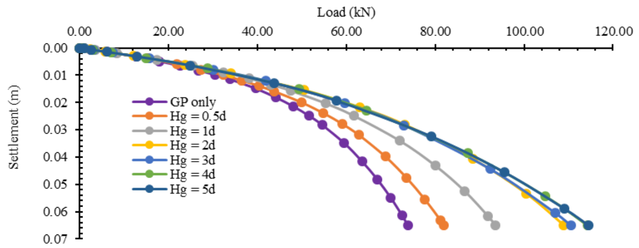

Fig. 5. Load settlement curve for single (plain) GP and geo-grid layer reinforced single GP (Hig = 0.5d, Sg = 0.5d case)

Settlements are found to reduce considerably for the reinforced GP with geo-grid layer. For H_{ig} = 1d, S_g = 1d case, for a loading intensity of 70 kN, as compared to unreinforced GP, the settlement has been found to reduce by 27.01%, 30.66% and 36.13% for GP with geo-grid layer for H_g = 1d, H_g = 2d and H_g = 3d respectively.

For H_{ig} = 0.5d, S_g = 1.0d case, for a loading intensity of 70 kN, as compared to unreinforced GP, the settlement has been found to reduce by 23.36%, 37.77% and 40.69% for GP with geo-grid layer for H_g = 0.5d, H_g = 1.5d and H_g = 2.5d respectively.

For H_{ig} = 0.5d, S_g = 0.5d case, for a loading intensity of 70 kN, as compared to unreinforced GP, the settlement has been found to reduce by 23.24%, 41.61% and 63.50% for GP with geo-grid layer for H_g = 0.5d, H_g = 1d and H_g = 2d respectively.

Figure 6 shows the load-settlement curve for GP in group with plain and geo-grid layer reinforcement for H_{ig} = 1d and S_g = 1d for H_g = 2d, 3d, 4d and 5d respectively. Figure 7 shows that the presence of geo-grid layer in GP increases the load carrying capacity of GP. As compared to unreinforced GP, an improvement of 1.80%, 4.45%, 5.01%, and 5.87% in load carrying capacity has been observed for H_g = 2d, 3d, 4d and 5d respectively. It has been observed that for H_{ig} = 1d and S_g = 1d, the effect of load carrying capacity due to geo-grid layer in GP, is less as compared to the single GP for the same condition of reinforcement. This may happen due to presence of soft clay layer under footing. For single GP loading the area replacement ratio is 1 (D = d) but in GP in group the area replacement ratio is 0.2 only.

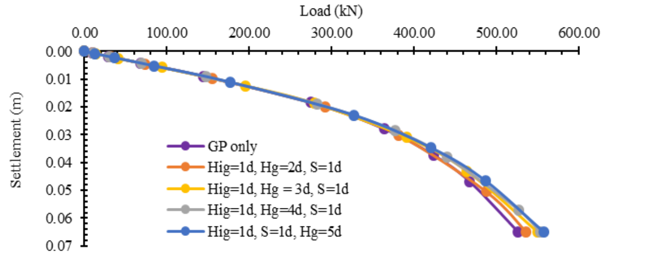

Fig. 6. Load settlement curve for (plain) GP and geo-grid layer reinforced GP in group (Hig = 1d case, Sg = 1d case)

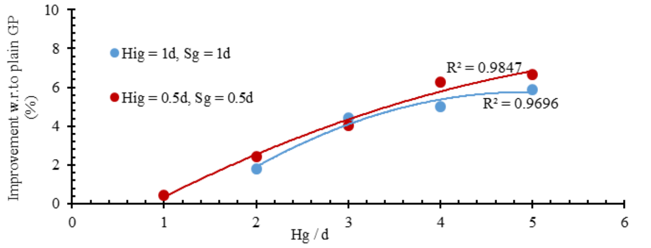

Fig. 7. Improvement in load carrying capacity of geo-grid layer reinforced GP in group w.r.to plain GP in group

Figure 8 shows the load-settlement curve for GP in group with plain and geo-grid layer reinforcement for H_{ig} = 0.5d and S_g = 0.5d for H_g = 1d, 2d, 3d, 4d and 5d respectively. Fig. 7 shows that the presence of geo-grid layer in GP increases the load carrying capacity of GP. As compared to unreinforced GP, an improvement of 0.47%, 2.45%, 4.04%, 6.29%, and 6.64% in load carrying capacity has been observed for H_g = 1d, 2d, 3d, 4d and 5d respectively. It has been observed that for H_{ig} = 0.5d and S_g = 0.5d, the effect of load carrying capacity due to geo-grid layer in GP, is less as compared to the single GP for same condition of reinforcement but it is more effective than H_{ig} = 1d and S_g = 1d case for GP in group.

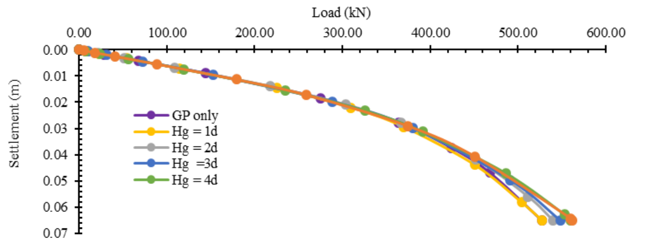

Fig. 8. Load settlement curve for (plain) GP and geo-grid layer reinforced GP in group (Hig = 0.5d case, Sg = 0.5d case)

Figure 9 shows the typical bulging pattern of single GP for (i) plain, (ii) H_{ig}=1d, S_g=1d, H_g=3d, (iii) H_{ig}=0.5d, S_g=1d, H_g=2.5d and (iv) H_{ig}=0.5d, S_g=0.5d, H_g=3d cases respectively. Similarly figure 10 shows typical bulging pattern of GP in group for (i) plain, (ii) H_{ig}=1d, S_g=1d, H_g=3d and (iii) H_{ig}=0.5d, S_g=0.5d, H_g=3d cases respectively. For plain GP, both the cases, single GP and GP in group shows that bulging

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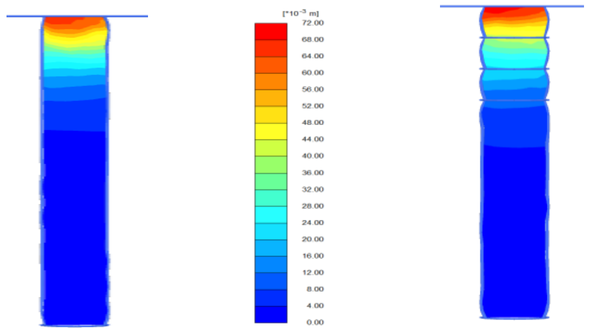
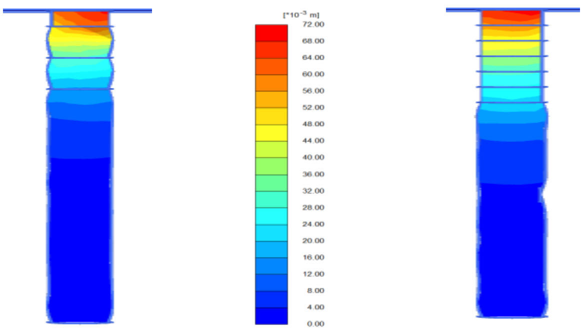
start from top of the GP. Maximum bulging occurs at top of GP. The diameter of the bulged bulb has been found to reduce due to the insertion of geogrid layers. The bulging depth has been increased after placing of geo-grid layer in GP. Due to interaction between geo-grid layers and GP material, the upper portion of the reinforced GP has acted as a rigid block. The portion below the bottom most geogrid layer has bulged in the absence of geo-grid reinforcement. Similar behavior has been reported by Samadhiya. et al. (2009). In this study also improvement due to use of geo-grid layer reinforcement in GP on load carrying capacity has been found to increase with the number of geo-grid and lesser spacing.



i.) Plain GP ii) H_{ig}=1d, S_g=1d, H_g=3d

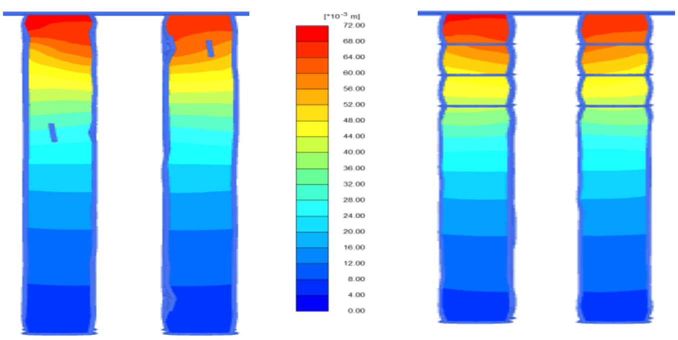
Fig. 9a. Bulging of single GP



iii) H_{ig}=0.5d, S_g=1d, H_g=2.5d iv) H_{ig}=0.5d, S_g=0.5d, H_g=3d

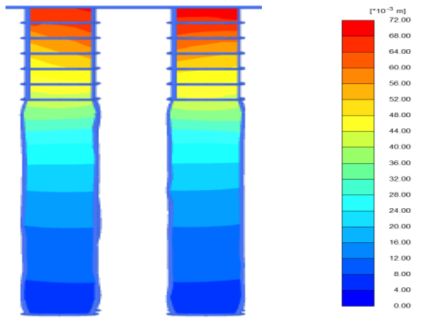
Fig. 9b. Bulging of single GP

Fig. 9. Bulging of single GP for unreinforced and different geo-grid layer reinforced cases



i.) Plain GP ii) H_{ig}=1d, S_g=1d, H_g=3d

Fig. 10a. Bulging of GP in group



i.) Plain GP

Fig. 10b. Bulging of GP in group

Figure 10: Bulging of GP in group for unreinforced and different geo-grid layer reinforced cases

III. COMPARISON

Samadhiya *et al.* (2009) studied the behaviour of a single pile reinforced with the layers of geogrid and installed in soft clay. Laboratory tests have been conducted to study the response of a geogrid reinforced granular pile under a rigid circular footing. The influence of spacing of geogrid layers and reinforced depth of pile (depth of bottom most geogrid layer), on the performance of reinforced pile has been investigated. The load tests were conducted on 50 mm diameter reinforced and unreinforced granular piles. To study the effect of layer geogrid reinforcement, load tests were conducted for geogrid installed at spacing of 0.5 times and 1.0 time the diameter of granular pile and up to the depth of 2.0, 3.0, 4.0 and 5.0 times the diameter of granular pile. The tests were conducted with loading only on column area, to observe pile response and to optimize the spacing and critical depth of geogrid layer. A load test was also conducted on clay bed without granular pile for the purpose of comparison of results with clay bed reinforced with granular piles.

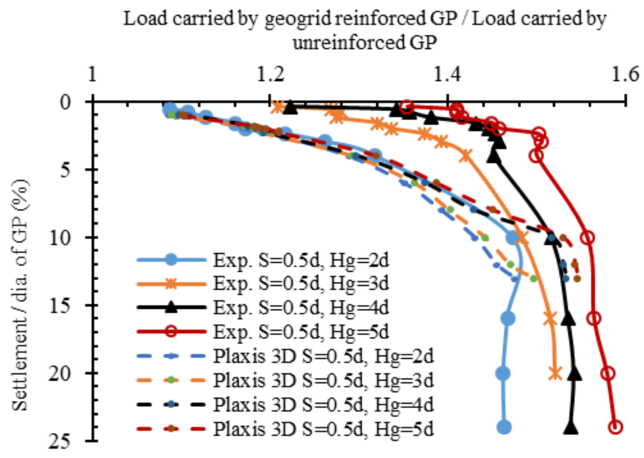


Fig.11: Comparison of numerical study with experimental study after Samadhiya et al. (2009)

A comparison (Fig. 11) has been made between present numerical finite element study and the experimental results by Samadhiya *et al.* (2009) for the same situation like spacing between geo-grid layers is 0.5d and depth of geo-grid layer

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reinforcement from top of GP are 2d, 3d, 4d and 5d respectively. The numerical study results have shown similar type of variation with the experimental results by Samadhiya *et al.* (2009). The magnitudes of experimental results shows higher as compare to numerical study. This may be attributed due to the position of 1st layer of geo-grid in GP. For experimental study, 1st layer of geo-grid has been placed in top of GP. But in numerical study, the 1st layer of geo-grid is placed below 0.5d from top of GP.

IV. Conclusion

In the present work, numerical analysis has been carried out to study the effect of layered reinforcement on load carrying capacity of granular pile installed in soft clay. Based on the analytical studies conducted, the following conclusions have been drawn:

1. Presence of geo-grid layer in GP increases the load carrying capacity of single GP. For H_{ig} = 1d and S_g = 1d case, as compared to unreinforced GP, an improvement of 19.67%, in load carrying capacity has been observed for H_g = 3d. Beyond depth 3d (H_g = 3d) from top of GP, no such improvement of load carrying capacity has been found.
For single GP, H_{ig} = 0.5d and S_g = 1d case, as compared to unreinforced GP, an improvement of 25.24%, in load carrying capacity has been observed for H_g = 3.5d. Beyond geo-grid layer depth 3.5d (H_g = 3.5d) from top of GP, no such improvement of load carrying capacity has been found.
For single GP, H_{ig} = 0.5d and S_g = 0.5d case, as compared to unreinforced GP, an improvement of 54.65%, in load carrying capacity has been observed for H_g = 4d. Beyond geo-grid layer depth 4d (H_g = 4d) from top of GP, no such improvement of load carrying capacity has been found.
2. Presence of geo-grid layer in GP, increases the load carrying capacity of GP in group. For H_{ig} = 1d and S_g = 1d case, as compared to unreinforced GP, an improvement of 5.01%, in load carrying capacity has been observed for H_g = 4d. Similarly, for H_{ig} = 0.5d and S_g = 0.5d case, as compared to unreinforced GP, an improvement of 6.29%, in load carrying capacity has been observed for H_g = 4d. Beyond geo-grid layer depth 4d (H_g = 4d) from top of GP, no such improvement of load carrying capacity has found for GP in group.
3. Bulge diameter has been found to reduce for a granular pile reinforced with geogrid layers.
4. The extent of bulging along the length of GP has been found to increase due to increase of number of geo-grid layers in GP.
5. Settlements are found to reduce considerably for the reinforced GP with geo-grid layer. GP with more the number of geo-grid layer, shows more settlement reduction as compared to plain GP.
6. Group capacity has not been improved significantly by introducing geo-grid layers. However, further study may be done with GP placed closer than the spacing adopted here (2d).

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