3D NUMERICAL ANALYSIS OF GRANULAR PILES WITH INTERNAL HORIZONTAL GEOGRID STRIPS IN LAYERS

Hasan M[1], Samadhiya N.K[2]
[1]Research scholar, [2]Professor, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India – 247667
E mail ID: [1]murtazadce@gmail.com, [2]nksamfce@iitr.ac.in

ABSTRACT: In very soft soils, granular piles do not achieve significant load carrying capacity due to poor lateral confinement therefore geosynthetic reinforced granular piles are effectively installed to provide additional reinforcement either as vertical encasing or in horizontal layers. In the present paper, numerical analysis of reinforced floating granular piles installed in soft clays has been carried out by using a finite element software, PLAXIS 3D. The reinforcement has been provided in the form of horizontal geogrid strips. A linear elastic perfectly plastic Mohr Coulomb model was used for clay and stone aggregates. A 75 mm diameter single granular pile was simulated in the middle of a square tank of 200 mm width and 525 mm height. Geogrid strips of 65 mm diameter were used over the full length of granular piles. The effect of various parameters such as strips spacing, undrained shear strength of clay and geogrid stiffness are studied. Vertical load intensity settlement relationships of granular piles were obtained by applying load only on granular pile and compared to that obtained from untreated ground. The results show significant improvement in the ultimate load intensity of granular piles due to the incorporation of reinforcement as horizontal strips.

Keywords: FEM, ground improvement, stone columns, geogrid

1 INTRODUCTION

Out of several ground improvement techniques available, reinforced granular piles have been widely adopted in very soft soils to increase bearing capacity as well as rate of consolidation and to reduce settlements. The major applications of granular piles are in embankments, liquid storage tanks, raft foundations and other low rise structures. The performance of granular piles depends on the lateral confining pressure from the surrounding soils. In very soft clays, granular piles do not achieve significant load carrying capacity, so additional confinement is needed for its better performance. In recent years, geosynthetic has been successfully used with granular piles installed in very soft soils, in the form of vertical encasing or in horizontal layers to provide additional confinement. In the past, various researchers have conducted large and small scale laboratory tests, numerical analysis and field tests on vertical encased granular piles in very soft soils (Murugesan and Rajagopal, 2006, 2007; Gniel and Bouazza, 2009; Pulko et al., 2011; Ali et al., 2012; Yoo and Lee, 2012; Ghazavi and Afshar, 2013; Almeida et al., 2014; Zhang and Zhao, 2015; Mohapatra et al., 2016; Hasan and Samadhiya, 2016). Granular piles reinforced with horizontal strips improve load capacity of treated ground and control bulging by development of shear stress at the strips-stone aggregates interface. Madhav (1982) has performed small scale in situ tests on granular piles reinforced with horizontal strips. Sharma et al. (2004), Ayadat et al. (2008) and Ali et al. (2012) have conducted laboratory model tests on horizontally striped granular piles whereas Madhav et al. (1994) and Wu and Hong (2008) have given an analytical procedure to predict the response of treated ground with horizontally striped granular piles. Sharma et al. (2004) presented a series of results of experiments performed to investigate the effect of horizontal geogrid layers on bulging and load carrying capacity of granular piles in a soft clay bed. Hong and Wu (2013) carried out numerical analysis and laboratory triaxial compression tests on sand columns internally reinforced with horizontal geotextile layers. The authors compared numerical and experimental results in the form of deviatoric stresses and volumetric strains.

Very limited literature is available on granular piles (GP) not resting on firm stratum but have their tips embedded in soft clays. The numerical analysis has not been reported in the literature on floating GP installed in very soft clays reinforced with horizontal strips. In the present study, numerical analysis has been carried out on floating unreinforced granular pile (URGP) and GP reinforced with internal horizontal geogrid strips in layers by using PLAXIS 3D. The parameters included in the study are strips spacing, undrained shear strength of clay and geogrid stiffness.

2 OUTLINE OF ANALYSIS

The numerical analysis has been carried out on 75 mm diameter and 375 (5d) mm length single floating GP, where d is the diameter of the pile. The granular piles are simulated in a square tank of 200 mm width and

525 mm height. Circular strips of geogrid as horizontal strips of 65 mm diameter were assumed over the entire length of granular piles. These strips were placed at three different centre to centre spacing (S) of 25 mm (d/3), 50 mm (2d/3) and 70 mm (≈d). First geogrid strip in each case was placed at 25 mm depth form the top of granular piles.

2.1 Properties of Materials Used

Clay, crushed stone aggregates and geogrid were used in the present analysis. These materials were collected from locally available sites and tested in the Geotechnical Engg. Lab, IIT Roorkee. The physical properties of clay are specific gravity = 2.73, optimum moisture content = 17.56%, maximum dry unit weight = 17.22 kN/m^3, liquid limit = 48%, Plastic limit = 18% and Plasticity index = 30 %. The dry unit weight and undrained shear strength corresponding to 34% water content were 13.85 kN/m^3 and close to 5 kPa respectively. It was classified as CI as per IS: 1498:2000. Modulus of elasticity of soft clay was determined by consolidation test corresponding to a pressure range of 100–200 kPa as reported by Ambily and Gandhi (2007). The Poisson's ratio for soft clay and aggregates were taken as per typical values suggested by Bowles (1997).

The crushed stone aggregates made of granite and were 2–6.3 mm in size. The maximum and minimum dry unit weights of the aggregate are 15.04 kN/m^3 and 13.41 kN/m^3 respectively. The dry unit weight and angle of internal friction of stone aggregates at 70% relative density were 14.51 kN/m^3 and 43° respectively. The ultimate tensile strength of geosynthetic was determined from standard wide-width tension tests (ASTM D4595). The ultimate tensile strength and axial stiffness of 1.5 mm thick biaxial geogrid sample were found to be 7.96 kN/m and 38 kN/m respectively corresponding to 20.21% strain.

FINITE ELEMENT ANALYSIS

FEM study was carried out by finite element software, PLAXIS 3D. The vertical load intensity settlement behaviour of GP was obtained from PLAXIS models. PLAXIS 3D model was validated by simulating load settlement behaviour of single sand-fibre mixed GP by Basu (2009). Basu (2009) conducted laboratory test on rectangular tank of size 0.2625 m × 0.2625 m × 0.6 m. A GP of 75 mm diameter and 600 mm length was installed in the centre of tank and loaded alone. In present study, a model was generated in PLAXIS 3D and analysed using Mohr–Coulomb failure criterion. The material properties used in the modelling are given in Table 1. The comparison of experimental and PLAXIS 3D results is presented in Fig. 1. The results are in reasonably good agreement.

Table 1 Material properties for PLAXIS 3D

Parameters	Basu (2009)		Present study	
	Clay	Sand-fibre mix	Clay	Stone aggregates
Young's modulus, E (kPa)	250	6700	420	42500
Cohesion (kPa)	16.0	15.55	5	0
Angle of internal friction, ϕ (°)	0	34.47	0	43
Poisson's ratio, μ	0.3	0.3	0.48	0.3
Dry unit weight (kN/m3)	14.90	18.0	13.85	14.51
Bulk unit weight (kN/m3)	19.37	-	18.58	-

In the present study, consolidation effect of clay was not taken into account. The linear elastic perfectly plastic Mohr Coulomb model, which has also been adopted by various authors (Ambily and Gandhi, 2007; Ghazavi and Afshar, 2013; Pulko et al., 2011) for similar study, has been used for clay and stone aggregates. Geotextile has been modelled as elastic material. The bottom boundary of the tank is restricted to move in all the three directions whereas the vertical boundaries can move only in the vertical directions. Strips were created by using function of polycurve with circular shape and then applying geogrid in PLAXIS model. The vertical load was applied in the form of prescribed displacement assuming rigid behaviour of loading plate. Loading period is kept short to ensure undrained loading condition which simulates loading during construction. The material parameters (E, c_u, ϕ, γ_d, ψ) have been determined from relevant laboratory model tests and are given in Table. 2. The interface between a GP and clay is a mixed zone where the shear strength properties can vary, depending on the method of installation. Therefore an interface element is not used in the present study. The meshes used for GP reinforced with 50 mm spaced horizontal strips are presented in Fig. 2.

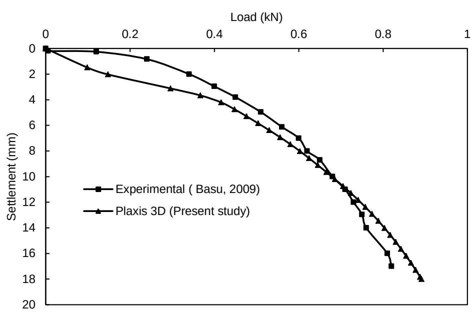

Fig. 1 PLAXIS validation (Basu, 2009)

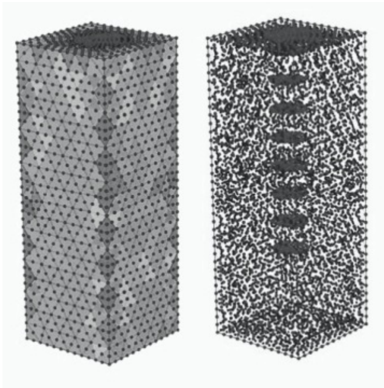

Fig. 2 Plaxis model of Granular piles reinforced with 50 mm spaced horizontal strips

3 RESULTS AND DISCUSSION

The numerical analysis has been conducted to estimate the ultimate load intensity of URGP and reinforced GP with horizontal strips. The results in terms of vertical load intensity-settlement behaviour of clay bed, floating URGP and GP reinforced with horizontal strips, for three different spacing are presented in Fig. 3. The ultimate load intensity for URGP treated ground was found to increase by 185% as compared to untreated ground. It was observed that ultimate load intensity of improved ground increases with reduction in vertical spacing of strips. The ultimate load intensity for 25 mm, 50 mm and 70 mm centre to centre spaced horizontally reinforced GP was found to increase by 442%, 396% and 316% respectively as compared to untreated ground, 89%, 73% and 45% with respect to URGP.

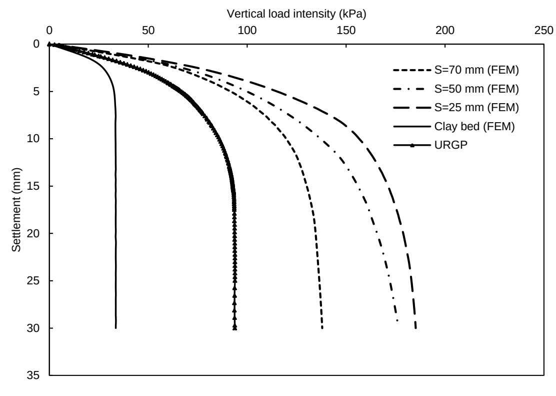

Fig. 3 Vertical load intensity settlement behaviour of horizontal reinforced floating granular piles

Numerical analysis has also been extended to study the influence of undrained shear strength of the soft clay and geogrid stiffness on the behaviour of floating GP. All numerical models were simulated for reinforced GP with 25 mm horizontal strips spacing. The undrained shear strength of clay bed was kept as 5 kPa, 10 kPa and 15 kPa and axial stiffness of geogrid as 38 kPa. The variation of ultimate load intensity with undrained shear strength is shown in Fig. 4. The ultimate load intensity of GP with horizontal strips increased with the increase in undrained shear strength of clay. It may be attributed to the higher lateral resistance provided by surrounding clay. The axial stiffness of geotextile used in reinforced floating GP was kept in the range of 20-160 kN/m and undrained shear strength of clay as 5 kPa. The influence of stiffness on the ultimate load intensity of floating GP is shown in Fig. 5. Initially ultimate load intensity increased marginally and became constant for higher stiffness. It may be noted that the floating GP reinforced with higher geogrid stiffness start penetrating into soft clay rather than bulge.

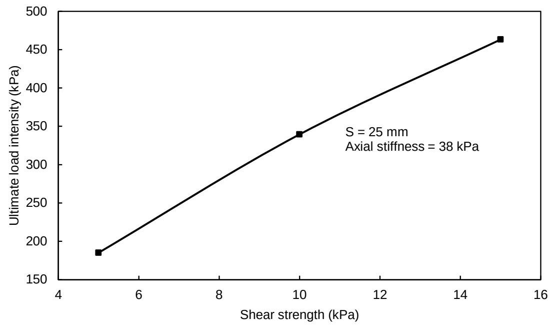

Fig. 4 Variation of the ultimate load intensity with undrained shear strength of clay

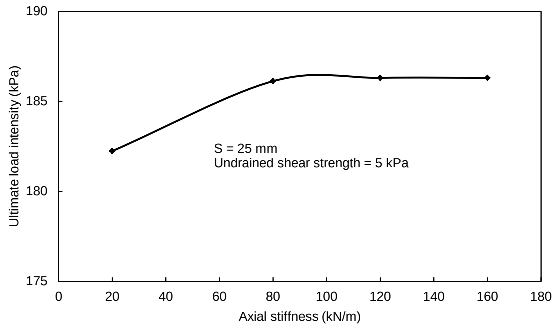

Fig. 5 Variation of the ultimate load intensity with axial stiffness of geogrid

4 Conclusions

In the present investigation, numerical analysis was carried out on 75 mm diameter floating GP reinforced with horizontal geogrid strips. The effects of strips spacing, undrained shear strength of clay and geogrid stiffness were studied. The vertical load intensity-settlement plots from PLAXIS 3D numerical models were compared with that obtained from untreated ground. The following conclusions can be drawn:

- The ultimate load intensity of treated ground has been found to improve due to installation of granular piles. It further improves due to inclusion of geogrid strips in the granular piles.
- The ultimate load intensity of improved ground increases with reduction in vertical spacing of geogrid strips in granular piles.
- The ultimate load intensity for GP reinforced with horizontal strips increases with the increase in undrained shear strength of clay due to higher lateral resistance provided by surrounding clay.
- The ultimate load intensity of GP reinforced with horizontal strips is found to increase marginally for lower stiffness and becomes constant for higher stiffness of geogrid.

References

Ali, K., Shahu, J.T., and Sharma, K.G. (2012) 'Model tests on geosynthetic-reinforced stone columns: a comparative study', *Geosynthetics International*, 19(4), pp 292-305

Almeida, M., Hosseinpour, I., Ricci, M., and Alexiew, D. (2014) 'Behavior of Geotextile-Encased Granular Columns Supporting Test Embankment on Soft Deposit', *J. Geotech. Geoenviron. Eng. ASCE*, 1943-5606.0001256, 04014116

Ambily, A.P., and Gandhi, S.R. (2007), ' Behavior of stone columns based on experimental and FEM analysis', *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, 133(4), pp 405-415

ASTM D4595 (1986), *Standard test method for tensile properties of geotextiles by the wide-width strip method*, ASTM International, West Conshohocken, PA, USA

Ayadat, T., Hanna, A.M., and Hamitouche, A. (2008) 'Soil improvement by internally reinforced stone column', *Ground Improvement* 161(2), pp 55-63

Basu, P. (2009) *Behaviour of sand-fibre mixed granular piles*. Ph.d Thesis, Indian Institute of Technology Roorkee, Roorkee

Bowles, J.E. (1997) *Foundation analysis and design*, Mc Graw Hill International Editions, Singapore

Ghazavi, M., and Afshar, J.N. (2013) 'Bearing capacity of geosynthetic encased stone columns', *Geotextiles and Geomembranes*, 38, pp 26-36

Gniel, J., and Bouazza, A. (2009) 'Improvement of soft soils using geogrid encased granular columns', *Geotextiles and Geomembranes*, 27(3), pp 167-175

Hasan, M., and Samadhiya, N.K. (2016) 'Experimental and numerical analysis of geosynthetic-reinforced floating granular piles in soft clays', *Int. J. of Geosynth. and Ground Eng.* 2: 22, DOI: 10.1007/s40891-016-0062-6

Hong, Y.S., and Wu, C.S. (2013) 'The performance of a sand column internally reinforced with horizontal reinforcement layers', *Geotextiles and Geomembranes*, 41, pp 36-49

Iai, S. (1989) 'Similitude for shaking table tests on soil-structure fluid models in 1g gravitational field', *Soils and Foundations*, 29(1), pp105-118

IS: 1498 (2000), *Classification and identification of soils for general engineering purposes*, Indian Standards Institution, New Delhi, India

Madhav, M. R. (1982) 'Recent development in the use and analysis of granular piles'. *Proceedings of Symposium on Recent Development in Ground Improvement Techniques*, Bangkok, pp. 117–129.

Madhav, M. R., Alamghir, M., and Miura, N. (1994) 'Improving granular column capacity by geogrid reinforcement'. *Proceedings of the 5th International Conference on Geotextiles*, Geomembranes and Related Products, Singapore, pp. 351–356

Mohapatra, S.R., Rajagopal, K., and Sharma, J. (2016) 'Direct shear tests on geosynthetic-encased granular columns', *Geotextiles and Geomembranes*, 44:396-405

Murugesan, S., and Rajagopal, K. (2006) 'Geosynthetic-encased stone columns: numerical evaluation', *Geotextiles and Geomembranes*, 24, pp 349-358

Murugesan, S., and Rajagopal, K. (2007) 'Model tests on geosynthetic encased stone columns', *Geosynthetics International*, J 24(6):346-354

Pulko, B., Majes, B., and Logar, J. (2011) 'Geosynthetic-encased stone columns: analytical calculation model', *Geotextiles and Geomembranes*, 29(1), pp 29-39

Sharma, R.S., Kumar, B.R.P., and Nagendra, G. (2004) 'Compressive load response of granular piles reinforced with geogrids', *Canadian Geotechnical Journal*, 41(1), pp187-192

Yoo, C., and Lee, D. (2012) 'Performance of geogrid-encased stone columns in soft ground: full-scale load tests', *Geosynthetics International*, 19(6), pp 480-490

Zhang, L., and Zhao, M. (2015) 'Deformation analysis of geotextile-encased stone columns', *Int. J. Geomech, ASCE*, 15(3):04014053