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A comparative study on the uplift capacity of single helix helical anchor and granular pile anchor in sand

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Abstract. Helical anchors are tension members widely used to provide tension resistance to structures that are prone to uplift. A relatively new method called granular pile anchor is a modified form of a conventional stone column with an anchor plate at the bottom connected to an axial rod that can provide tension resistance when connected to the base of a structure footing during uplift. In this paper, experimental investigations on the uplift behavior of laboratory-scale model helical screw anchors and Granular pile anchors installed in loose sand bed under the influence of vertical uplift loads are presented. The model anchors were subjected to a constant uplift strain, and the uplift resistance and the uplift displacement were measured during the experiment. The model helix/anchor diameter was kept as a constant of 70 mm, and the effect of embedment ratio (length to diameter ratio) on the uplift capacity and uplift behavior are studied and reported. A granular pile anchor was found to provide significantly larger uplift resistance compared to a single helix helical anchor and may be used as an alternative or in addition to it.

Keywords: Helical screw anchor, granular pile anchor, tension resistant foundation, uplift.

1 Introduction

1.1 Background

Helical piles and anchors have been in use for more than 170 years (Tsuha 2016). Helical piles were first put into use in the coastal regions of England lighthouse foundation in 1833 by an English inventor Alexander Mitchell. Later, they were adopted for the same purpose in north America. Helical anchors find application in various building foundations like dock foundation, solar panel foundation, communication, power transmission tower foundation, underpinning of settling structures, etc. They are foundation systems that can be used to support or resist any loading like compressive, tensile or lateral. They are relatively easy to install and can be readily put into usage after the installation. The helical anchor consists of a hollow shaft made of steel and a helical plate fixed to this shaft. The number of helical plates can vary depending on the resistance needed. The helical shape helps in the installation of the helical anchor by acting as a cutting edge when it is being screwed into the ground by applying a torque at the top end. The torque is applied using a motor that may be fixed to the hydraulic arm extending from a vehicle. Granular pile anchor (GPA) was introduced as a modification to the currently existing stone column technique to carry tensile loading (Rao et al. 2007). The conventional stone column technique consists of making a cylindrically shaped hole in the ground and depositing granular material, which is then compacted to form a stiff column inside the soil mass. The compaction also increases the bearing capacity of the adjacent soil mass. In a granular anchor pile, a tensile element in the form of an anchor plate and an anchor rod is inserted inside the cylindrical hole before the granular material is deposited and compacted. The anchor plate is a mild steel plate of the same diameter as that of the hole or a concrete pedestal. The anchor rod should be of sufficient thickness and strength. The anchor rod is connected to the footing of the structure, which needs anchoring. A review of the literature revealed that the granular anchor pile is currently underutilized as a tension resistance foundation technique despite its relative simplicity and low-cost installation.

This paper aims to present a comparative study of the single helix anchor and GPA installed in cohesionless soil based on the small-scale laboratory uplift tests. The uplift load versus displacement behavior of single model helical anchor and GPA are studied. A comparison of the ultimate uplift load and the effect of embedment depth on the uplift performance is given in this paper.

2 Literature review

A limited review of the helical anchor and the GPA is provided in this section. Meyerhof and Adams. 1968 conducted uplift tests on model circular anchor plates buried in sand by varying the anchor diameter, embedment depth, and sand relative density. They concluded that a complex mechanism is involved in providing the resistance to the footings against the uplift where soil weight and the soil strength act together to resist the uplift force. Ghaly et al. 1991 carried out pullout test on different types of single helical anchor, which were installed in sand beds of various densities and presented the experimental and theoretical investigations. The depth of the anchor and frictiom angle of the sand have a significant effect on the failure mechanism and the pullout capacity. The helical anchors were classified based on the failure mechanisms as shallow, transit, and deep and a limit-equilibrium based mathematical model was developed. Hanna et al. 2007 presented analytical models that predicted the uplift capacity and the load-displacement behavior for shallow single helical and plate anchors. Empirical expressions were presented to determine the critical depth of anchors, which separated shallow and deep failure mechanisms. The critical depth was found to depend on the anchor diameter and the friction angle of the sand. Sakr et al. 2011 carried out uplift tests on large-scale helical piles installed in dense to very dense sand. It was noted that the 5% failure criterion, which estimates the ultimate capacity as the load at displacement equal to 5% of the helix diameter, is practically reasonable. George et al. 2019 conducted an experimental and numerical investigation on the uplift capacity of helical anchors installed in the sand by displacement and non-displacement methods. A finite element method analysis using PLAXIS 3D software was also carried out to understand and simulate the effect of installation on the uplift capacity. It was observed that the uplift capacity depended on parameters like the relative density of sand, embedment depth, and installation method. A semi-empirical equation was also proposed by the authors to predict the uplift capacity. Most of available literature on GPA deals with its performance in expansive soil (Muthukumar and Shukla 2020; Muthukumar & Phanikumar, (2015); Rao et al. 2007; Srirama Rao et al. 2008). It was found that the GPA resists the uplift forces due to swelling of the expansive soil and, at the same time, improves its bearing capacity. Some of the studies like Sivakumar et al. 2013 and O'Kelly et al. 2014 have compared the uplift performance GPA with concrete pile in expansive soil and c-ϕ soil. A comparative study was also carried out to compare the swelling uplift performance of GPA and helical pile anchor installed in expansive soil by Muthukumar and Shukla 2020. The limited available literature gives an indication that GPA can also be adopted as an anchoring method in cohesionless soil, and an embedment ratio of 10 is the optimum, after which the gain in uplift capacity is minimal (Kranthikumar et al. 2016, 2017; Kumar 2002; Singh et al. 2019). It is noted in the study conducted by Liu et al. 2006 tested the GPA system under compression and tension in field conditions and found it fit to be used as an anchor under sewage tanks. A study conducted on laboratory models and finite element modeling using PLAXIS 3D has revealed that the GPA can perform better than bored concrete piles in loose sand (Joseph et al. 2022). The GPA has been found to perform better than multi-helix plate helical anchor in medium dense sand (Joseph et al. 2022). Even though GPA has the potential to be used as an economical anchoring method, the available literature on its field application is minimal.

3 Experimental methodology and materials

3.1 Experimental program

The experimental study consisted of a total of six uplift tests carried out on a single helix model helical anchor and GPA installed in loose sand beds. The diameter (d) of the helical plate and anchor plate was kept as a constant of 70 mm. The embedment length (L) of the model anchors were varied as 350, 525, 700 mm. It is to be noted that the embedment length of a helical anchor was considered as the depth of the helical plate from the sand bed surface. The helical anchor installed are displacement-type anchors, which means they are installed by penetrating the sand bed by applying a downward vertical force and torque.

3.2 Materials

Sand. Sand used in the experiment to prepare the sand bed was sourced from Surat city. The sand passing through a 4.75 mm sieve with a specific gravity of 2.65 was used, and before conducting the experiment, it was air-dried. The sand was classified as poorly graded as per IS 1498 (Bureau of Indian Standards 1970) with maximum and minimum dry unit weights were 14.65 and 17.29 kN/m3, respectively, with an effective size of 0.33 mm, uniformity coefficient of 3.52, and coefficient of curvature of 0.94. The loose sand bed of relative density, D_r = 25%, had a dry density of 15.23 kN/m3 and an angle of friction equal to 31.250. The particle size distribution of the curve is shown in figure 1.

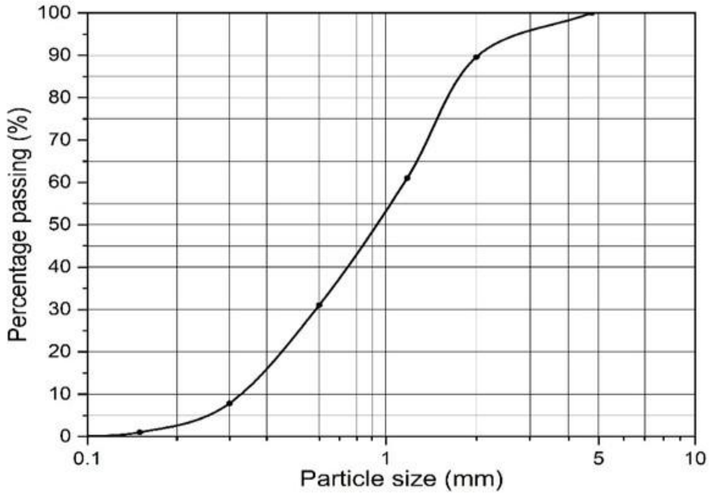

Fig. 1. Particle size distribution curve of sand.

Helical anchor and GPA. The helical anchor consisted of a single helical plate of diameter 70 mm and a hollow shaft of diameter 25 mm. The pitch of the helical plate was 20 mm. The bottom end of the helical anchor was closed and pointed to facilitate penetration during installation. The helical plate and hollow shaft pipe were fabricated using 3 mm thick mild steel. The GPA consisted of an anchor plate of thickness 10 mm and an anchor rod of 5 mm thickness. The helical anchor and the GPA plate rod assembly used in the current study are shown in figure 2. The GPA material, i.e., the granular material, consisted of sand and gravel mixed at a ratio of 1:1.85. The sand used in the mixture passed through a 4.75 mm sieve, and the gravel size ranged from 4.75 mm to 8 mm. The GPA material mixture was decided based on the procedure adopted by Kumar 2002 and Kranthikumar et al. 2017.

Fig. 2. Helical anchor and anchor plate with rod.

3.3 Sand bed preparation and installation of model anchors

The sand bed was prepared using the sand rainfall method. A hopper with a perforated mild steel plate at the bottom was used to deposit the required quantity of sand from a predetermined height to form sand layers of 50 mm each. The helical anchor was installed by manually applying torque to the shaft and pushing it inside the sand bed using a screw jack with the load frame acting as a reaction frame. Special care was taken to penetrate the helical anchor at the rate of 1 pitch (20 mm) per rotation of the helical anchor. The GPA installation was carried out simultaneously with sand bed preparation. The GPA plate and rod assembly were initially placed on a 50 mm sand layer. A hollow plastic pipe was placed on the GPA plate with the anchor rod passing centrally. The sand layers were placed around the hollow pipe, and simultaneously, the required quantity of GPA material was placed in the hollow pipe as layers of 50 mm each and compacted. The GPA material layers were compacted using a specially fabricated cylinder-shaped annular mild steel hammer, and at the same time, the hollow pipe was lifted. The process of sand layer deposition, filling of GPA material, compaction, and lifting of the hollow pipe was repeated until the required sand bed and GPA length was formed. The installation method adopted in the installation of the GPA is similar to Kranthikumar et al. 2016, 2017, and Kumar 2002.

3.4 Uplift test apparatus and testing procedure

The uplift test apparatus consisted of a square tank of side length of 1000 mm and a depth of 750 mm, the load frame on which a multispeed load testing machine was mounted, and load/ displacement measuring devices (Figure 3). The square tank boundaries were well outside the influence of the model anchors. The multispeed load testing machine was used to apply the pullout load at a constant pullout displacement of 0.5 mm/min. The strain rate was fixed after a review of the work done by Ilamparuthi and Muthukrishnaiah 1999 on the pullout of plate anchors in sand. The measure devices consisted of load cell and two linear variable displacement transducers, which were connected to a data logger. The data logger was connected to a laptop in which the data logging software was installed and gave real-time monitoring of the uplift load-displacement behavior.

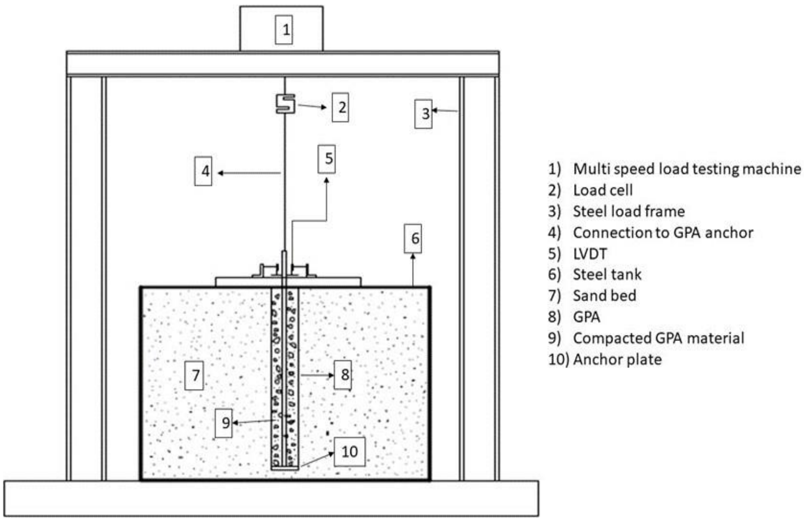

Fig. 3. Schematic diagram of uplift test apparatus

3.5 Results and Discussions

The uplift test results in the form of uplift load-displacement curves and the variation of ultimate uplift capacity with embedment length are given and discussed in the following sections.

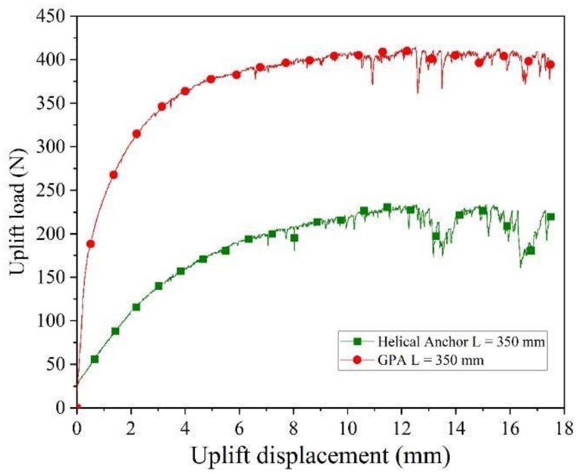

Figure 4. Uplift load-displacement behavior of Helical anchor and GPA at L = 350 mm

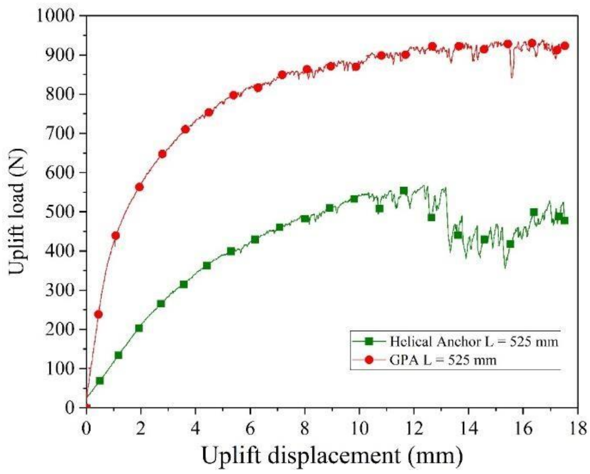

Figure 5. Uplift load-displacement behavior of Helical anchor and GPA at L = 525 mm

Uplift load-displacement behavior. The uplift load-displacement behavior of the helical anchor and the GPA are given in figures 4 to 6. The load-displacement curve can be divided into approximately three parts. In the first part, there is a linear increase in the uplift load resistance with respect to the displacement, which is rapid in the case of the GPA with respect to the helical anchor. In the second part, the increase in uplift is accompanied by a rapid increase in the displacement for both methods. In the third part, the uplift load becomes a constant with comparatively larger fluctuations in the helical anchor's case. The rapid increase in the uplift resistance in case of the GPA in the initial part of curve can be attributed to the confining pressure of the surrounding sand at the bottom portion of the GPA. The bottom portion of the GPA just above the anchor plate undergoes deformation during uplift which is resisted by the surrounding soil mass. As the uplift load increases this confining support offered by the surrounding sand is overcome and the GPA material starts to deform which is reflected in the form of a flatter uplift load-displacement curve in the second part. The large fluctuations in the third part indicate plastic rearrangement sand/ GPA material occurring above the helical/anchor plate. Similar uplift load-displacement behavior was also noted by Ilamparuthi and Muthukrishnaiah 1999 for plate anchors.

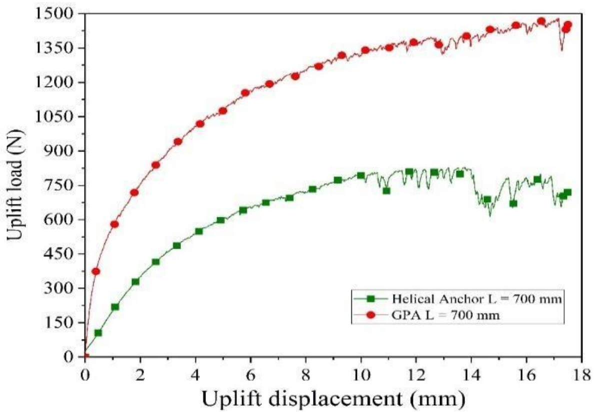

Figure 6. Uplift load-displacement behavior of Helical anchor and GPA at L = 700 mm

Ultimate uplift load capacity. The ultimate uplift capacity of the helical anchor/GPA was estimated as the uplift load at 10% of d uplift displacement of the helical plate/anchor plate (ISSMFE criterion). The change in ultimate uplift capacity with an increase in L/d ratio is shown in figure 7 and tabulated in table 1. It was observed that the ultimate uplift capacity increases with an increase in the embedment length for both methods.

Table 1. Geotechnical properties of the soil collected from the slope.

L/d ratio	Ultimate uplift capacity (N)	
	Helical Anchor	GPA
5	199	391
7.5	458	844
10	691	1207

In the case of helical anchor, the percentage increase in uplift capacity when the embedment ratio changes from 5 to 7.5 is 130%, and 7.5 to 10 is 51%. Similarly, in GPA, the percentage increase in uplift capacity is 116% and 43% for the previously mentioned embedment ratio change. The decrease in the percentage increase in the uplift capacity is due to the change in the uplift resistance mechanism. In the lower embedment ratio, the uplift failure is shallow type in which the failure plane reaches the sand bed surface. In a larger embedment ratio, the failure is a deep anchor type in which the failure plane is confined inside the sand bed. A comparison of the uplift capacities is illustrated in figure 7. The GPA gives a significantly larger uplift capacity compared to the helical anchor. The GPA's ultimate uplift capacity is found to be almost 2, 1.8, and 1.75 times that of the helical anchor for the embedment ratio 5, 7.5, and 10, respectively. The larges values of uplift resistance may be due to two reasons, firstly a part of the uplift being resisted by the compacted GPA material column above the anchor plate, and secondly, the confining pressure that is provided by the surrounding soil mass to the GPA material just above the anchor plate. Whereas the uplift resistance in case of the helical anchor is provided only by the sand mass above the helical plate.

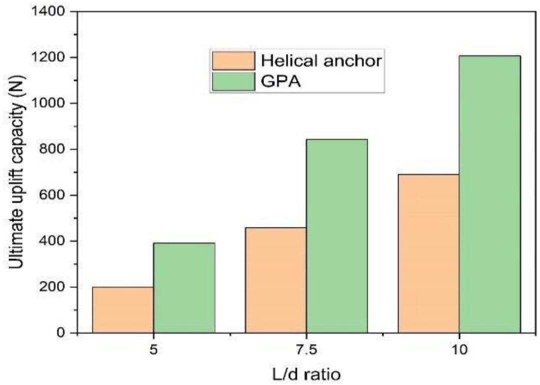

Figure 7. Comparison of ultimate uplift capacity

4 Conclusions

A comparison of the load-displacement behavior and the ultimate uplift capacity of two methods that can be used to resist uplift loading is made in this study using small experimental modeling is closely monitored laboratory conditions. Laboratory-based small-scale testing cannot be relied upon to reflect field conditions fully. Nevertheless, the current study offers some limited insights into the comparative behavior of the two methods. The GPA resists uplift more uplift load compared to the helical anchor even at lower uplift displacement. The uplift capacity of both methods increases with the increase in embedment ratio, but the percentage increase in the uplift capacity was observed to decrease. This decrease owing to the failure mechanism points to an optimum embedment ratio for both methods. The GPA had 2 to 1.75 times the ultimate uplift capacity of the helical pile, which can be attributed to the compacted granular column above the GPA plate. Thus, the GPA is a much efficient method to resist uplift load than single helix helical anchors.

References

1. George, B. E., Banerjee, S., and Gandhi, S. R. (2019). "Helical Piles Installed in Cohesionless Soil by Displacement Method." International Journal of Geomechanics, 19(7), 1–18.

2. Ghaly, A., Adel, H., and Hanna, M. (1991). "Uplift behaviour of screw of screw anchors in sand. I: Dry sand." Journal of Geotechnical Engineering, 117(5), 773–793.
3. Hanna, A., Ayadat, T., and Sabry, M. (2007). "Pullout resistance of single vertical shallow helical and plate anchors in sand." Journal of Geotechnical and Geological Engineering, 25(5), 559.
4. Ilamparuthi, K., and Muthukrishnaiah, K. (1999). "Anchors in sand bed: delineation of rupture surface." Ocean Engineering, 26(12), 1249–1273.
5. Joseph, J., Kumar, S., Patel, J. B., Sawant, V., & Tandel, Y. (2022). "Model tests on granular pile anchor and helical anchor: a comparative study". International Journal of Geosynthetics and Ground Engineering, 8(3), 1-12.
6. Joseph, J., Kumar, S., Sawant, V. A., & Patel, J. B. (2022). "An experimental and numerical comparative study on the uplift capacity of single granular pile anchor and rough pile in sand." International Journal of Geotechnical Engineering, 16(4), 499-513.
7. Kranthikumar, A., Sawant, V. A., and Shukla, S. K. (2016). "Numerical Modeling of Granular Anchor Pile System in Loose Sandy Soil Subjected to Uplift Loading." International Journal of Geosynthetics and Ground Engineering, Springer International Publishing, 2(2), 15.
8. Kranthikumar, A., Sawant, V. A., Kumar, P., and Shukla, S. K. (2017). "Numerical and Experimental Investigations of Granular Anchor Piles in Loose Sandy Soil Subjected to Uplift Loading." International Journal of Geomechanics, 17(2), 4016059.
9. Kumar, P. (2002). "Granular anchor pile system under Axial Pullout Loads." Ph.D thesis I.I.T. Roorkee.
10. Liu, K. F., Xie, X. F., and Zhang, J. F. (2006). "Compression / tension load capacity of stone column anchors." Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 159(3), 161–165.
11. Meyerhof, G. G., and Adams., J. I. (1968). "The ultimate uplift capacity of foundations." Canadian geotechnical journal, 5(4), 225–244.
12. Muthukumar, M., & Phanikumar, B. R. (2015). Shrinkage behaviour of GPA-reinforced expansive clay beds subjected to swell–shrink cycles. Geotechnical and Geological Engineering, 33(3), 475-485.
13. Muthukumar, M., and Shukla, S. K. (2020). "Comparative study on the behaviour of granular pile anchors and helical pile anchors in expansive soils subjected to swelling." International Journal of Geotechnical Engineering, Taylor & Francis, 14(1), 49–54.
14. O'Kelly, B. C., Brinkgreve, R. B. J., and Sivakumar, V. (2014). "Pullout resistance of granular anchors in clay for undrained condition." Soils and Foundations, Elsevier, 54(6), 1145–1158.
15. Rao, A. S., Phanikumar, B. R., Babu, R. D., and Suresh, K. (2007). "Pullout behavior of granular pile-anchors in expansive clay beds in situ." Journal of Geotechnical and Geoenvironmental Engineering, 133(5), 531–538.
16. Sakr, M., Eng, P., Core, G., Manager, S., and Canada, W. P. (2011). "Installation and Performance Characteristics of High Capacity Helical Piles in Cohesionless Soils." DFI Journal-The Journal of the Deep Foundations Institute, 5(1), 39–57.
17. Singh, J., Mital, A., and Arora, V. K. (2019). "Load displacement behaviour of Granular Anchor Pile (GAP) and group piles under oblique pullout loads." Indian Geotechnical Journal, Springer India, 49(1), 100–107.

18. Sivakumar, V., O'Kelly, B. C., Madhav, M. R., Moorhead, C., and Rankin, B. (2013). "Granular anchors under vertical loading – axial pull." Canadian Geotechnical Journal, 50(2), 123–132.
19. Srirama Rao, A., Phanikumar, B. R., and Suresh, K. (2008). "Response of granular pile-anchors under compression." Proceedings of the Institution of Civil Engineers-Ground Improvement, 161(3), 121–129.
20. Tsuha, C. H. C. (2016). "Physical Modelling of the Behaviour of Helical Anchors." 3rd European Conf. on Physical Modelling in Geotechnics (EUROFUGE 2016). IFSTTAR Nantes Centre, France, 1st-3rd June.