INVESTIGATIONS OF GRANULAR PILE ANCHORS IN GRANULATED SOIL SUBJECTED TO UPLIFT

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Abstract - *Abstract Granular pile anchors (GPA) is a novel, economical and efficient ground improvement technique used to increment the capacity of soil against uplift loads by improving shear-strength properties of surrounding soil. In this paper a detailed numerical study has been carried on to examine the effect of key parameters, like Dia (D) of pile and Span(L) of pile and soil parameters like Internal friction angle and Relative Density, on the capacity of GPA to resist uplifting forces. The relation between the load- movement responses of the GPA for varied parameters have been graphically represented and analyzed in this paper. The numerical analysis in PLAXIS 3D revealed that with increment in the parameter of both Pile and surrounding soil there is a increment in the uplift capacity of the GPA by various degrees. It has also been observed that with respect to an unaltered Dia of the GPA, its ultimate capacity against uplifting forces increments as the Span to Dia ratio goes up but for ratios beyond ten, the load sharing is not significantly affected.*

Key Words**: (Granular pile anchors, Uplift piles, Plaxis 3D, parametric study)**

1. INTRODUCTION

The construction industry today requires more and more efficient ways to transfer the compressive loads as well as tension loads safely to the ground. The growing demand for space is pushing the industry to construct larger and taller structure in seismic zones or in difficult soil conditions such as loose sand(cohesionless soils), clayey soils(cohesive soils). These structures are subjected to greater wind loads, seismic activities which cause uplift loads on the foundation structures due to overturning moments.

The Granular piles are one of the most efficient soil improvement techniques due to the ability of GPA to enhance the performance of various soil such as soft, loose sand deposits etc. However conventional granular piles offer negligible resistance to uplifting forces and hence cannot be used as tension members this limitation is further aggravated fact that loose sandy soil offers very low tensile resistance. This limitation of the granular piles can be overcome through modifying its inherent nature by attaching a mild steel plate at the lower end of granular pile and tying the plate to the structures footing through one MS slender rod. This Anchor rod transmits the pullout forces generated by the structure to the baseplate of the GPA.

The uplift resistance offered by the granular pile anchors is based on (i) granular pile's self-weight (ii) shearing forces resisting along span of the granular pile due to the soil-pile interaction.

The transmission of force to the pile soil contact in the pile anchor occurs due to the rigid connection of the base plate to the anchor. The resistance offered by the pile anchor to uplifting forces establishes the behavior of foundation system

2. OBJETIVES

The main objective of the current analytic study is to understand the effect of change in various characteristics, such as Span and Dia of the GPA and Relative density and angle of internal friction of surrounding soil, on the uplift capacity of GPA

3. LITERATURE REVIEW.

Drilled piers, Under-Reamed and Belled piers are some of the major foundation's techniques used to resist tension loads. However, applying these techniques require skilled or trained workers as well as special equipment's which makes them uneconomical and time consuming. It has been demonstrated that granular pile construction is one of the most competent method to reduce the settlement in soft clay soils and granulated soil profiles while also increasing their load-bearing capacity. (Rao 1982;Rajan 1989).The granular piles impart compression and shear resistance to soils by improving the soils strengthen and stiffen, but their ability to resist pullout under tensile or uplift loads is low. The Granular pile anchors are obtained through a small alteration to the normal granular piles, in GPA a metal anchor plate is placed at the bottom of the granular pile which is anchored to the upper footing using a mild steel cable or rod. The anchoring of the granular pile foundation increments the resistance provided by the granular pile against tensile forces generated by swelling of soil. In a laboratory study conducted by Phanikumar, et al 1997, on granular pile anchor behavior in expansive clay beds the reduction in heave was reported to be 96%.The resistance provided by the GPA to the tensile forces applied on the foundation can be credited to the weight of the pile, frictional resistance generated along the pile-soil contact and effect of anchorage which made the GPA to resist the uplifting forces applied on the foundation.(Ibrahim S.F et.al 2014; M.Muthukumar et.al 2010)

A experimental model study on the efficacy of granular pile anchors in resisting uplifting forces in expansive clay **(K.Swatantra Bharathi et al.2017**), showed that the swell potential of the soil decreases with the increment in the surface are of granular piles. The study concluded that pullout capacity for the expansive clay installed with granular piles was more compared to that of untreated soils. This conclusion was further backed by the study by **Neenu Johnson (2015)** where it was found that the an increment in Dia of the pile lead to increment in pullout resistance of the granular pile

3.1 Concept of GPA System

GPA foundation system is a soil enhancing technique used to increment the granular soils resistance towards uplifting forces and improves the various properties of soil such as shear-strength. GPA is imparting a small and simple modification in the usual stone column/granular pile to enhance the foundations ability to resist the tensile forces. Procedure for constructing GPA's has been documented with clear steps by Phanikumar (1997). The process of constructing a GPA in granulated soils is as follows.

- A borehole is penetrated into granulated ground and a pipe is advanced as a support casing to withhold surrounding soil in its position and prevent collapse of soil into the borehole due to inadequate cohesion between the particles of soil.
- A metal plate linked to a MS anchor rod is advanced into the borehole.
- Granular materials are poured in layers of equal thickness into the borehole. A uniform density of the material is achieved by compacting after filling each layer.
- The top portion of the mild-steel anchor cable/rod is linked to the footing of structure.

The friction acting on the pile-soil face and pile self-weight are the factors that provide the uplift resistance in GPA. The friction generated along the pile and soil surface is the resists the upward movement of the GPA system

4. METHODOLOGY

Numerical Modelling of GPA system

A Finite Element Model of the GPA was made using the PLAXIS 3D. The model of soil layer for analysis was made using the option of borehole in PLAXIS, the dimension of soil layer was taken as 20 m x 20m and deepness of 20m. The soil properties were defined using the material defining window. The modelling of GPA was done by using the polycurve and extrudes option to project the surface to required deepness. Pile and soil layers were modelled as tetrahedral elements of 10node. The surface was generated over the polycurves to add plate elements for the plates of footing and anchor. The anchor rod of GPA system was modelled using the node to node element. Triangular elements of six nodes were used to model the plate elements. The dimension of the anchor plate was considered equal tom he pile Dia, and a footing plate of 2m Dia was modelled on top of the GPA. Both pile material and soil material were taken to be in drained condition. The constitutive relationship of volume elements such as loose sandy soil as well as granular pile were defined using Mohr-Coulomb criterion. A unaltered soil modulus was taken for both soil and pile for the entire deepness. For getting accurate results a fine-element mesh was generated for analysis. At the centre of top of the pile a single node point was taken to determine piles uplift capacity. Prescribed movement option was used to give a upward movement of 0.1m at ground surface. Phases in staged construction were defined in such a way to analyse step wise the upward movement from 0 to 0.1 (with 0.01 interval). The Toggle visibility option was used to switch the visibility of various soil layers to observe the change of the GPA with each step of analysis

Table 1: Material Properties defined for soil elements in Numerical Model

Parameters	γ(kN/m^3)	γ_{sat}(kN/m^3)	φ (degrees)	E(Mpa)	c(kN/m^2)	υ
Loose Sand	19	21	25	5	0	0.3
Pile material	22	24	35	11	0	0.3

Table 2: Material Properties defined for plate elements in Numerical Model

Model Type	Parameters	E(Gpa)	d(m)	υ
Linear Elastic	Anchor Plate	200	0.025	0.15
	Footing	200	0.06	0.15

4.1Parametric Study

In this study loose sand was taken as the soil surrounding the GPA extending up to 20m deepness and the water table at a deepness of 6m below the ground surface. The span and Dia of the granular pile were varied from 2 to 5m and 0.2 to 0.6 m respectively. The ratio of span to Dia ranges from 3 to 25. The footing; anchor plates and anchor rod have been modelled with a higher flexural rigidity. The material properties taken for the pile and soil are given in Table 1, Table 2 has the material properties of the plate elements. The relationship between the uplifting force to the upward movement was observed in this parametric study for studying the change in resistance provided by the GPA system for change in various parameters the graphical representation of the results is shown with uplifting force (kN) and upward movement (m) on the y and x axis respectively.

5. FINDINGS

5.1 Effect of varying Dia of pile on the uplift resistance of GPA

The pile Dia influences the load-bearing structure and dispersion of pore water pressure. In the numerical model at a constant span of 5m the Dia of the GPA was altered between 0.2 to 0.6 m with 0.1m interval, to study the influence of Dia on the resistance to uplift. **Fig.1** shows the change in uplifting force of a GPA for varied movements at center of GPA's top face

The uplifting force of a GPA system for a given prescribed upward movement of ten percent of dia is 22kN for 0.2-m-Dia pile, 52 kN for 0.3-m-dia, 92kN for 0.4-m-dia, 138 kN for 0.5-m-Dia and 162 kN for 0.6-m-dia pile respectively. It is observed that with increment in Dia of the pile the uplift resistance of the GPA system increments approximately by 139% for an increment in dia from 0.2 m to 0.3 m,77% for 0.3m to 0.4m , 50% for 0.4m to 0.5m and 17% for 0.5m to 0.6m respectively.

From the graph it can be inferred that the effect of pile Dia is drastic when the increment is from 0.2m to 0.3 m

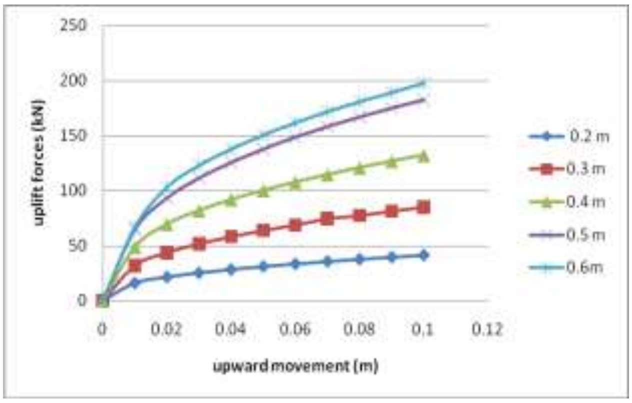

Fig 1 Uplifting force-upward movement plot for various Dias at Span of 5m

5.2 Effect of Change in Span of pile on resistance of GPA system to uplift

A numerical study was conducted for understanding and observing change in the uplift resistance of GPA system for varied spans of a pile. The Friction mobilized along the span of the pile and the greater self-weight of the pile increment the uplift resistance and soil stiffness of the pile system due to higher span of granular pile.

The percentage increment to the prescribed upward movement of ten percent of Dia(0.5m) for varied span are 54%,23%, and 18% for change in span from 3m to 4m, 4m to 5m and 5m to 6m respectively

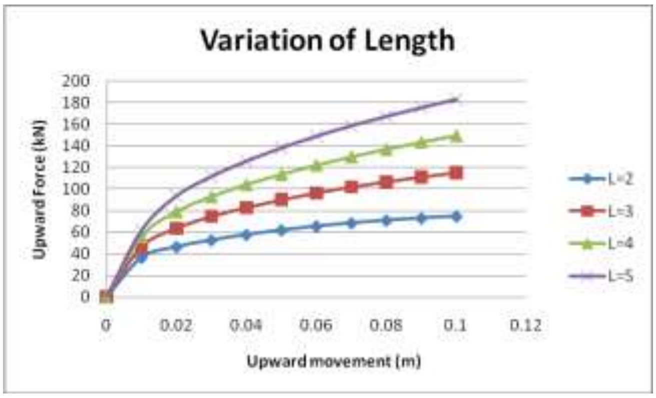

Fig -2: Uplifting force-upward movement plot for various spans with D=0.5m

5.3 Effect of Change in surrounding soils Relative Density on Uplift Resistance of GPA system

To understand the effect of relative density (D_r), six various relative densities have been taken, with an interval of 10% from 30 to 80%(Dia of pile 0.5 m and 5m L).The uplifting force for movement of 0.05m(ten percent of dia) for 50% relative density is 98kN, for an increment in relative density from 50 to 60% increment of uplift capacity is by 7.5% while the increment is 12% for increment from 60% to 70%. The increment is almost linear as shown in Fig.3

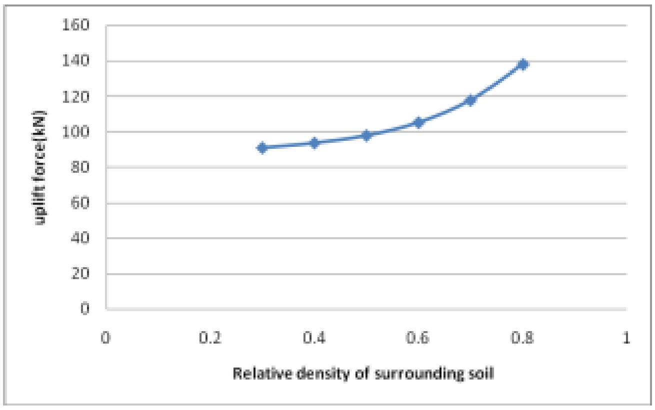

Fig. 3 Uplifting force- at movement of 10% Dia(0.5m) and Span 5m for various relative densities..

5.4 Effect of Change in angle of internal friction on resistance of GPA system to uplift:

For a change in internal friction angle from 20 degrees to 40 degrees with GPA dimensions as 0.5 D and 5m L, it was observed that the increment in uplift capacity was 112% for increment in friction angle from 20 to 25 deg. The increment smoothly reduced to 82%,60% and 46% for changes of friction angle from 25 to 30 degrees,30 to 35 degrees and 35 to 40 degrees respectively

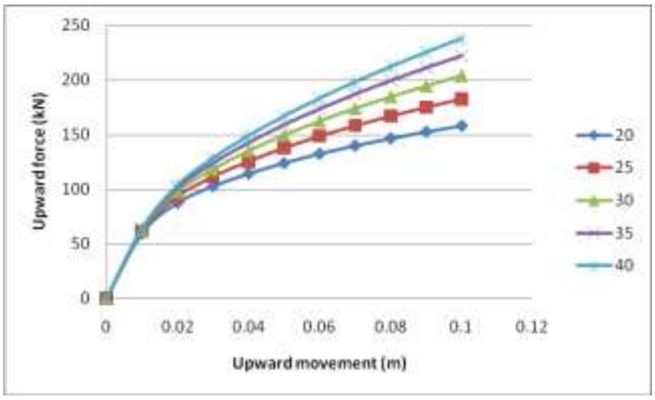

Fig 4. Uplifting force-Upward movement for L= 5m , D=0.5m for varied angle of internal friction of surrounding soils

Fig. 5: GPA model in PLAXIS 3D before loading

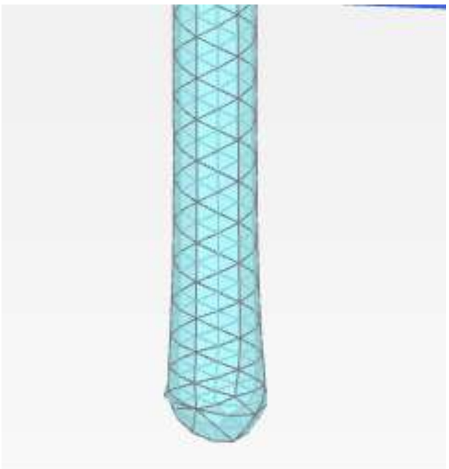

Fig.6 Failed model GPA in PLAXIS 3D post loading

6. CONCLUSIONS

Based on the numerical investigation that has been carried out, the following conclusions are arrived.

The resistance against uplift of granular pile anchor found to increase with increase in the diameter of the granular pile anchor. The resistance also increases with increase in the length of granular pile anchor. The increase in the resistance against uplift is due to the increase in the surface area of the granular pile anchor which contributes to the increase in uplift resistance.

From the investigations it is observed that the granular pile anchor fails by bulging failure at the bottom of the granular pile anchor. The uplift resistance increased with increase in the relative density as well as the angle of internal friction of the surrounding soils. This is due to the fact that the surrounding soil offers more resistance against bulging with increase in the relative density.

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