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Numerical study of granular anchor pile subjected to uplift load

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Abstract. Over the past few decades, several researchers have suggested adequate experimental and numerical approaches to calculate the granular anchor piles' (GAPs) uplift capacity in expansive soils. There haven't been many studies done on the uplift potential of GAPs in loose sands. The outcomes of numerical analysis using PLAXIS 3D software to determine the maximum lift capability of single granular piles and group piles are presented in this paper. In loose sands, the foundation system is thought to be made up of a distinct number of consistently spaced GAPs. The analysis compares the effectiveness of varying configurations of GAP systems and investigates the effect of several factors such as the number of piles, *n* and aspect ratio (*L/D*), as well as the properties of the materials for granular piles

Keywords: *Finite element method; Anchor pile; Group piles; loose sand; Uplift capacity.*

1 Introduction

The structure construction in coastal areas made with weak soils at shallow depths necessitates careful consideration of the safety and stability of the surrounding structure, which may be compromised due to the weak engineering properties and weak soil. As a result, special care must be exercised when the foundation of structures rests in these environments. The soils in these areas must be improvised using cost-effective and efficient ground improvement techniques. Compaction piles, excavation and replacement, Vibro-flotation, explosive compaction, dynamic compaction, well-point system, grouting, and other methods can all be used to improve the ground condition of loose cohesion less soils [1]. The most appropriate method is determined by several factors including maximum compaction depth, soil conditions, degree of compaction, and the structure type to be supported. Ground improvement techniques are typically favored for economic reasons, and granular piles (GP) are one of the most commonly used techniques. Granular piles (GP) strengthen the neighborhood soil and improve its properties, it establishes an efficient drainage condition and also increased the resistance against liquefaction in LSS (Loose saturated soils)[2]. This method also improves embankment stability, increases consolidation rate, increases soil bearing capacity, and reduces settlements, this technique was first adopted by European countries. These are also used in improving slope stability, transmission tower construction, high-rise skyscrapers, and high-rise structures have increased noticeably recently. These engineering structures must have a foundation system that can withstand vertical uplift forces to function properly. In such circumstances, the GP alone cannot provide much resistance against the uplift/ tensile force, necessitating the use of an appealing and cost-effective design solution, It is doable with a minor adjustment to the granular pile. A base plate is set at the bottom of the pile and connected to an anchor rod to withstand the uplift forces that are applied to the foundation. Compressible piles are used in the relatively new granular anchor pile (GAP) technique to withstand uplift loads it is an affordable and effective ground improvement approach[3]. The foundation system for these engineering structures must be able to withstand uplift forces vertically as well as laterally. Recent research examines the effectiveness (behavior) of stone columns with or without the application of geosynthetics in soft soils to surround the GP using numerical and experimental methods. The relationship between a GAP system's uplift capacity and water table depth is approximately linear. As the water table depth increases, the uplift capacity declines[1]. Granular anchor piles are a new, cost-effective, and efficient ground improvement technique (GAP) system. The GP becomes a granular pile-anchor foundation that resists tension, reducing upward tensile stress and heaving expanding soil exerts on the structure[4]. The behavior of GAP in situ was the subject of thorough field research. The study examined both the pullout and heave behavior of GAP-reinforced expansive clay beds[5]. At lower modulus ratios, GAP seems to act like a rigid pile, while at the higher modulus ratio the behavior is changed to flexible nature[6]. For boosting the pull-out bearing capability of foundations in expanding soil, the granular anchor pile is determined to be a more cost-effective foundation treatment option than the traditional concrete piles[7]. In the literature, there are only very less field studies on the GAP system in loose cohesion less soils. An examination of the literature found that few attempts have been made to numerically model the GAP system in expanding soils. There doesn't seem to be any numerical analysis of how well a collection of GAPs work in loose sandy soil under uplift loading. A group of GAPs' uplift loading performance is evaluated in this study utilizing the PLAXIS 3D finite element analysis. Nowadays, various software is used to conduct the majority of research, software like PLAXIS 2D, and 3D is popular, especially in the geotechnical field, as it produces results that are familiar to those seen in real-world applications.

2 Methodology

2.1 Numerical modeling

For the analysis of uplift capability, a granular pile anchor model with a range of lengths and diameters is created using the PLAXIS 3D. The soil that surrounds the GAP is considered to be loose sand and it reaches 600 mm below the surface of the ground. By using the drilling choice in PLAXIS 3D and the soil layer is represented by selecting appropriate plan dimensions. The soil layer's plan dimensions are 300 with a depth of 600 mm. In PLAXIS 3D software, the single granular pile is modeled using the poly-curve and extrude options. Using the array option in structural mode, two piles in a group are modeled. The plate elements are used to model the footing and anchor plate. The anchor rod of the GAP system is modeled by a node-to-node element and connects the footing plate, anchor plate, and GAP. A linear elastic model is used for the anchoring of nodes between plates. The essential connection between volume components like loose sandy soil and granular piles was described by Mohr-Coulomb (MC) failure criteria. One assumed the depth because of a constant soil modulus over the entire pile. The GAP model's boundary conditions were taken to be typical fixity criteria. Tetrahedral elements with ten nodes are used to model volume elements, whereas triangular elements with six nodes are used to model plate elements.
The top of the GAP system is maintained with a circular footing for the single pile that has the same diameter as the anchor plate. The hit and trial approach is applied to different diameter values to determine the pile group effect to prevent the influence of boundary conditions, and it

is discovered that the impact of boundary conditions was found to be low when the footing diameter was 4 times the pile diameter. 2*D*, 2.5*D*, and 3*D* are utilized as three different spacing values to analyze the GPA group effect. The findings analyzed the uplift behavior of the GAP system by measuring skyward movement (mm) on the X-axis and the related uplift capacity (N) on the Y-axis. For each model, a 10% upward displacement of the pile diameter is applied at the GAP's center, and the appropriate uplift is determined. The Material properties used in the current study are adopted from Kranthi Kumar et al. [1]. Tables 1 and 2 list the material characteristics of the soil, GAP, structural components, and footing utilized in the numerical modeling.

Table 1. Dimensions of materials

GPA Length, L	Dia of GAP and anchor plate(D) (mm)	Thickness of the Footing plate and anchor plate (mm)	Ratio of L/D
100	5, 6.67, 10, 15, 20, 30	5	20,15,10,6.67,5, 3.33
200	10, 13.3315, 20, 30, 40	5	20, 15, 13.33, 10, 6.67
300	15, 20, 30, 45, 60	5	20, 15, 10, 6.67, 5

Table 2. Material properties used in the model (Kranthi Kumar et al. [1])

Soil	Loose sand	Granular material
Model	Mohr coulomb	Mohr coulomb
Soil Type	Drained	Drained
Unsaturated unit weight (kN/m^3)	17	22
Unit weight of saturated soil (kN/m^3)	19	24
Elasticity modulus (E) kPa	3800	15000
Cohesion (c_u) kPa	0.1	0.1
Poisson’s ratio	0.3	0.3
The angle of internal friction	29°	36°

Table 3. Input Properties of structural elements (Kranthi Kumar et al. [1])

Material used	Anchor rod	Anchor plate	Footing plate
	Mild steel	Mild steel	Mild steel
Modulus of elasticity (E), MPa		2×10^5	2×10^5
Axial stiffness, (EA) kN/m	2×10^9	-	-
Poisson’s ratio	-	0.15	0.15

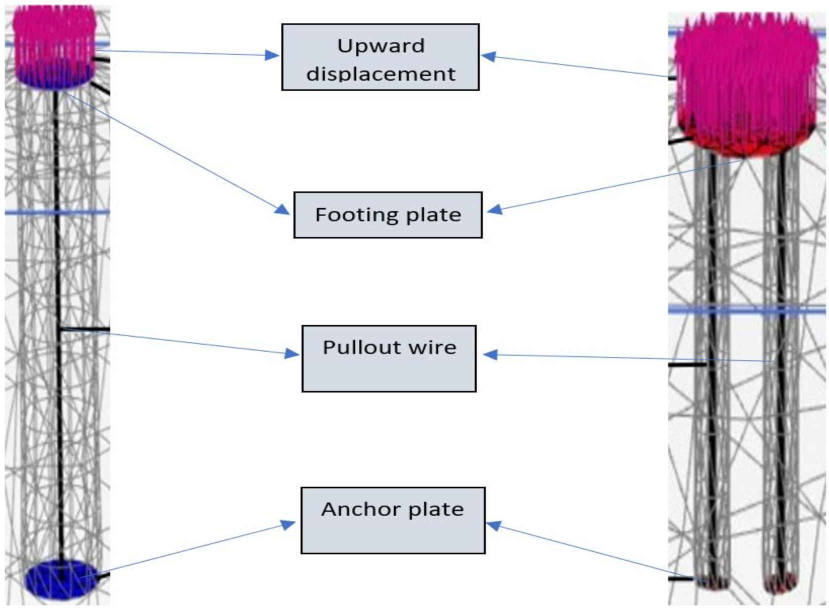

Fig. 1. Modeling of a Two-GAP

3 Results and discussions

3.1 Validation

The Plaxis 3D software is validate by comparing the experimental results given in Kranthi Kumar et al., (2017). To avoid the buckling, the mild steel material of high flexural rigidity was used for both anchor rod and plate. A model is prepared in the Plaxis 3D software having the 1.25m x 1.25m x 1.0m soil bed and pile of 1.0 m length and 10mm diameter. The results obtained from the model analysis have been compared to that of the experimental results and shown in figure 2. The variation of Experimental v/s numerical plots are shown in figure 2, it can be inferred that the deviation of numerical load v/s deflection experimental results is found to be negligible. Hence PLAXIS 3D is used for further analysis.

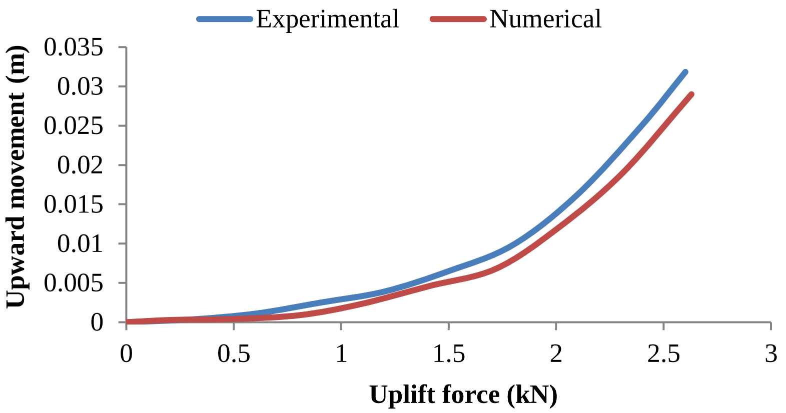

Fig. 2. The response of GAP of 30 mm diameter

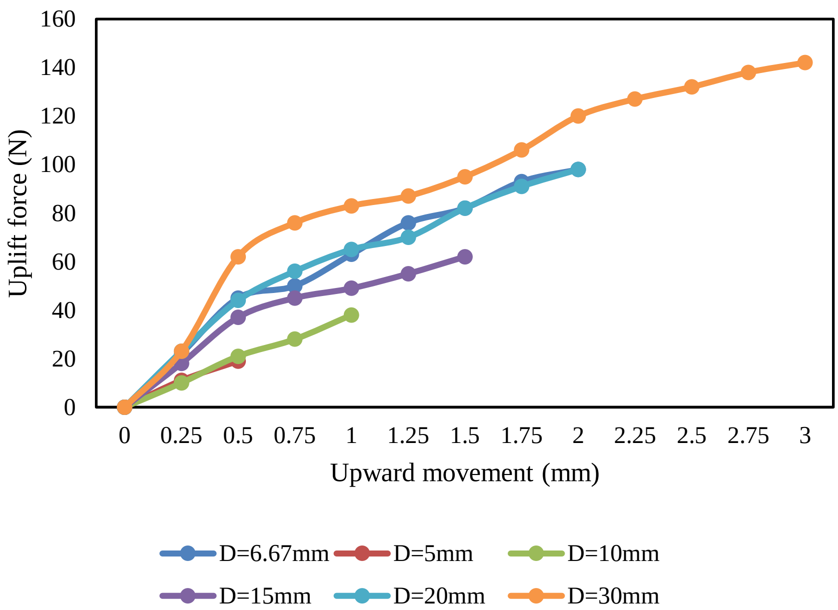

Fig. 3. The effect of GAP diameter on GAP system uplift capacity

A numerical study is conducted to assess the influence of GP diameter on GAP system pullout capability. To ascertain the GAP system's uplift behavior, GAPs of various diameters for lengths of 100,200, and 300 mm are modeled. For the system of GAP, the capacity of the uplift resistance for a directed upward movement of 10% is noticed to be 16.27 N for a 5mm GAP diameter, 22.46 N for a 6.67 mm GAP diameter, 38.67 N for a 10mm GAP diameter, 62.16 N for a 15 mm GAP diameter, 98.13 N for a 20mm GAP diameter, and 142.16 N for a 30mm diameter GAP for 100mm length. When the diameter of GAP is rise from 5mm to 6.67 mm, the percentage rise in uplift resistance capacity is approximately 40% for 100 mm length, 72 percent for GAP diameter rise from 6.67mm to 10 mm, 60 percent for GAP diameter rise from 10mm to 15 mm, 57 percent for GPA diameter rise from 15mm to 20 mm, and 44 percent for GAP diameter rise from 20mm to 30 mm. According to the results of the finite element study, the rise in pull-out resistance is caused by not because resistance provided by the pile's self-weight only, but also by the failure mechanism spreading outside of the pile superficial with the contribution of a significant soil mass. For other diameter values, a similar pattern is found for the length of piles of 200 mm and 300 mm GPA capacity with and without construction effect E= 3.8 MPa.

Table 4 Uplift capacity variation with and without construction effect

Length, (mm)	L/D	Uplift resistance capacity without construction effect(N)	Uplift capacity with construction effect (N), 10% lateral strain	% Increase
100	10	38.67	48.92	26.5
100	5	98.13	112.72	14.86
200	10	97.16	113.56	16.8
200	5	290	310	6.89
300	10	198	224	13.13
300	5	468	474	1.28

A GAP system's resistance to uplift pressures is essentially governed by the physical qualities of the soil and pile, as well as the compaction force required for granular pile compaction. After the granular pile material has been compacted, the earth around it is compacted, resulting in a change in the loose sandy soil shear strength around the GAP system.

3.2 Effect of GAP L/D ratio on GAP system uplift capacity

To investigate the uplift behavior of GAP, several L/D ratios were observed, and the associated uplift resistance is determined by taking into account a predetermined displacement of 10% of the pile's diameter. The length of an anchor pile has been discovered to boost its uplift resistance capacity. This has to do with the GAP system's self-weight and an increase in the amount of friction mobilized at the pile-soil interface. The model demonstrated a very slow-growing trend in the uplift capacity as the L/D ratio decreased at 100 mm of consistent pile length. The uplift capacity is greater for piles of 200mm length; nevertheless, a significant difference was noticed when the pile length was increased from 200 mm to 300 mm. The results of the current model indicate that raising the length of the anchor pile enhanced the GAP system's surface area and self-weight, which strengthened its resistance to uplift pressures.

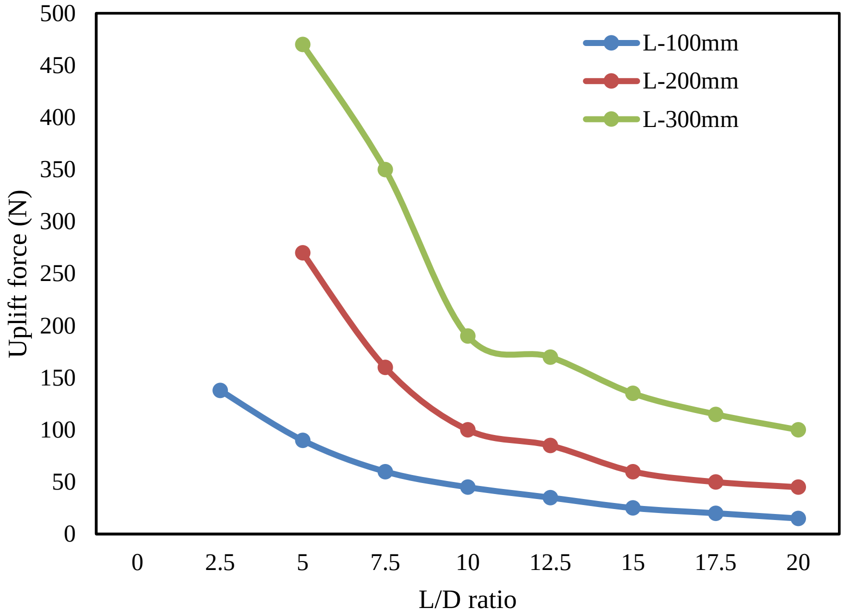

Fig. 4. Uplift force vs. L/D ratio

3.3 Effect of the group of granular anchor piles

Table 5: Different configuration uplift capacity and efficiency

Aspect ratio	Uplift capacity					Efficiency (%)	
	Single pile	2 Pile S-2D	2 Pile S-2.5D	2 Pile S-3D	2D	2.5D	3D
20	16.27	22.34	28.56	31.42	68.65	87.76	96.55
15	22.46	31.25	36.42	40.46	69.56	81.07	90.07
10	38.67	68.16	74.23	76.52	88.13	95.97	98.93
6.67	62.16	108.24	121.32	123.12	87.06	97.58	99.03
5	98.13	141.24	145.82	151.43	71.96	74.29	77.15
3.33	142.16	170.89	175.41	182.3	60.1	61.69	64.09

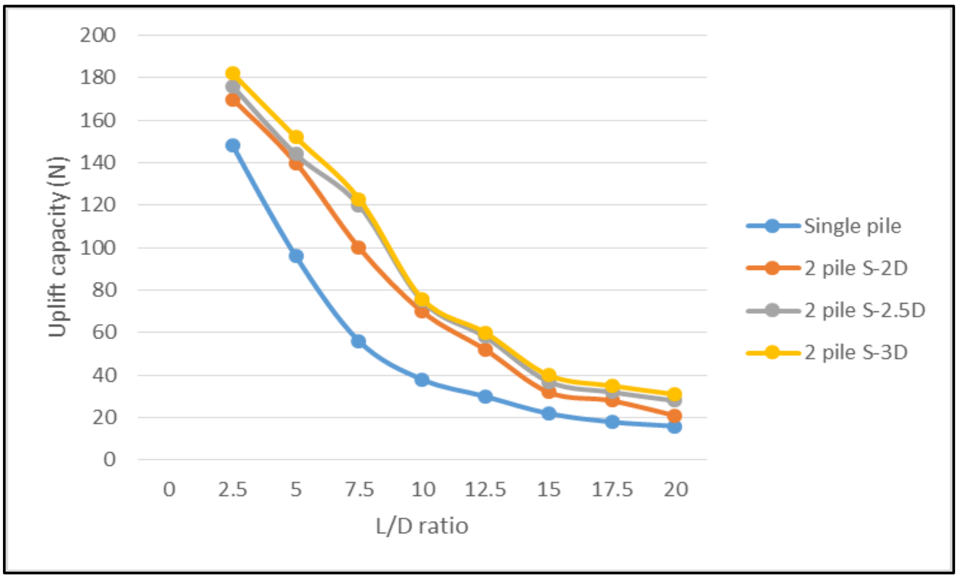

Fig 5 uplift capacity of 2 GPA with spacing variation

As spacing rises from 2.5D to 3D for lengths of 100 mm GAP, uplift resistance capacity remains largely unchanged. This is because the rise in the gap between two close by GAP yonder 2.5D causes the pressure bulbs for single piles to not overlapping, making mobilization of uplift resistance capacity yonder a particular spacing of 2.5D insignificant. A similar kind of result is presented for the remaining length of piles 200mm and 300 mm.

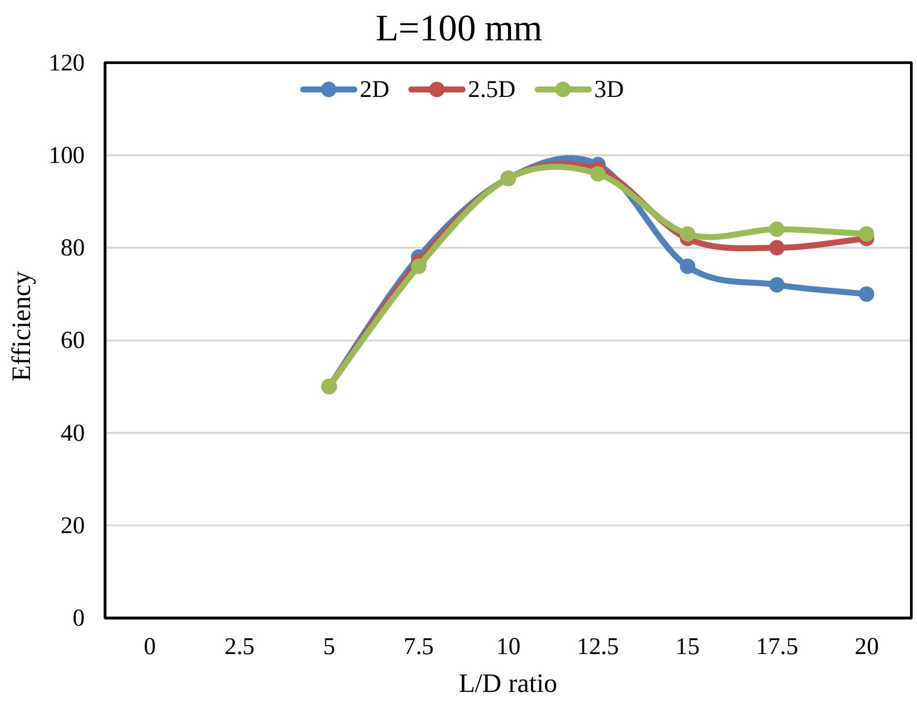

Fig.6. Effect of ratio of L/D on pile group efficiency

The graph showed that the efficiency of piles increased as the ratio of L/D increased from 3.33 to 5, 5 to 6.67, and 6.67 to 10, for the length of pile 100 mm, for a constant GAP length. The efficiency value almost decreased for the 2D, 2.5D, and 3D spacing values when the L/D ratio increased from 10 to 15 and 15 to 20, respectively. Similar results are obtained and presented for various GAP lengths at comparable spacing values.

4 Conclusions

- The GAP system on loose sandy soils showed higher resistance to uplift as the length and diameter of the pile increased. This increase in the uplift resistance can be attributed to the increased self-weight of the pile and the friction that is produced along the pile-soil contact.
- For both single GAPs and groups of GAPs, uplift resistance capability increased as the ratio of L/D increased while maintaining the length.
- A loose GAP system's uplift resistance as the length and density of the sandy soil increase circumference of the pile.
- The effectiveness of the pile group decreases as the number of piles rises. The number of piles required at a certain spacing, since improving the carrying capacity of piles and group size. The capacity of the pile group can be diminished as a result of the overlapping. From the piles to the stresses piling foundation terrain that is nearby.

- The uplift capacity of the GAP system is found to be stronger when the impacts of construction due to the densification of the surrounding soil are taken into consideration.

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