Numerical Analysis of Anchored Granular Pile (AGP) under Tensile Loads

Analyse numérique de la pile granulaire ancrée (AGP) sous charges de traction

Narendra Kumar Samadhiya
Department of Civil Engineering, IIT Roorkee, India, nksamfce@iitr.ac.in; samadhiyank@gmail.com

ABSTRACT: Anchored Granular Pile (AGP) or Granular Anchor Pile (GAP) has proved its mettle under both compressive as well as tensile loads. The paper presents modeling of Anchored Granular Piles Foundation (AGPF) and its behavior under tensile loads. A Finite Element based parametric analysis has been conducted to study the effect of varying model parameters on load carrying capacity of AGP. Based on the analysis of different models of AGPF created in PLAXIS 3D and varying different parameters, the following conclusions are drawn. i) The strength of AGP is directly proportional to the L/D ratio, ii) The rate of increase of strength with the increase of L/D ratio is relatively less when the ratio is either very high or very low. iii) The effect of construction of AGP on the surrounding soil is to increase the load bearing capacity of AGPF. iv) The resistance to heave under the footing or the decrease in heave is directly proportional to the swelling potential. The more the heaving, the more will be the resistance to it for the number of piles ranging from 1 to 4, provided the area ratio and the spacing of piles is constant. v) The spacing of piles was not found to be as effective parameter as swelling potential and area ratio.

RÉSUMÉ: Anchored Granular Pile (AGP) or Granular Anchor Pile (GAP) has proved its metal under both compressive as well as tensile loads. The paper presents modeling of Anchored Granular Piles Foundation (AGPF) and its behavior under tensile loads. A Finite Element based parametric analysis has been conducted to study the effect of varying model parameters on load carrying capacity of AGP. Based on the analysis of different models of AGPF created in PLAXIS 3D and varying different parameters, the following conclusions are drawn. i) The strength of AGP is directly proportional to the L/D ratio, ii) The rate of increase of strength with the increase of L/D ratio is relatively less when the ratio is either very high or very low. iii) The effect of construction of AGP on the surrounding soil is to increase the load bearing capacity of AGPF. iv) The resistance to heave under the footing or the decrease in heave is directly proportional to the swelling potential. The more the heaving, the more will be the resistance to it for the number of piles ranging from 1 to 4, provided the area ratio and the spacing of piles is constant. v) The spacing of piles was not found to be as effective parameter as swelling potential and area ratio.

KEYWORDS: Anchored Granular Pile, Finite Element analysis, strength, load bearing capacity, swelling potential

1 INTRODUCTION

The transfer of compressive forces safely to the subsoil is a prerequisite for foundations of civil engineering structures. However, structures like transmission lines towers, suspension bridges and other similar structures ask for a suitable foundation, capable of providing resistance to not only compressive but pullout forces also. In Anchored Granular Pile (AGP), a mild steel rod is anchored to an anchor plate at the bottom of the granular pile rendering the granular pile tension-resistant and enabling it to offer resistance to the uplift forces. These forces are usually exerted on the foundation by the swelling soil. The resistance to the uplift largely depends upon the strength parameters of the pile soil interface and the lateral pressure of the soil caused due to swelling. Vidyaranya et. al. (2007) presented a method for calculating the ultimate pullout capacity of AGP in homogenous soft ground. Phanikumar et. al. (2008) described an extensive field study of the behaviour of Anchored Granular Pile foundations of expansive clay beds. Phanikumar and Muthukumar, 2013 carried out laboratory-scale heave tests on an unreinforced expansive clay bed (n = 0) and expansive clay beds reinforced by a single GPA (n = 1), twin AGPs (n = 2) and a group of GPAs laid in equilateral triangular pattern (n = 3).

1 .1 *AGP Mechanism*

Figure 1 shows the concept of AGP foundation system. The anchor plate is responsible for resisting the uplift forces. The uplift force due to swelling of soil is conclusively resisted by shearing stress along the interface of the granular pile as well as the weight of the pile itself.

1 .2 *Forces Acting on AGP*

Figure 2 illustrates the forces acting on an Anchored Granular Pile. The design considers the uplift force on the foundation,P_u and the sum of all the resisting forces, P_R. The tensile uplift force (P_u) is caused by the swelling tendency of the expansive soils, caused by the swelling pressure (p_s). The resistance to uplift (P_R) includes the weight of the AGP (W_{gp}) and the shear resistance mobilized over the entire length of cylindrical pile–soil interface by virtue of the shear parameters at the interface, namely, *c*' and 'ϕ'.

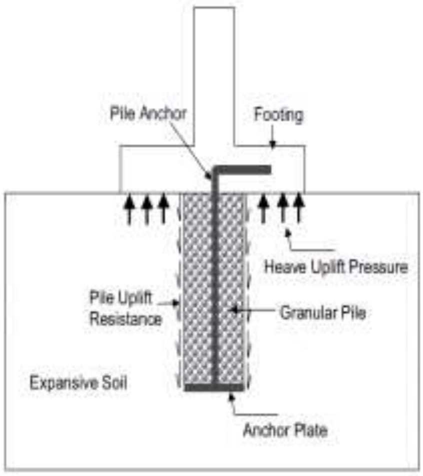

Figure 1. Concept of AGP Foundation System (After Rao et. al. 2007)

2 MODELLING AND ANALYSIS

The analysis has been performed using PLAXIS 3D. The influence of parameters such as length to diameter Ratio (L/D), construction effects, swelling Potential (effect of heaving), Number of piles, spacing of Piles (for pile in groups only) and area ratio has been studied.

Different Material Models used in the modeling of different elements of AGPF viz. soft soil, granular pile, anchor pile or tie rod, base/ anchor plate, footing and heave uplift pressure as shown in Figure 1 are explained in brief below:

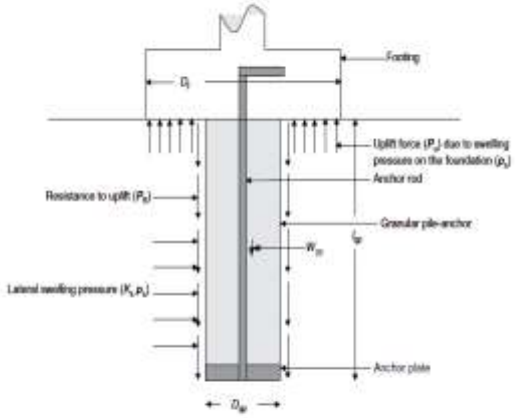

Figure 2. Forces acting on AGP (After Rao et. al., 2008)

The reactive or the soft clay and granular pile material are modeled using the *Hardening Soil Model* (HS). The primary loading is governed by a secant deformation modulus (E_{50}) at 50% of the material strength. Loading and unloading within the current yield surface are assumed elastic (defined by a separate modulus, (E_{ur}) with failure governed by the Mohr-Coulomb failure criterion. Both E_{50} and E_{ur} vary with the minor effective stress according to the following formula:

$$E_{50} = E_{50}^{ref}\left(\frac{c\cos\phi - \sigma_3 \sin\phi}{c\cos\phi + p^{ref}\sin\phi}\right)^m$$

$$E_{ur} = E_{ur}^{ref}\left(\frac{c\cos\phi - \sigma_3 \sin\phi}{c\cos\phi + p^{ref}\sin\phi}\right)^m$$

Where E_{50}^{ref} = reference stiffness modulus corresponding to the reference confining pressure, E_{ur}^{ref} = unload reload deformation modulus at reference pressure, p^{ref} = reference pressure, m = defines dependency of stiffness on lateral effective stress

A summary of the parameters used for all soils are presented in Table 1. The Anchor plate and the footing are modeled as 3D plate elements.

Table 1. Material properties of soil used in the AGPF Model

Soil	Soft Clay	Granular Pile
γ_{unsat} (kN/m^3)	16.0	19.0
γ_{sat} (kN/m^3)	17.0	21.0
E_{50}^{ref} (MPa)	2.0	70.0
E_{ur}^{ref} (MPa)	10.0	210.0
c (kPa)	5.0	1.0
φ (°)	25.0	40.0
ψ (kPa)	0.0	10.0
m	1.0	0.3

A summary of the parameters used for the plates are presented in Table 2. The elastic behaviour of anchor involves a relationship between the axial force '*N*' and displacement (elongation), *u* of the form N=(EA/L) u. Heave of the reactive clay is modeled by applying a uniform volumetric strain across the full thickness of the clay layer.

The construction in the program has been done in 3 phases excluding the initial phase. In the initial phase only parent soil is active. It involves the calculation of the initial stresses using K_0 procedure. The phase 1 simulates all the steps from digging a borehole up to a desired depth, filling it with the granular material and finally compacting it to the desired density. In this phase, the granular pile(s) is/are activated in the program. The phase 2 simulates the installation of base plate. Also the installation of tie rod and construction of footing are simulated simultaneously. Therefore, all the structural elements viz. Anchor plate, Tie Rod and Footing are activated in the program in phase 2 of construction. The phase 3 is the final phase of the current model i.e. loading phase. The tensile load is applied on the stone column directly or in form of displacement equal to 20% diameter of AGP. In case of heaving, no external load is applied on the AGP rather the volumetric strain in the clay layer is activated. After the final phase is activated, the model is set for the calculations.

Table 2. Material properties of soil used in the AGPF Model

Plate Element	Anchor Plate	Footing
Diameter (m)	AGP dia	4..0
Thickness (m)	12.5 % of AGP dia	0.6
γ (kN/m^3)	78.0	24.0
E_1 (GPa)	200.0	25.0
υ_{12}	0.3	0.15

3 RESULTS AND DISCUSSION

3 .1 *Without Considering the Effect of Construction*

In this case, the compaction of surrounding soil or the weak subsoil due to construction of the granular pile is ignored. The parameter varied is the length to the diameter ratio (L/D). A typical normalized Load ($P^*=F_z/\pi D^2 cu$) and normalized displacement (δ^* = uz*100/D) plot for 0.4 m diameter and varying lengths is shown in Figure 3. Similar plots were obtained various combinations of length (1, 2, 4, 8m) and diameter (0.4, 0.5, 0.6, 0.8m).

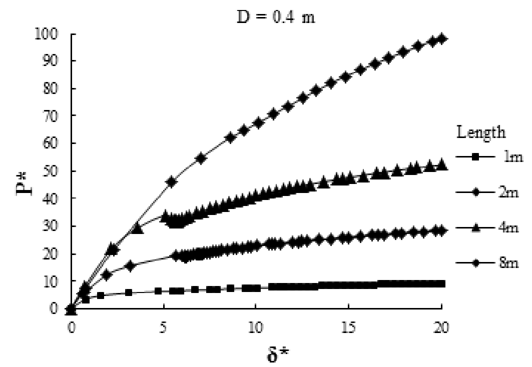

Figure 3. Load-Displacement curves for different lengths (D=0.4m)

It can be observed that for any given value of displacement the load taken by the pile is higher for a greater length than for a shorter one. It has also been observed that for any given value of displacement the load taken by the pile is more for a smaller diameter than for a larger one, provided the length is kept constant. So, it can be summed up that the load carrying capacity is directly proportional to the length and inversely proportional to the diameter. Therefore, larger the L/D ratio higher will be the strength of the AGP, which is depicted by Figure 4 and Figure 5 very clearly.

A general tendency of the pile under tensile loading is to fail by the shearing of the soft soil around granular pile. The failure plane originates from the bottom of the pile; at the edges of the base plate where the entire load is acting. The pile fails when this plane extends till the surface or the ground level. This kind of failure is not possible for larger length as the high overburden of the soil prevents the failure plane to extend till top and hence it fails in bulging. The same was concluded in the parametric study by Vidyaranya et al. (2007). However there is definitely a limiting value of the L/D ratio beyond which the capacity of the pile doesn't increase much. The limiting value in the present case is *13*. It has been found that the increase is mild at lower and higher values of L/D, while for L/D ratio in the range of 8 to 12, the jump is quite steep. Such variation could be the result of the change of mode of failure of AGP from pile/ shaft failure to bulging failure. Therefore, for designing of AGP, its length should be kept around 10 times the diameter. Similar result was obtained by Sawant et al. (2010). For the same values of L/D, the one with the greater volume will have more strength. This is because of the fact that the capacity to resist the uplift force comes from the self weight also.

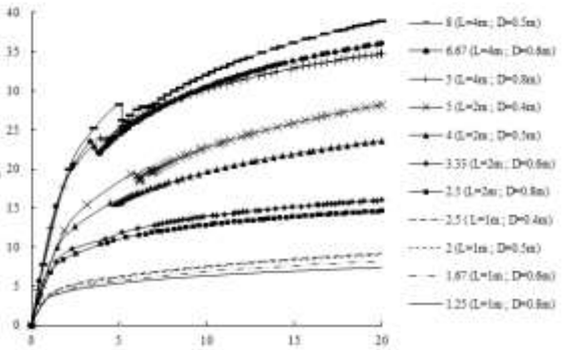

Figure 4. Load-Displacement curves for different L/D ratios (≤8)

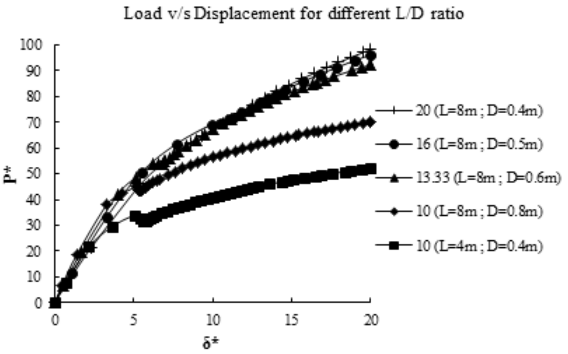

Figure 5. Load-Displacement curves for different L/D ratios (>8)

Figure 6 shows the total displacement of the AGP for 0.4m diameter and lengths 1m, 2m, 4m and 8m. In case when length is 1m and 2m, the entire soil volume around the pile is getting displaced. This is because the overburden required to resist the movement of soil upwards is less and so the entire soil mass around the pile gets sheared off. As the length is increased to 4m, the soil around lower half of the pile gets displaced. The overburden increases and hence resists the formation of failure plane. The displacement of soil further decreases when the length of pile is increased to 8 m. The above observations prove the fact that for shorter lengths or smaller values of L/D, shaft or pile failure occurs and at higher values of L/D bulging failure occurs.

3 .2 *Considering the Effect of Construction*

In this case, the compaction of surrounding weak subsoil due to construction of the granular pile is considered. The change in the state of strength can be estimated by Cylindrical Cavity Expansion Theory (CCET). According to the theory, the stresses generated in the surrounding soil can be simulated as the stresses generated when a pile made of dummy material of zero radius undergoes undrained cylindrical expansion from zero to the radius of pile and then dummy material replaced by the granular pile material. A numerical analysis by Randolph et al. 1979 reveals that expanding a cavity by doubling the radius is sufficient to simulate expanding a cavity from a zero initial diameter. McCabe et al. 2008 concluded that if a lateral strain of 10% is applied to the granular pile then the radial stresses generated in the surrounding soil closely follow the undrained CCE formulation.

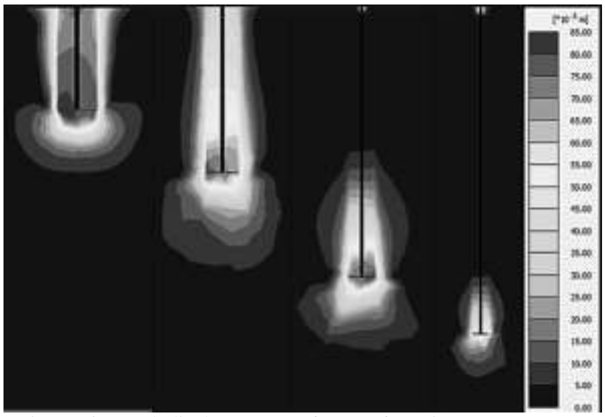

Figure 6. Total displacements of AGF for Diameter = 0.4m

A typical normalized Load- normalized Displacement curve for different lengths and at Diameter 0.4m (with and without construction effects) is shown in Figure 7. Similar plots were obtained various combinations of length (1, 2, 4, 8m) and diameter (0.4, 0.5, 0.6, 0.8m).

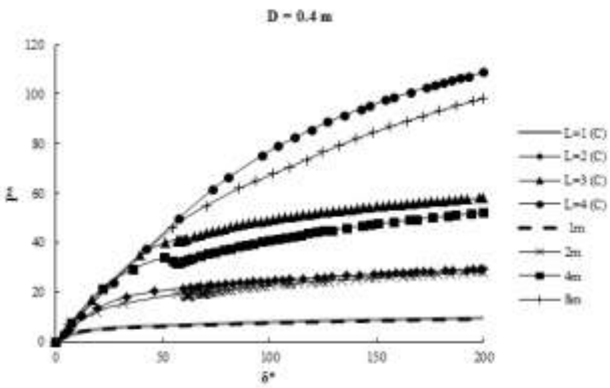

Figure 7. Load-Displacement curves for different lengths at Dia = 0.4m (with and without construction effects)

Figure 7 clearly indicates that due to the compaction of surrounding soil while constructing the granular pile, the load carrying capacity of the granular pile increases. The effect is more pronounced for larger lengths. It has been observed that the average increase in strength is just 2.52% when the L/D ratio is less than 6 whereas the average percentage increases to 11.66 at L/D ratios greater than 6. It is also known from the previous research works that the transition from pile failure to the bulging failure starts at L/D ratio between 6 and 8 (Vidyaranya et al., 2007).

3 .3 *Effect of Heaving*

The heaving exerts an upward push in the soil which AGP resists by its virtue of being anchored into the ground. Figure 8 shows that for all pile groups (1-4), as the heaving or swelling potential increases, the extent of resistance to that also increases. Figure 9 shows the reduction of heave under the footing at a constant swelling potential and changing the number of piles. It can be judged that there is a gentle rise in the level of resistance as the number of pile increases but not a great increase.

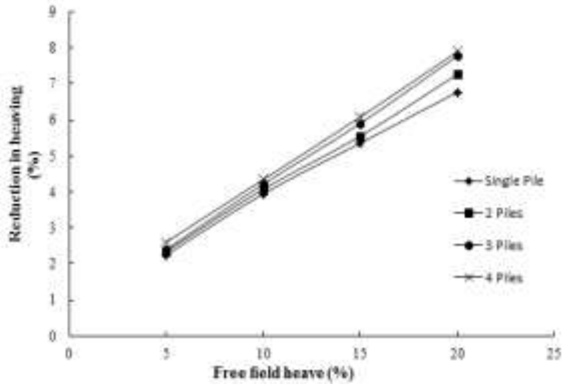

Figure 8. Variation of percentage reduction in heaving under the f ooting with free field heave (swelling potential)

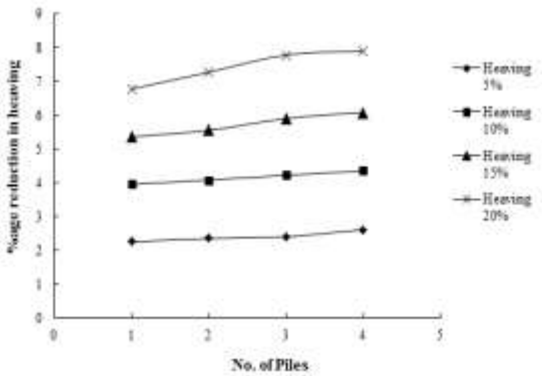

Figure 9. Variation of percentage reduction in heaving under the footing with the number of piles

3 .4 *Effect of Spacing of Piles*

It has been observed that there is no fixed pattern followed by the percentage reduction in heave by changing the number of piles. There is a slight change in the percentage but more or less it is constant thereby, stating the fact that spacing does not have much of influence on the resistance provided by the ground reinforced with AGP having any number of piles.

3 .5 *Effect of Spacing Area Ratio*

Figure 10 shows the variation of percentage reduction in heaving at a constant swelling potential of 10% with increasing area ratio for a single pile. The area ratio is defined as the ratio of the area of footing covered with AGPs to the total area of the footing. It has been observed that the area ratio has a direct bearing on the resistance of the pile/pile group against heaving i.e. more the area ratio; more will be the ability of the pile/pile group to arrest heaving.

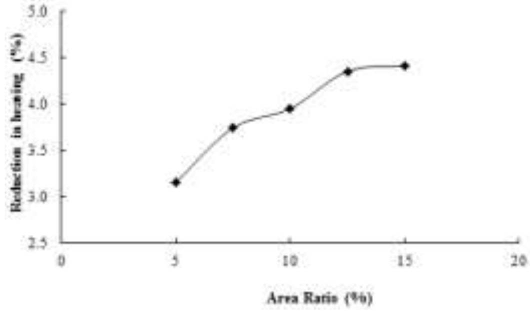

Figure 10. Variation of percentage reduction in heaving with area ratio (single pile)

4 CONCLUSIONS

Based on the analysis of different models of Anchored Granular Pile Foundation (AGPF) created in PLAXIS 3D, varying different parameters, the following conclusions were drawn.

i. The strength of AGP is directly proportional to the L/D ratio with the upper limit being 13 after which the increase in uplift resistance is not significant.
ii. The rate of increase of strength with the increase of L/D ratio is relatively less when the ratio is either very high or very low. While for the ratios between 8 and 12, at displacement equal to 20% of the diameter of the pile, the normalized load enhanced from 38.95 to 92.27.
iii. The effect of construction of AGP on the surrounding soil, if taken into account, increases the load bearing capacity of AGPF. The increase in strength (for 10% lateral strain to simulate the installation effect) is more at higher values of L/D than that at lower values of L/D. The results show that the average increase in strength of AGP is 2.5% when L/D is less than 6 while it is 11.7% when L/D is more than 6.
iv. In case of heaving, the resistance to heave under the footing or the decrease in heave is directly proportional to the swelling potential or the level of heaving in the ground. The more the heaving, the more will be the resistance to it. The above fact stands true for the number of piles ranging from 1 to 4, provided the area ratio and the spacing of piles is constant.
v. The spacing of piles was not found to be as effective parameter as swelling potential and area ratio. There is not much of a change in the strength of AGPF due to change in spacing of piles for any number of piles.

5 REFERENCES

McCabe B.A., Killeen M.M. and Egan D. 2008. Challenges faced in 3-D finite element modelling of stone column construction. *Proc. Joint Symposium on Concrete Research and Bridge and Infrastructure Research in Ireland*, NUI Galway, 393–400.

Phanikumar B.R. and Muthukumar M. 2013. Reducing heave of expansive clay beds through granular pile–anchor groups. *Proceedings of the ICE*, 1-9.

Phanikumar B.R., Rao A.S., and Suresh K. 2008. Field behaviour of granular pile-anchors in expansive soils. *Proceedings of the ICE – Ground Improvement, 1*61(4), 199–206.

Rao A.S., Phanikumar B.R., Babu R.D. and Suresh, K.S. 2007. Pullout behaviour of granular pile-anchors in expansive clay beds insitu. *ASCE Geotechnical and Geoenvironmental Engineering*, 133(5), 531–538.

Sawant V. A., Kumar P. and Ranjan, G. 2010. AGP system for resisting uplift forces. *Indian Geotechnical Conference, Bombay*,849-852.

Vidyaranya B., Madhav M.R and Sivakumar, V. (2007). Analysis and Comparison of Displacements Granular Pile Anchors. *Proceedings of ICE - Ground Improvement,* Vol. 161(1), pp 31-41.