UPLIFT CAPACITY OF SINGLE AND GROUP OF GRANULAR ANCHOR PILE SYSTEM

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Abstract – In view of increased development in the infrastructure across the world, now it becomes necessary to go for the marginal sites having weak soil for foundation. Foundations are normally designed to transfer compressive and uplift forces safely to the subsoil, wherein piles provide an appropriate solution. But the option of pile foundation is quite expensive. Before going for pile foundation, the feasibility of other alternatives must be accessed thoroughly. If it is possible to adopt some suitable ground improvement technique for enhancement of foundation strength, then it should be considered. In the present study, Granular Anchor Pile System is proposed to with stand uplift forces. The present paper, based on a field study, briefly discusses the basic principles associated with the granular pile. The analysis of field test data indicates that the proposed granular pile system is a viable means for ground improvement. It is found effective for improving varying soil conditions and capable of providing resistance to compressive forces in addition to the uplift resistance. Besides, this foundation technique has been found cost effective as compared to the concrete piles.

***Keywords*:** Granular anchor pile, uplift capacity, anchor plate

1.0 INTRODUCTION

Keeping in view the emerging demand of infrastructure, utilization of the poor and marginal sites is unavoidable. Development of these sites with ground improvement techniques has become a subject of profound interest for geotechnical engineers. A variety of ground improvement methods are in practice these days. Various compaction techniques can be adopted for stabilization of loose cohesionless soils. For cohesive soils, consolidation by preloading, grouting, electro-osmosis, electrochemical hardening, stabilization through lime columns, are preferred ground improvement techniques. Ground improvement by various methods can be quantified by assessing the improved bearing capacity and reduced settlement of the treated ground. In real field situations one may come across situations like, limited area for foundation due to presence of existing structures, or where piling may not be adopted due risks of settlement from vibrations, excavations/ loss of ground. In such situations, granular piles can be used as an economical and effective alternative. Installing granular piles in soft cohesive soils and loose cohesionless deposits is an accepted and popular ground improvement technique [1]. Granular pile installation does not require heavy machinery or skilled labour like pile foundation. Gravel backfill is placed into the borehole in stages. In each stage, backfill is compacted by a steel hammer. Compaction displaces the filling material in radial outward direction resulting densification of surrounding soil. This has resulted in significant increase in load carrying capacity and reduction in settlement. Installation of granular piles is one of most preferred method of improving soft ground or loose sand deposits. Granular piles act as reinforcement in the subsoil. It improves drainage pattern and helps in dissipation of excess pore water pressure. Installation of granular pile results in densification of surrounding soil. This will improve bearing capacity, the rate of consolidation and the liquefaction resistance of the ground. In addition, total and differential settlements get reduced by 60-80%. In field, granular piles are installed with the help of vibro-processes or through rammed stone columns technique.

Structures like transmission towers or foundations on expansive soil are subjected to uplift forces. In such case, conventional approach is to adopt under-reamed pile foundation. But in the present study, normal granular pile technique with little modification is suggested to counter the uplift force. ‘Granular Anchor Pile (GAP)’ is the modified form of granular pile. It may be defined as the enhanced granular pile which is reinforced with anchor plate and anchor rod. An anchor plate is a circular steel plate embedded into a concrete pedestal at the bottom of predrilled hole. It is connected to a steel anchor rod which may protrude above pile head (*Figure 1*).

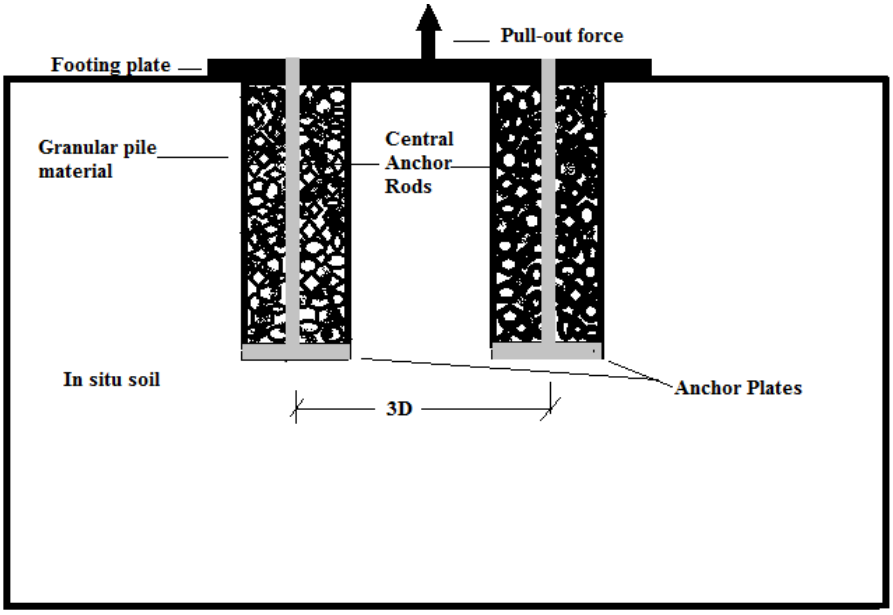

Figure 1 Concept of the granular anchor pile (GAP) foundation system

Few studies have been reported on granular anchored pile to resist uplift forces [1-5]. Kumar and Ranjan [6] have reported the field study of GAP system. Phanikumar et al. [7] reported laboratory investigations on a limited scale for heave control of expansive soils. Ibrahim et al. [8] conducted laboratory tests in addition to a series of numerical modelling using PLAXIS software to study the behavior of GAPF system in expansive soil. Study revealed that the heave can be reduced with increasing length and diameter of GAP. Johnson and Sandeep [9] conducted laboratory tests to study the effect of relative density of fill material and granular pile diameter on the pull capacity of the GAP. The pull-out capacity of the GAP observed to increase with relative density of the granular material and diameter of the GAP. Krishna and Murty [10] discovered that the GAPs exhibit promising pullout capacity even under fully wet condition compared to conventional concrete piles. Phanikumar [11] studied the influence of geogrid reinforcement on uplift capacity of GAP in expansive clay beds. The pullout capacity of the GAP increased with increasing number of geogrid layers, decreasing spacing between them, and with decreasing distance between anchor plate and bottom geogrid.

The uplift capacity can be accurately predicted only when reliable estimation of the in situ properties of the ground and of the granular pile material is possible. A method for determination of the same is presented here. Present study reports the field investigation of GAP at two sites. Estimation of uplift capacity from limit equilibrium approach is also discussed. The predicted capacities from limit equilibrium approach are in good agreement with measured uplift capacity of GAP in the field.

2.0 METHODOLOGY

Two sites are selected for conducting field investigations. They are designated as Site-1 and Site-2. The detailed subsoil investigations in the field have been carried out at the selected sites. Then necessary laboratory investigations are carried out on disturbed/undisturbed samples collected from field for measurement of essential soil properties. Testing program included advancement of borehole supplemented with standard penetration tests (SPT) at regular intervals, dynamic cone penetration tests

(DCPT) and static cone penetration tests (SCPT). Further, the undisturbed and disturbed soil samples were collected from appropriate locations for laboratory investigations. Basic classification tests were carried out on undisturbed samples.

2.1 SITE-1

The water table during the testing period was 6.2 m below ground. Study of bore log at site indicate the presence of poorly graded sand (SP) starting from the surface to 4 m depth. It is underlain by 1 m thick inorganic silt (ML). Again soil between 5 m to 8 m depth was found to be poorly graded sand (SP). Further extension of borehole beyond 8 m depth indicated the presence of this silty soil (ML). Observed SPT *N* values at different depths are tabulated in Table 1. Similarly static cone resistance values were recorded as 3600 kPa and 3200 kPa at 2 m and 3 m depth, respectively. But the values decreased to 2200 kPa and 1000 kPa at 4 m and 6 m depth, respectively. Beyond this depth it was again observed increasing. The grain size analysis marked the presence of fine to medium sand between 82 to 97 % with 10 to 12 % of silt contents with almost no clay. However, a thin layer of 10 % clay content was observed as exception.

Table 1 SPT value and angle of internal friction along depth at site-1

Depth (m)	SPT (*N*)	Angle of friction
0.75	6	28°
3	6	28°
5	11	29°
6	12	29°
7	14	30°
8. 5	9	29°

2.2 SITE-2

As per the bore-log, the subsoil at the site reported an upper clay layer of intermediate plasticity (CI) starting from the ground surface to 3 m depth. It is followed by clay of low plasticity (CL) between 3 m to 6 m depth. Between 6 m to 10 m depth again clay of intermediate plasticity (CI) was observed. Thus, the subsoil in general consists of soft cohesive-soil deposit ranging from CL to CI. Observed SPT *N* values at different depths are tabulated in Table 2. The grain size analysis of samples collected from different depths was carried out using Digital Particle Size Analyzer. It indicated the presence of silt and clay. The percentages of silts varied from 95% to 52%. Triaxial tests have been conducted on undisturbed samples of cohesive soils.

Table 2 Soil properties along depth at site-2

Depth (m)	SPT (*N*)	Liquid limit	Plastic limit	Cohesion kPa	Angle of friction
0.75	4				
1.5	7	43	22	50	15°
3	10	43	24		
4.5	9	29	17	50	10°
6	14	27	16		
7.5	13	37	19	50	15°
9. 5	16	20	NP		

(NP- Non-plastic)

2.3 PROCEDURE FOR CONSTRUCTION OF GAP AND LOAD APPLICATION IN THE FIELD

Initially, borehole of desired depth in the ground is drilled using a manually operated spiral auger. Then, cement concrete mixture (1:2:4) is poured at its bottom through a tremie pipe. Then a prefabricated anchor plate with anchor rod is lowered and positioned at the bottom. Another layer of 150 mm thick concrete is poured over anchor plate. Borehole is then left for seven days for initial setting of concrete. Then granular pile is installed with stone aggregate sand mixture in predetermined layers. Each layer was given uniform amount of compaction energy throughout the investigations.

After the test bed is ready, the other end of MS anchor rod is connected to the loading jack with the help of specially designed and fabricated attachment provided at its top to transfer the uplift force to the GAP system. The pullout force is then applied through the remote controlled hydraulic pump and jack placed at the loading/top girder of the MS frame. Pullout force is applied in increments. The exact load increment is measured through a load cell. The upward movement of GAP is measured with the help of two dial gauges. The uplift movements corresponding to each incremental uplift force were recorded till the soil fails in bulging.

In this study, the uplift capacity of single GAP and group of GAP system (both 2 GAP and 4 GAP system) is determined. In case of group piles, center to centre spacing of 3 times pile diameter is considered in the present study. The diameter of GAP is considered as 0.3 m. But to examine the effect of diameter, two cases with 0.35 m diameter are also considered. To study the effect of Length to Diameter on uplift capacity of single GAP, four different L/D ratios are considered in the field study. For the case of group GAP, L/D ratio is taken as 20.

3.0 LIMIT EQUILIBRIUM APPROACH

Bottom portion of GAP equal to critical height H_c is considered to bulge due to uniform lateral stress σ_r in subsoil due to gradual increase in uplift stress q and consequently σ_r in pile body (*Figure 2*). Cylindrical zone around the bulged pile having a radius R_u will undergo a state of plastic equilibrium. Beyond this zone of plastic equilibrium of radius R_p, soil is considered to be in elastic state. Ultimate uplift force applied at pile top is considered to be resisted by weight of GAP and force required to provide to restraint against bulging of GAP. Unit friction along the GAP shaft is not considered as there is no enough relative movement between GAP and surrounding soil. Ratio of radius of plastic zone and cylindrical cavity (R_p/ R_u), reduced rigidity index I_{rr} and lateral limiting stress σ_{rL} are parameters controlling uplift capacity.

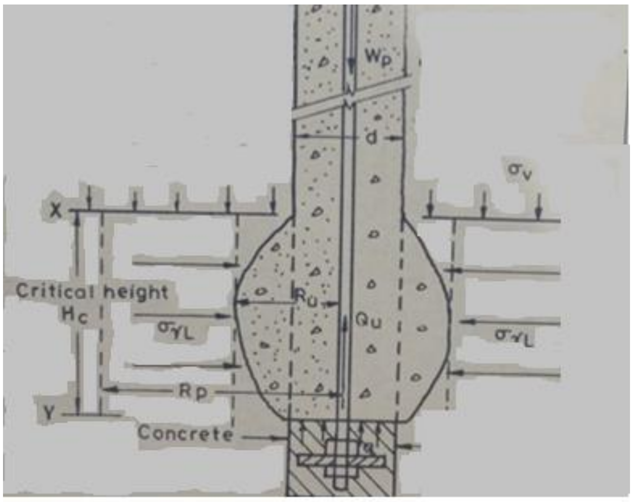

Figure 2 Bulging at bottom of GAP [12]

Ultimate uplift capacity Q_u is calculated using following steps:

1. Effective normal stress σ_V at bulging
   Assuming H_c equal to five times diameter of pile,
$$\sigma_v = \gamma \times z = \gamma \times (L - 5D) \qquad (1)$$
2. Effective mean normal stress σ_m
$$\sigma_m = \left(\frac{1+2K_0}{3}\right)\sigma_v \quad where \quad K_0 = 1 - \sin(1.2\phi) \qquad (2)$$
3. Elastic soil modulus is obtained from
$$E_s = 2q_c\left(1+R_D^2\right) \qquad (3)$$
   In which, q_c is static cone penetration resistance and R_D is relative density of soil.
   Corrected Modulus
$$E_{cor} = E_s\left(\frac{\sigma_v}{100}\right)^{0.5} \qquad (4)$$
4. Rigidity Index I_r
$$I_r = \left(\frac{0.5E_{cor}/(1+\mu)}{c+\sigma_m \tan\phi}\right) \qquad (5)$$
   Reduced Rigidity Index I_{rr}
$$I_{rr} = \left(\frac{I_r}{1+I_r\varepsilon_v}\right) \quad where \quad \varepsilon_v = \frac{\sigma_m}{K_{bulk}} \qquad (6)$$
   Dimensionless cavity expansion factors F_q and F_c
$$F_q = (1+\sin\phi)(I_{rr}\sec\phi)^{\sin\phi/(1+\sin\phi)}$$
$$F_c = (F_q - 1)\cot\phi \qquad (7)$$
$$F_c = 1 + \ln(I_{rr}) \quad for \quad \phi = 0$$
5. Lateral limiting stress σ_{rL} are
$$\sigma_{rL} = F_c c_u + F_q \sigma_m \qquad (8)$$
6. Ultimate resistance in bulging q_{ult}
$$q_{ult} = K_p \sigma_{rL} = \frac{1+\sin\phi_p}{1-\sin\phi_p} \times \sigma_{rL} \qquad (9)$$
7. Resistance in bulging Q_0
$$Q_0 = q_{ult} A_p \qquad (10)$$
8. Weight of GAP
$$W_p = \gamma_p A_p L \qquad (11)$$
9. Ultimate uplift capacity Q_u
$$Q_u = Q_0 + W_p \qquad (12)$$

4.0 RESULTS AND ANALYSIS

The pullout capacities were obtained from the pullout force versus displacement curves by intersecting tangent methods. Values of pullout capacities are listed in *Table 3* and *4*. Values of pullout capacities are observed to be increasing with the increase in *L*/*D* ratio. This increase is observed to be marginal beyond *L*/*D* equal to 13.3. There is a particular length of pile beyond which further increase in length will not have significant effect on the pullout capacity. In the present study this length may be considered corresponding to *L*/*D* ratio of about 13.3. For groups of GAP systems, the pullout capacities were found almost equal to the value of a single GAP system multiplied by the number of GAP systems.

Table 3 Ultimate Uplift capacity at site-1

Type of GAP	*L*/*D*	*S*/*D*	Ultimate Uplift capacity (kN)	
			Field Test	Analytical
Single	6.66	-	45	27.4
Single	10.0	-	70	54.1
Single	13.3	-	75	67.7
Single	20.0	-	80	78.8
2 GAP	20.0	3	170	157.6
4 GAP	20.0	3	310	315.2

GAP- Granular Anchor Pile, 2 GAP- Group of 2 GAP, 4 GAP- Group of 4 GAP,
S/*D*- c/c pile spacing to diameter ratio in group pile

Table 4 Ultimate Uplift capacity at site-2

Type of GAP	*L*/*D*	*D* (m)	*S*/*D*	Ultimate Uplift capacity (kN)	
				Field Test	Analytical
Single	6.66	0.3	-	35	44.0
Single	13.3	0.3	-	45	48.9
Single	20.0	0.3	-	47	54.4
2 GAP	13.3	0.3	3	80	97.8
2 GAP	20.0	0.3	3	90	108.8
2 GAP	20.0	0.35	3	200	154.8
3 GAP	13.3	0.3	3	120	146.7
3 GAP	20.0	0.3	3	140	163.2
3 GAP	20.0	0.35	3	220	222.2
6 GAP	13.3	0.3	3	260	293.4
6 GAP	20	0.3	3	300	326.4

Analytical estimation of pull out capacity is also given in the same tables for comparison. The pull out capacity of group of GAP is estimated by multiplying number of piles with capacity of single GAP. It forces group efficiency equal to one. Assuming densification of soil taking place in the installation and pile spacing greater than or equal to 3 times diameter, this assumption is justifiable. The comparison of field and analytical result indicates average error of 15% with field results. Difference is more for lower values of *L*/*D* ratio. With increase in of *L*/*D* ratio good agreement is observed between field and analytical approaches.

Various parameters that are observed to influence the ultimate pullout capacity of the GAP system in the present study were length, diameter, spacing, number of GAP and the soil characteristics.

5.0 PERFORMANCE STUDY

Granular anchor pile (GAP) are mainly designed focusing its ability to resist uplift forces. In the present study, the performance of GAP and pile of same length and diameter are compared from economic considerations and their ultimate capacities. In the economic comparison, it is assumed that cost of installation of GAP and concrete pile is nearly same. Hence, only material costs are compared. Material costs are evaluated for four *L*/*D* considered in the study. Their material cost is reported in *Table 5* along with percentage difference. It can be observed that material cost is nearly increased by 100% for concrete piles. Difference is increasing with *L*/*D* ratio. Similarly, uplift capacity of concrete pile in same ground conditions are evaluated for four *L*/*D* considered in the study. The uplift capacity of GAP and pile are compared in *Table 5*. For smaller *L*/*D* ratio capacity of pile is 77 % less as compared to GAP. However, with increase in length, difference in capacity is reducing. For *L*/*D* ratio of 20, capacities are almost equal. This fact again underlines the importance of optimum *L*/*D* ratio of GAP.

Table 5 Ultimate Uplift capacity at site-1for 300mm diameter GAP

No.	L/d	Material cost of GAP (INR)	Material cost of concrete pile (INR)	% difference	Ultimate Uplift capacity of GAP(kN)		Concrete Pile Strength (kN)
					Field Test	Analytical	
1	6.66	836.80	1653.25	97.57	45	27.4	9.92
2	10.0	1096.64	2248.58	105.04	70	54.1	20.19
3	13.3	1356.48	2843.91	109.65	75	67.7	34.39
4	20.0	1876.16	4034.57	115.04	80	78.8	74.02

6.0 CONCLUSIONS

The analysis of field test data indicate that the GAP system is an effective foundation system for structure subjected to uplift loads. Various parameters that are observed to influence the ultimate pullout capacity of the GAP system in the present study were length, diameter, spacing, number of GAP and the soil characteristics. Based on the study following conclusions are made:

1. Pullout capacities are observed to be increasing with the increase in *L*/*D* ratio up to an optimum value for *L*/*D* ratio.
2. For groups of GAP systems, the pullout capacities were found almost equal to the value of a single GAP system multiplied by the number of GAP systems.
3. The comparison of field and analytical result indicates average error of 15% with field results. Difference is more for lower values of *L*/*D* ratio. With increase in of *L*/*D* ratio good agreement is observed between field and analytical approaches.
4. From economic considerations, the material cost of GAP is nearly half of the concrete pile of same dimension. Hence it can be considered as an alternative option to pile foundation where site is not prone to earthquake hazard.
5. Comparison of uplift capacities indicated that GAP is more effective than pile at smaller *L*/*D* ratio.

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