Ground Improvement by Granular Anchor Pile Foundation in Cohesive Soil under Axial Pull-Out Loads

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Abstract. Due to rapid urbanization and increase of population, the demand of construction has increased significantly during the last few decades and thus resulting in scarcity of land. So, to eradicate this problem, geotechnical engineers are using several ground improvement techniques such as use of geosynthetics, stabilization of soil, vibro-compaction, stone column, blasting, compacting piles and granular anchor pile foundation to construct buildings on weak sub-soil strata for the optimum usage of land. These techniques are used to improve the soil bearing capacity to withstand compressive as well as uplift forces imposed on the structure. The adoption of suitable type of foundation technique will depend upon various factors such as nature of soil, type of loading, type of structure etc. Granular anchor pile foundation is the innovative technique used to sustain the compressive and pullout loads over weak subsoil. In this paper, the laboratory experiments were conducted to understand the behavior of axial pullout load of granular anchor pile foundation in cohesive soil. The parameters studied were length of the pile, diameter of the pile, L/D ratio and size of the granular fill material. The test results indicate that the pull-out capacity decreases with the increase in L/D ratio from 7.5 to 12.5. There was an increase in the pull-out load resistance, when the diameter of the pile increases. Moreover, pullout load capacity increases when size of the granular fill increased.

**Keywords:** Granular Anchor Pile Foundation (GAPF), Pullout Load, cohesive Soil

1. Introduction

There are many structures such as television and transmission towers, tall chimneys, tension cable for suspension bridges and marine structures such as floating platforms, bridge abutments, retaining walls, bulkheads, avalanche control structures (snow nets,

umbrella system), tall buildings etc., whose foundations are subjected to large uplift forces. The conventional shallow foundation in cohesive soil may not be sufficient to withstand the uplift forces, such cases required deep foundations such as concrete pile, under reamed piles foundations, belled pier foundations. The structures are subjected to compressive vertical load, uplift loads (tension forces), lateral loads or a combination of all these to make resultant load oblique. Granular piles (GP) were developed initially to resist compressive loads through predominantly pile action. Granular piles, also known as stone columns, have been extensively used in soft clays and loose sands to rectify their geotechnical properties [1, 2]. However, the capacity of single or small groups of GPs was restricted due to bulging near the upper end of pile. It can be installed in wide variety of soils, ranging from loose to medium sands, soft to medium clays and organic soils but is deficient in taking uplift loads. The failure mechanism of GP under uplift loads demonstrates the granular material displacing out from the sides of the pile-soil interface. Hence, any pressure bulb is not formed, thus restricting its uplift capacity near the bottom of the pile. This deficiency of granular pile may be improved by providing an anchor plate at the base of the granular pile with a rod attached to the bottom of foundation to resist pullout loads [3 - 6]. The Granular Anchor Pile (GAP) is much superior to that of solid piles as the load is directly transferred to the tip where the bulging capacity is the highest [7]. Therefore, the behavior of GAP is required to be studied in the case of non- expansive clayey soil also. Therefore, for a thorough understanding of pile-soil interaction, it is necessary to study the behavior of a granular anchor pile foundation by varying different parameters subjected to pullout loads embedded in cohesive soil. In this paper, extensive experimental tests were conducted on laboratory -scale GAP installed in clayey soils under uplift loads by varying different pile parameters.

2. Concept of Granular Anchor Pile

Granular Anchor Piles (GAP) is a new ground improvement technique used widely for improving the settlement and strength characteristics of cohesive soils for shallow foundation. A granular anchor pile is one in which the foundation is anchored at the bottom of the granular pile to a mild steel plate through a central mild steel rod (Fig.1). This serves to hold the particulate granular medium and prevents the granular pile from being sheared away and is thus instrumental in mobilizing the frictional resistance to the uplift force on the foundation.
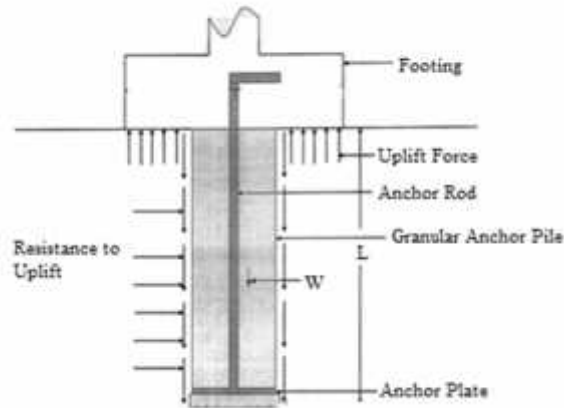
Fig.1 Concept of Granular Pile Anchor

3. Materials

The soil used in pull-out tests was collected from Village Sarsod, District Hisar, Haryana (India). Table 1. shows the index properties of the soil. Based on the index properties, the soil was classified as CI as per IS 1498:1970 [8]. The soil had a maximum dry unit weight of 15.1 kN/ m^3 at optimum moisture content (OMC) of 18% as determined from the standard Proctor compaction test IS:2720-PART 7 [9]. The grain size distribution curve is shown in Fig. 2.

Table 1. Index Properties of the Soil

Properties	Value	IS Code
Specific gravity	2.71	IS:2720-PART 3 [10]
Sand (%)	3	
Silt (%)	67	
Clay (%)	30	
Liquid limit (%)	46	IS: 2720-PART 5 [11]
Plastic limit (%)	23	IS: 2720-PART 5 [11]
Plasticity index (%)	23	
Free swell index, FSI (%)	22.7	IS: 2720 PART 40 [12]
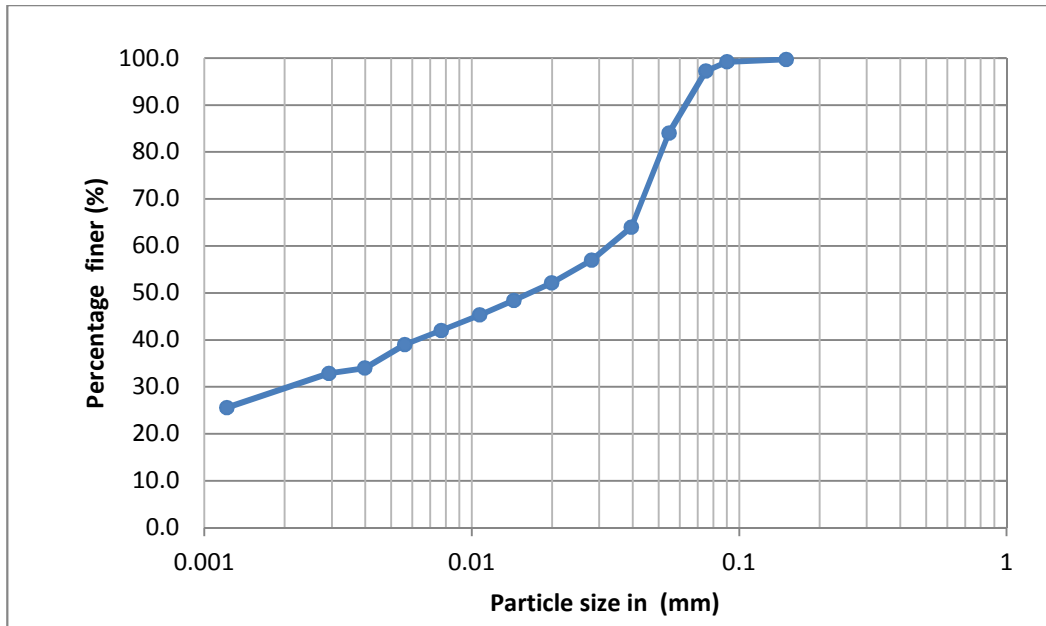
Fig.2. Grain Size Distribution Curve of soil

Granular anchor piles were installed in the soil beds using a granular material that was a mixture of particle size of coarse aggregates varies between 3 mm to 6 mm and 8 mm to 10 mm. All the granular anchor piles studied in this laboratory -test program were compacted by ramming the granular material into equal parts up to the required height. The maximum and minimum density of the granular material from relative density test is 20.1 kN/m^3 and 14.1 kN/m^3 respectively. Granular material was filled in the pile at 60% relative density i.e 17 kN/m^3.

In order to study the effect of pull-out loads on granular anchor pile foundation (GAPF), the steel anchor piles were fabricated as shown in Fig.5.The circular anchor plate of diameter equal to diameter of pile has been welded to the bottom of the tie rod, thus making a rigid bond for embedded lengths as 250 mm, 350 mm and 450 mm for L/D ratio 7.5, 10 and 12.5. The hook was made at the top of the pile to connect the loading wire and apply the uplift load on the granular anchor pile.

Fig3.Granular material of size 3 to 6 mm   Fig4.Granular material of size 8 to 10 mm

Fig. 5 Anchor Piles used in laboratory Tests

4. Experiment program

The laboratory tests were performed on soil to study the uplift capacity of a GAPF system. The aim of the study was to investigate the behavior of the granular anchor pile foundation system as a new foundation technique used in improvement of cohesive soils. Various tests have been conducted by varying different pile parameters to understand the

behavior of granular anchor pile foundation. The parameters such as pile length, pile diameter, L/D ratio, load inclination, group pile, encasing of pile periphery with geotextile and geonet, spacing of piles has been studied.

4.1 Model test setup

The rectangular tank of size 900 mm (L) x 900 mm (B) x 600 mm (H) was fabricated to perform model laboratory test. The wall thickness of the metal tank was kept 5 mm. The experimental setup is shown in Fig.6. The soil was filled in the tank at MDD i.e 15.1 kN/m^3 and weight of the soil required to fill the tank was calculated. The tank was divided into convenient number of equal parts, each part having to be compacted for desired unit weight so as to achieve the required density. A total of 9 no. GAP piles were casted simultaneously at c/c distance of 225 mm. A steel tie rod with a circular plate of diameter equal to that of GAP was welded and placed vertically at the bottom of the test tank at the required position with c/c spacing of 225 mm distance from each pile w.r.t tank dimensions. This spacing was adopted by considering the uplift load influence on the pile surface. The anchor rod and pile casing were held in position with the help of the steel bars placed on the top of the tank, tied with the binding wires as shown in Fig. 6. The soil was filled in layers of 50-mm thickness in the tank. Each part of the soil was carefully placed in the tank such that it abstains from entering the casing pipe and thus compacting with the rammer up to the required height of the test tank The amount of the granular pile material required to be filled at uniform density, was filled in layers of equal thickness with simultaneous removal of casing pipe.

Fig.6. Preparation of test bed and construction of GAP

After the test bed and construction of GAP was ready, the top end of the MS anchor rod was connected to the loading arrangement with the help of a specially designed and fabricated attachment provided at the top to transfer the uplift force to the GAP system. After compaction, the loading frame was placed over the granular anchor pile centrally, the side frame was fastened with the nut-bolt with the test tank to resist the upward thrust on the loading frame. The pull out load was applied at the center of the pile axis with the properly designed load arrangement, which consists of the steel frame, a flexible steel wire rope (10 mm dia), and 3 nos. of frictionless pulleys, a loading platform and dead weights. A special fabricated 6 mm dia steel hook was made to attach the loading setup with the granular anchor pile from which the pull-out load was transferred to the GAP. On the other hand, a steel wire was connected with the U- shaped hook fastened with nut bolt to make its connection with the loading platform. The pullout dead loads were applied with respect to axis of granular pile, by taking steel wire rope through pulleys and placing loading setup at accurate position from the granular pile. In each case, this was achieved by placing the loading setup at calculated position, attaching wire rope with granular anchor pile and putting 8 kg weight on the loading platform for straightening of the wire rope. The tank was fabricated for load carrying capacity of 650 kg. Incremental loading was provided in 10–15 increments by putting known dead weights in the loading platform, till granular anchor pile completely pulled out of the clay bed. For measuring the upward displacements in vertical direction a L-shape steel plate was welded with the steel hook attachment from which the pull out load was applied, two dial gauges were placed on the steel plate to measure the upward movements. The average displacement found from the two dial gauges was considered to be the final uplift movement.

5. Results and discussion

The results of pullout test on single GAP by varying different parameters such as length of piles, diameter of piles, L/D ratio, size of granular fill are discussed in terms of pullout load- uplift displacement behavior. To study the effect of pull-out load, the graphical representation of results are presented showing the applied uplift load (N) on x-axis and the axis and the corresponding upward displacement (mm) on y-axis.

5.1 Effect of length and diameter on Granular Anchors pile foundation

The effect of vertical pullout load-upward displacement curve for GAP of different length and diameters with L/D ratio 10 is shown in Fig.7. The curves indicates that, at all stages of loading, the upward load required to be applied on the GAP to cause a given upward movement increased with increase in length of GAP. The ultimate capacity of pile is evaluated using the double tangent intersection method. In this method, two tangents are drawn one form the initial flatter position and second through the final steeper portion of load displacement curve. The load corresponding to intersection point of two tangents is considered to be the ultimate capacity of pile. Fig.7 shows the ultimate Pull-out load from

double tangent intersection method for length L= 250 mm. The ultimate pull-out load for all the cases of GAP was calculated and mentioned in Table.2.

In Fig.8, pullout behavior of the curve reflects the effect of diameter of GAP on pullout behavior. The applied upward load was observed to increase with increasing diameter of the GAP at all stages of the test as the resistance to uplift increased with increasing surface area of the pile-soil interface. It has also been observed from the results that as the L//D ratio of GAP increases, the pullout load decreases. Therefore, the uplift resistance depends upon the frictional characteristics and the surface area of the interface. The higher the surface area of the interface, the greater the uplift resistance. Increasing the diameter increases the surface area and pile anchor weight and consequently uplift resistance and results in increased failure pullout load.
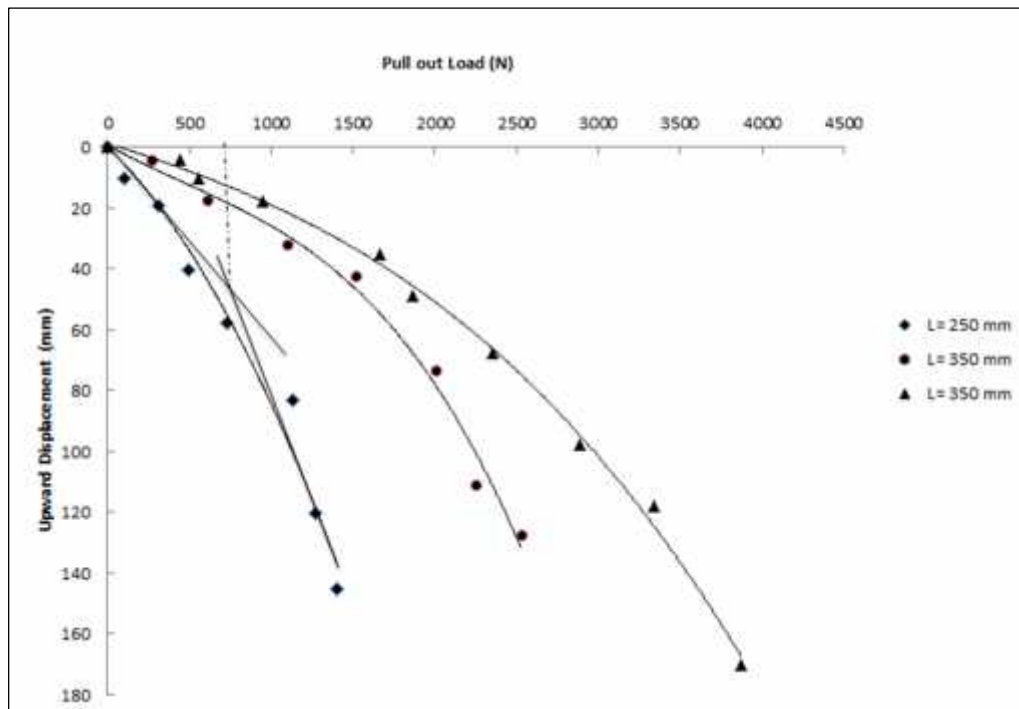
Fig. 7. Pullout deformation curves for L/D=10
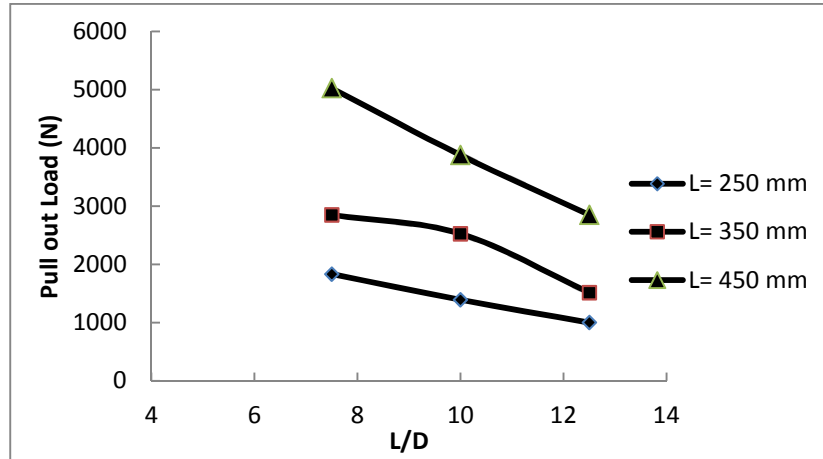
Fig. 8.Pullout deformation curve of L/D versus Pull-out load

Table2. Ultimate pull-out capacity of single GAP for length 250mm, 350mm and 450 mm

Length of Pile (mm)	L/D	Ultimate Pull-out capacity of clay (N)
	7.5	820
250	10	641
	12.5	457
	7.5	1310
350	10	1161
	12.5	697
	7.5	2490
450	10	1921
	12.5	1413

5.2 Effect of size of the granular material fill on pullout load capacity

The influence of size of granular material on ultimate pullout capacity of GAP was studied for two sizes of granular material i.e 3-6 mm and 8-10 mm. Table 3. presents the results of ultimate pullout capacity of granular anchor pile. It is observed from the Table 3.that with increase in the size of the aggregates the ultimate pull out capacity of GAP increased. This is due to the movement of aggregate in soil is restricted thus making large pressure bulb in comparison to smaller aggregates. Also, with the increase in size of the granular fill, the weight of the granular anchor pile increases, thus results in resistance to uplift load due to self-weight of the pile. As shown in Table3 the percentage increase in pullout capacity is more in case of length L= 250 mm with increase in aggregate size.

Table3. Ultimate pull-out capacity of single GAP for varying sizes of granular material

Length (mm)	L/D	Pull out load (N)		Percentage increase
		Agg size (3-6 mm)	Agg size (8-10 mm)	
	7.5	820	941	14.8
250	10	641	708	10.5
	12.5	457	493	7.8
	7.5	1310	1425	8.8
350	10	1161	1235	6.4
	12.5	697	758	8.7
	7.5	2490	2680	7.6
450	10	1921	1970	2.5
	12.5	1413	1546	9.4

6. Conclusions

A comprehensive laboratory-test program was performed to study the pullout load response of GAP embedded in non- expansive clayey soil. The test program studied pullout load-upward movement behavior of GAP embedded in soil with varying parameters. Following conclusions can be drawn from the present study.

1. The uplift load increases with the increase in diameter of the GAP. The resistance to uplift force increases with increasing surface area of the pile-soil interface consequent upon increase in the diameter.
2. For a given L/D ratio, the failure pullout load increased with increasing length of the GAP. Similarly, for a given length of the GAP, the failure pullout load increased with decreasing L/D ratio. Increasing diameter increases the surface area and consequently the uplift resistance and results in increased failure pullout load.
3. With the increase in size of the granular material, resistance to uplift load increases due to formation of large pressure bulb in case of large aggregates as compared to smaller aggregates.

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