Fig. 5.6 Bulge profiles of granular pile-anchors ($L_{gr} = 1000$ mm)
CHAPTER 6

STUDIES, RESULTS AND DISCUSSION ON PULLOUT LOAD RESPONSE OF GRANULAR PILE-ANCHORS

6.1 Introduction

In this chapter, the results of pullout load tests on expansive soil reinforced with granular pile-anchors are presented and the in situ behaviour of granular pile-anchors in expansive clay beds under uplift discussed.

6.2 Measurement of shear parameters of the granular pile-clay interface

Shear box tests were conducted by compacting the granular pile material and expansive clay in the upper and lower halves of the shear box respectively, for determining the shear parameters, $c'$ and $\phi'$, of the granular pile-clay interface. The expansive clay was compacted at the initial water content ($w_i$) and the required initial dry density ($\gamma_d$). The granular material was compacted at the appropriate relative density ($D_r$). The tests were conducted in a shear box of size $60 \times 60 \times 20$ mm. The clay sample
was allowed to swell completely before the shear test. Heave was monitored, and the shear test conducted when there was no further swell. Shear tests were conducted for evaluating the effect of friction mobilized at the interface formed by the granular pile and the expansive clay. The values of shear parameters $c'$ and $\phi'$ were respectively 10 kPa and 28°.

6.3 Pullout load test and test procedure

6.3.1 Loading frame arrangement

The same loading frame, the description of which was given in the earlier chapter was used. For the uplift test, a slight modification is made in the central loading frame portion. On either side of the ISMB 300 section running perpendicular to the H-frames, M.S rods of 20 mm diameter with threaded ends are placed vertically and connected to circular plates at the top and the bottom by nuts. The hydraulic jack is placed on the ISMB 300 section running perpendicular to the H-frame and reacts against the top circular plate. To the bottom circular plate an eye-bolt is provided as shown in Fig. 6.1 through the eye of which an inverted U-shaped hook passes. The two ends of the inverted U-shaped hook are connected to the footing plate of the granular-pile anchor as shown in Fig 6.1. As the load is applied to the hydraulic jack the top circular plate gets lifted and through the M.S rods, the eye-bolt and the inverted U-shaped hook and thus the uplift force is transmitted to the granular-pile anchor. The GPA is then pulled out of the ground.
6.3.2 Load test procedure

After compaction, the expansive clay bed reinforced with granular pile-anchor (in the case of single pile-anchor) or granular pile-anchors (in the case of group of pile-anchors) was inundated with water up to the point of saturation. Saturation of clay beds was confirmed when final heave was attained. Heave was continuously monitored with dial gauges placed on footing plate fastened to the top end of the mild steel anchor rod.

Fig. 6.1 shows the pullout load test set up. The loading frame was placed over the granular pile-anchor centrally. Sand bags were used to resist the upward thrust on the loading frame. The pullout load was applied with the help of hydraulic jack placed on the central beam of the loading frame. The figure shows the loading platform used for applying the loading. After confirming saturation, pullout load was applied in increments of 1 kN and the corresponding upward movement of the granular pile-anchor was recorded. Each increment of loading was applied till the final upward movement of the granular pile-anchor under the applied load increment was attained. After the attainment of the final upward movement under the applied load increment, the next load increment was applied and the procedure repeated. The load increment of 1 kN was chosen for the sake of convenience. As the load was applied on the granular pile-anchor, the top footing plate was lifted up raising the granular pile-anchor along with it. The reaction from the expansive clay bed or composite ground or the granular pile-anchor alone was measured from a proving ring. The upward movement of the granular pile-anchor under each increment of load was measured with dial gauges of sensitivity 0.01 mm at the time intervals of 1, 2.25, 4, 6.25, 9, 16 and 25 minutes, and thereafter, at hourly intervals for
24 hours. The tests were continued up to the point of failure. Loading was applied in different cases as detailed below:

(a) **Granular pile-anchor alone**: Pertaining to this case, nine tests were performed. The $l_{pa}/d_{pa}$ ratio of the test granular pile-anchors ranged from 2.5 to 10 (Table 3.3). The diameter of the footing plate used up to the point of saturation also varied such that the ratio of the diameter of the footing plate to that of the pile-anchor was 2.5. However, after saturation, the footing plate was fastened to the top plate kept on the central beam through a pulley (Fig. 6.1) for applying uplift loads.

(b) **Group of granular pile-anchors**: In this test, the expansive clay bed was reinforced with a granular pile-anchor surrounded by five granular pile-anchors installed in a triangular pattern. The spacing between any two granular pile-anchors was kept equal to twice the diameter of granular pile-anchor. All the granular pile-anchors were of diameter 150 mm and length 1000 mm. The granular pile-anchor at the center of the group was loaded (Fig. 3.1c).

### 6.4 Pullout load behavior

The results of pullout tests on a single granular pile-anchor and a single granular pile-anchor surrounded by a group of granular pile-anchors are discussed in terms of pullout load-upward movement behavior. To study the pullout behavior, the results are plotted graphically by showing the applied uplift load (kN) on the Y-axis and the corresponding upward movement (mm) on the X-axis. Fig. 6.2 shows the pullout load-upward
movement curves for single granular pile-anchors of a uniform diameter of 200 mm with lengths varying as 500, 750 and 1000 mm. The curves indicate the influence of length of granular pile-anchor. All the granular pile-anchors were tested up to failure. The curves presented in the figure show that the failure pullout load increased with increasing length of the granular pile-anchor. The curves also indicate that, at all stages of loading, the upward load required to be applied on the granular pile-anchor to cause a given upward movement increased with increasing length of granular pile-anchor. However, it may be observed that, up to an applied uplift load of 4 kN, there was no significant upward movement in the granular pile-anchors.

As has been discussed in the previous sections the resistance to uplift caused on the foundation by the swelling soil is mobilized because of the effect of anchorage and also because of the shear resistance mobilized along the cylindrical pile-soil interface. Therefore, the uplift resistance depends upon the frictional characteristics ($c'$ and $\phi'$) and the surface area of the interface. The larger the surface area of the interface the greater is the uplift resistance. For example, the uplift load required to cause an upward movement of 25 mm in the granular pile-anchor was respectively 9, 12 and 14 kN for granular pile-anchors of length 500, 750 and 1000 mm. This shows that, when the length of the granular pile-anchor was increased from 500 mm to 750 mm and 1000 mm, the percentage increase in the uplift load required for an upward movement of 25 mm was 33.3% and 55.5% respectively.
Fig. 6.1 Schematic Diagram of the Uplift Load Test
Plate 6.1 Pullout load arrangement
Fig. 6.3 shows the pullout behaviour of granular pile-anchors of 1000 mm length but of diameters varying as 100, 150 and 200 mm. The curves in the figure reflect the effect of diameter of granular pile-anchor (GPA). All the curves in the figure show that the failure pullout load increased with the increasing diameter of the granular pile-anchor. The applied upward load was observed to increase with increasing diameter of granular pile-anchor at all stages of the test as the resistance to uplift increased with increasing surface area of the pile-soil interface. For example, the uplift load required to be applied on the granular pile-anchor to cause an upward movement of 25 mm was respectively 11, 11.5 and 14.2 kN for granular pile-anchors (GPA) of diameter 100, 150 and 200 mm. This shows that, when the diameter of the granular pile-anchor was increased from 100 mm to 150 mm and 200 mm, the percentage increase in the uplift load required for an upward movement of 25 mm was 5% and 30%. These results pertain to granular pile-anchors of length 1000 mm.

Table 6.1 shows the comparison of loads for theoretical and field load tests in pullout on granular pile-anchors embedded in expansive clay beds. Also comparison is made between the ultimate pullout load computed with and without the effect of lateral swell pressure component (equation 2.29) and the % variation of observed failure pullout load with respect to the computed ultimate pullout load for different granular pile-anchors is presented. The failure pullout load presented in this table is obtained by adding the pullout caused by the swell pressure exerted on the footing plate (2.5 $d_{sp}$) in the saturation process to the actual pullout load from the pullout load test conducted after complete saturation. For example, the observed failure pullout load for the granular pile-anchor
GPA) of length 1000 mm and diameter 200 mm was 43.1 kN where as the computed ultimate pullout load with lateral swell pressure component was 63 kN with a % variation of 31.6. It can be seen that for the same granular pile-anchor the computed ultimate pullout load without the lateral swell pressure component was 4.87 kN. This clearly shows the effect of the lateral swell pressure which is 58.13 kN, a contribution of 92 % of the total ultimate pullout load. This feature of utilizing swell pressure, which is considered as a negative factor, in a positive manner makes the granular pile-anchor foundation system a very novel and effective foundation practice in expansive soils.

Fig. 6.4 shows the variation of failure pullout load (kN) with the $l_{gp}/d_{gp}$ ratio of granular pile-anchors (GPA). The curves present the data for different lengths of the granular pile-anchors. For a given $l_{gp}/d_{gp}$ ratio the failure pullout load increased with increasing length of the granular pile-anchor. This is attributed to the increase in the pullout resistance with increasing surface area of the granular pile-anchor. For example, the failure pullout load for granular pile-anchors (GPA) of $l_{gp}/d_{gp}$ ratio of 5 was respectively 5, 11 and 15 kN, when length of granular pile-anchor changed as 500, 750 and 1000 mm. Similarly, for a given length of the granular pile-anchor (GPA), the failure pullout load increased with decreasing $l_{gp}/d_{gp}$ ratio. This is understandable because $l_{gp}/d_{gp}$ ratio decreases with increasing diameter of granular pile-anchor for a given length. Increasing diameter increases the surface area and consequently uplift resistance and results in increased failure pullout load. For example, the failure pullout load of granular pile-anchor of length 1000 mm was 11, 13 and 15 kN where the $l_{gp}/d_{gp}$ ratio was 10, 6.67 and 5 respectively (for diameters 100, 150 and 200 mm).
<table>
<thead>
<tr>
<th>( l_g ) (mm)</th>
<th>( d_g = 100 \text{ mm} )</th>
<th>( d_g = 150 \text{ mm} )</th>
<th>( d_g = 200 \text{ mm} )</th>
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<tr>
<td></td>
<td>( P_{db} ) (kN)</td>
<td>( P_{cu} ) (kN)</td>
<td>( \nu ) (%)</td>
</tr>
<tr>
<td>500</td>
<td>15.7</td>
<td>1.2</td>
<td>12.1</td>
</tr>
<tr>
<td>750</td>
<td>23.4</td>
<td>1.8</td>
<td>15.1</td>
</tr>
<tr>
<td>1000</td>
<td>31.5</td>
<td>2.4</td>
<td>18.1</td>
</tr>
</tbody>
</table>

\( P_{db} \) - Computed ultimate pullout load with lateral swell pressure component, (kN)

\( P_{cu} \) - Computed ultimate pullout load without lateral swell pressure component, (kN)

\( P_{so} \) - Observed failure pullout load, (kN)

\( \nu \) - Percentage variation of observed failure pullout load with respect to the computed ultimate pullout load, (%)
An extensive study conducted on laboratory granular pile-anchors (GPA) embedded in expansive clay beds (Phanikumar, 1997; Phanikumar et al. 2004) revealed that granular pile-anchor foundation system could be effective in reducing heave of foundations and improving the engineering behaviour of expansive clay beds. Heave behaviour, compressive load behaviour and pullout load behavior were studied in a model study on laboratory scale granular pile-anchors embedded in expansive clay beds. The range of the \( \frac{l_{gp}}{d_{gp}} \) ratio of the laboratory scale granular pile-anchors was within 6 and 16.67. The diameter of the granular pile-anchors varied as 30, 40 and 50 mm. For each diameter of the granular pile-anchor the length was varied as 300, 400 and 500 mm in the laboratory scale test programme. Compressive load tests as well as pullout load tests were performed after complete saturation of the reinforced expansive clay beds.

Fig. 6.5 shows, by comparison, the pullout behavior of the laboratory scale granular pile-anchor and field scale granular pile-anchor. In both the cases, the granular pile material was compacted to a relative density of 70%. Similarly the \( \frac{l_{gp}}{d_{gp}} \) ratio of granular pile-anchor in both the cases was equal to 10. While the diameter and length of laboratory scale granular pile-anchor were 30 and 300 mm, those of the field scale granular pile-anchor were 100 and 1000 mm respectively. The thickness of the expansive clay bed was equal to the length of the granular pile-anchor (GPA) in both the cases. The curves in the figure show that the uplift load (kN) required to be applied for any given upward movement (mm) of the granular pile-anchor was significantly higher in the field.
scale granular pile-anchor (GPA) than that in the case of laboratory scale granular pile-anchor (GPA). For example, the uplift load required to cause an upward movement of 25 mm in the case of laboratory scale granular pile-anchor was equal to 0.35 kN. However, in the case of field scale granular pile-anchor, the uplift load required to cause the same amount of upward movement of 25 mm was found to be 11 kN, which indicated a huge variation in the uplift load from laboratory scale to field scale. This clearly suggests that field scale study of granular pile-anchors (GPA) alone gives a better picture of the behavior of granular pile-anchors in expansive clay beds in situ in view of the enormous difference in the behavior of laboratory scale granular pile-anchors and field scale granular pile-anchors.

Fig. 6.6 shows, by comparison, the variation of failure pullout load with \( \frac{l_{sp}}{d_{sp}} \) ratio of granular pile-anchors in laboratory scale study and field scale study. The data pertain to three field scale granular pile-anchors (GPA) of length 1000 mm (diameter = 100, 150 and 200 mm) and three laboratory scale granular pile-anchors (GPA) of length 500 mm (diameter = 30, 40 and 50 mm). The expansive clay beds in both the cases were compacted at a placement water content of 15% and dry unit weight of 14 kN/m\(^3\). All the granular piles were compacted to a relative density of 70%. The failure pullout load for field scale granular pile-anchors was much higher than that for laboratory scale granular pile-anchors. This was irrespective of the l/d ratio. As was discussed previously, the field scale granular pile-anchor resulted in significant pullout capacity because of the increase in surface area of the granular pile-anchor and the consequent increase in uplift resistance. The lateral swell pressure of expansive clay bed in situ, which confines the
granular pile-anchor (GPA), is also significantly high compared to that expected in the laboratory scale expansive clay bed. For example, the failure pullout load of field scale granular pile-anchor was 10 kN as against 0.90 kN in the case of laboratory scale granular pile-anchor for the same $l_{gp}/d_{gp}$ ratio of 10. The failure pullout loads of the three field scale granular pile-anchors ($l_{gp} = 1000$ mm) having $l_{gp}/d_{gp}$ ratios of 5, 6.67 and 10 were 14.7, 12 and 10 kN respectively. The values of failure pullout loads of the three laboratory scale granular pile-anchors ($l = 500$ mm) having $l/d$ ratios of 10, 12.50 and 16.67 were 0.90, 0.89 and 0.85 kN respectively.

6.6 Group effect on pullout behavior of granular pile-anchor

A granular pile-anchor of length 1000 mm and diameter 150 mm was tested under pullout load when single and when under group effect. The group granular pile-anchor test was described in the previous sections. Fig. 6.7 shows, by comparison, the pullout behavior of the granular pile-anchor when tested single and when tested under group effect. The granular pile-anchor under group effect resulted in increased uplift load for a given upward movement in comparison to that of the granular pile-anchor when tested single. This is because of the influence of the granular pile-anchors in the group on the test granular pile-anchor. As heave of the expansive clay bed was reduced significantly on the installation of group of granular pile-anchors, there was not much reduction in the weight of the expansive clay bed. As a result the pile-soil interface friction would be more than in the case of the single granular pile-anchor. This also resulted in a lateral swell pressure (confining the test granular pile-anchor radially) than in the
case of a single granular pile-anchor. The uplift load required to be applied on the granular pile-anchor to cause an upward movement of 25 mm was 13.7 kN when tested under group effect as against an uplift load of 11.25 kN for the same amount of upward movement of 25 mm when tested single. This indicated a percentage increase of 22.22% in the applied uplift load when the granular pile-anchor was tested under group effect.

The failure pullout load of the granular pile-anchor when tested under group was 18 kN as against a failure pullout load of 12 kN for the granular pile-anchor when tested single, indicating a % improvement of 50 in the failure pullout load.

A summary of the results obtained in the field pullout load test programme on granular pile-anchors (GPA) embedded in expansive clay beds is presented in Table 6.2. Failure pullout loads (kN) for different granular pile-anchors are presented. A typical view of the failure of the granular pile-anchor in pullout is shown in the Plate 6.2. A comparison is made between the failure pullout loads of various granular pile-anchors by showing the percentage increase in the pullout load with respect to that for the granular pile-anchor of least surface area ($l_{gp} = 500$ mm and $d_{gp} = 100$ mm). When the length of the granular pile-anchor increased from 500 mm to 750 mm and 1000 mm, the percentage increase in the pullout load was 60% and 100% when diameter was equal to 100 mm, and 160% and 194% when diameter was equal to 200 mm. The failure pullout loads of identical granular pile-anchors ($l_{gp} = 1000$ mm and $d_{gp} = 150$ mm) studied when single and when under the group effect are also presented. When single, the granular pile-anchor resulted in a failure pullout load of 12 kN. However, the group effect resulted in an increased failure pullout load of 18 kN, showing an improvement of 50%.
6.7 Conclusions

An extensive field-test program was performed to study the pullout load response of granular pile-anchors (GPA) embedded in expansive clay beds in situ. Granular pile-anchor foundations (GPAF), which are chiefly a tension-resistant foundation technique devised for counteracting heave of expansive clay beds, are basically subjected to uplift loads. Hence, field-scale pullout load tests were conducted in situ to establish the technique of GPAF as an efficacious foundation practice in expansive clay beds. The test program studied pullout load-upward movement behavior of granular pile-anchors embedded in expansive clay beds. The main conclusions drawn from the field tests are as follows:

1. The upward load required to be applied on the granular pile-anchor to cause a given upward movement increased with increasing length of granular pile-anchor. For granular pile-anchors (GPA) of length 500, 750 and 1000 mm, the uplift load required to cause an upward movement of 25 mm in the granular pile-anchor was respectively 9, 12 and 14 kN. When the length of the GPA was increased from 500 mm to 750 mm and 1000 mm, the percentage increase in the uplift load required for an upward movement of 25 mm was 33.3% and 55.5% respectively.

2. The uplift load or failure pullout load increased with the increasing diameter of the granular pile-anchor also. This is because the resistance to uplift increased with increasing surface area of the pile-soil interface consequent upon increase in
the diameter. The uplift load required to be applied on the granular pile-anchor (\( l = 1000 \text{ mm} \)) for an upward movement of 25 mm was respectively 11, 11.5 and 14.2 kN for granular pile-anchors (GPA) of diameter 100, 150 and 200 mm. This indicates that the percentage increase in the uplift load required for an upward movement of 25 mm was 5% and 30% when the diameter of the GPA was increased from 100 mm to 150 mm and 200 mm.

3. For a given \( l_{\text{gp}}/d_{\text{gp}} \) ratio the failure pullout load increased with increasing length of the granular pile-anchor. The failure pullout load for granular pile-anchors (GPA) of \( l_{\text{gp}}/d_{\text{gp}} \) ratio of 5 was respectively 5, 11 and 15 kN, when length of granular pile-anchor changed as 500, 750 and 1000 mm. Similarly, for a given length of the granular pile-anchor (GPA), the failure pullout load increased with decreasing \( l_{\text{gp}}/d_{\text{gp}} \) ratio. Increasing diameter increases the surface area and consequently the uplift resistance and results in increased failure pullout load. The failure pullout load of granular pile-anchor of length 1000 mm was 11, 13 and 15 kN where the \( l_{\text{gp}}/d_{\text{gp}} \) ratio was 10, 6.67 and 5 respectively (for diameters 100, 150 and 200 mm).

4. The uplift load (kN) required to be applied for any given upward movement (mm) of the field scale granular pile-anchor (GPA) was significantly higher than that in the case of laboratory scale granular pile-anchor. This was irrespective of the \( l_{\text{gp}}/d_{\text{gp}} \) ratio. For example, the failure pullout load of field scale granular pile-anchor was 10 kN as against 0.90 kN in the case of laboratory scale granular pile-anchor for the same \( l_{\text{gp}}/d_{\text{gp}} \) ratio of 10. The uplift load required to cause an upward
movement of 25 mm in the case of laboratory scale GPA was equal to 0.35 kN. whereas, in the case of field scale granular pile-anchor, the uplift load required for the same amount of upward movement of 25 mm was 11 kN.

5. The theoretically predicted ultimate resistance to pullout of the GPA tallied very closely with in situ failure pullout load in most of the cases. The percentage variation was between -23.4 to +42.6. This is within tolerable limits.

6. The granular pile-anchor under group effect resulted in increased uplift load for a given upward movement in comparison to that of the granular pile-anchor when tested single. The uplift load required to be applied on the granular pile-anchor to cause an upward movement of 25 mm was 13.7 kN when tested under group effect as against an uplift load of 11.25 kN for the same amount of upward movement of 25 mm when tested single. The failure pullout load of the granular pile-anchor when tested under group was 18 kN as against a failure pullout load of 12 kN for the granular pile-anchor when tested single, indicating an improvement of 50% in the failure pullout load.
Table 6.2 Comparison of failure uplift load (kN) for different cases

<table>
<thead>
<tr>
<th>Description</th>
<th>Uplift load (kN)</th>
<th>Increase in uplift load with respect to that of GPA of length 500 mm and diameter 100 mm (%)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Diameter = 100 mm</td>
<td>150 mm</td>
</tr>
<tr>
<td>Single granular pile-anchor (GPA)</td>
<td>Length = 500 mm</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>750 mm</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>1000 mm</td>
<td>10</td>
</tr>
<tr>
<td>Single GPA tested under group action of five GPAs (l = 1000 mm; d = 150 mm)</td>
<td>18</td>
<td>50</td>
</tr>
</tbody>
</table>
Plate 6.2 A view of the pullout failure of the granular pile-anchor
Fig 6.2 Pullout behaviour of granular pile-anchors of diameter 250 mm
Fig. 6.3 Pullout behavior of granular pile-anchors of 1000 mm length
Fig. 6.4 Variation of failure pullout load with \( \frac{l_{pa}}{d_{pa}} \) ratio of granular pile-anchor.
Fig. 6.5 Comparison of pullout behavior of laboratory scale and field scale granular pile-anchors ($l_p/d_p = 10; D_1, 70\%$)
Failure pullout load (kN) for field scale (GPa) vs. laboratory scale (GPa)
Fig. 6.7 Pullout behavior of single granular pile-anchor and group of granular pile-anchors (diameter = 150 mm and length = 1000 mm)