**Swell-shrink Behaviour of GPA: Reinforced Expansive Clay Beds**

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**ABSTRACT**

Among various innovative foundation techniques suggested for expansive soils, granular pile-anchors (GPA) are the latest and one of the most successful techniques. GPAs are a modified form of granular piles, wherein an anchor (an anchor rod with an anchor plate) is provided. Laboratory model tests and field scale tests conducted on GPAs yielded excellent results. About 95% of heave of expansive clay bed was reduced on reinforcing them with GPAs. Shrinkage behaviour of GPA-reinforced expansive clay beds has not been studied so far. This paper presents experimental test data on GPA-reinforced expansive clay beds, which were initially inundated with water and later subjected to pullout load as they were allowed to shrink.

**1. INTRODUCTION**

Expansive soils swell on imbibition of water and shrink on evaporation of water (Chen, 1988). As a result, lightly loaded civil engineering structures built in expansive clays are severely damaged. For mitigating these swell-shrink problems, many innovative foundation techniques have been suggested. Stabilization with various additives, sand cushion (Satyanarayana, 1966), cohesive-non-swelling (CNS) layer (Katti, 1978), belled piers and drilled piers (Chen, 1988) are useful foundation techniques. Under-reamed piles (Sharma et al. 1978) are tension-resistant foundations with enlarged bottom, which act as anchors.

Granular pile-anchors (GPA), which are conventional granular piles with an anchor within, can also be effectively used for reducing heave of expansive clay beds (Phanikumar, 1997). The behaviour of GPA during shrinkage has not been studied so far. This paper presents pullout test data on GPA-reinforced expansive clay beds, initially inundated with water and later allowed to undergo shrinkage.

**2. EXPERIMENTAL PROGRAMME**

The expansive soil used in the investigation had a free swell index (FSI) of 250%. By its LL and PI, the soil was classified as CH. The granular material used for the installation of GPAs was a mixture of 20% granite stone aggregate with particle size ranging between 6 mm and 10 mm and 80% coarse sand with size varying between 2.4 mm and 4.8 mm. The dry unit weight and initial water content of the expansive clay bed were kept constant at 13 kN/m$^3$ and 10% respectively. The thickness of the clay bed and the length of the GPAs ($l_{gp}$) were both equal to 200 mm. The diameter ($d_{gp}$) of the GPA was kept constant at 40 mm and the relative density ($D_{r}$) of the granular material at 60%.

**Tests Conducted and Quantities Determined**

Pullout tests were conducted on GPA-reinforced clay beds in test tanks of size 250 mm x 250 mm x 400 mm height. Expansive clay was air-dried, pulverised and passed through 4.75 mm sieve. For compaction of GPA-reinforced expansive clay beds, a casing pipe of diameter equal to that of granular pile-anchor (GPA) was held vertically on the top of bottom sand layer. An assembly of anchor rod and anchor plate fastened to each other was inserted into the casing pipe with the anchor plate resting on top of the bottom sand layer. Expansive clay was poured into the tank and compacted with a rammer in 4 layers of 50 mm each to give the required uniform dry unit weight. Granular material was poured into the casing pipe and compacted in 4 layers of 50 mm each to a uniform relative density of 60%. Compaction of the clay bed and the granular pile-anchor continued till the expansive clay bed and GPA reached a height of 200 mm. Casing pipe was withdrawn gradually while the process of compaction continued. After compaction, the expansive clay bed was inundated with water. Heave of the clay bed was recorded with a dial gauge placed on a surface footing plate of diameter 180 mm. After equilibrium heave, the clay bed was subjected to shrinkage for different periods like 90 days, 60 days and 30 days. Pilot studies conducted earlier indicated that these shrinkage periods gave respective equilibrium water contents of 10%, 20% and 30% of GPA-reinforced clay bed subjected to shrinkage.
Pullout loads were applied on the GPAs. The initial seating load applied was 7.18 N. Thereafter, ten increments of 28 N were applied in the GPAs. Upward movement of the GPAs was recorded with a dial gauge fitted to the anchor rod of the GPA. Resistance to upward movement of GPA would be mobilised through shear parameters of GPA-clay interface. These shear parameters were measured by performing shear box tests on GPA material compacted in the bottom half of the box corresponding to the relative density of 60% and respective expansive clay corresponding to water contents of 10%, 20% and 30% compacted in the upper half of the box. Interface shear parameters (c’ and \( \phi’ \)) were obtained.

3. DISCUSSION OF TEST RESULTS

Fig 1 shows the failure envelopes of varying interfaces. As shrinkage period increased or as water content of the clay bed decreased, the failure envelopes shifted up giving rise to increased interface friction angle (\( \phi’ \)) and decreased cohesion (c’).

![Fig. 1: Failure Envelopes](image)

Fig 1: Failure Envelopes

Fig 2: Shows Pullout Load-Deformation Curves for GPAs Subjected to Varying Periods of Shrinkage (30 days, 60 days and 90 days) that Resulted in Respective Equilibrium Water Content of 30%, 20% and 10%.

![Fig. 2: Pullout Curves](image)

Fig. 2: Pullout Curves

Pullout load (N) required to be applied on the GPAs for a given upward movement increased with increasing periods of shrinkage. Pullout curves of GPAs subjected to shrinkage of longer periods in comparison to those of GPAs subjected to shrinkage of shorter period. The GPA subjected to shrinkage for 90 days underwent an upward movement of 0.70 mm and GPAs subjected to shrinkage of 30 days an upward movement of 1.0 mm. With increasing shrinkage, resistance to uplift load increased. Pullout curves of GPAs allowed for longer shrinkage resulted in higher stiffness. The stiffness of GPA at an applied load of 150N was respectively 682 N/mm, 484 N/mm and 429 N/mm for shrinkage periods of 90 days, 60 days and 30 days. Pullout capacity of the GPAs increased with increased shrinkage period. As shrinkage period increased, there was an increase of 33% in pullout load (N) because interface friction angle increased. Pullout behaviour was governed more by interface friction angle than by cohesion. Table 2 summarises the test results. The percentage variation in pullout load (N) for a given upward movement of 0.50mm was more in respect of interface friction angle (\( \phi’ \)) than in respect of interface cohesion (c’). The percentage variation was found to be 26% in respect of interface cohesion.

<table>
<thead>
<tr>
<th>Water Content (w)</th>
<th>Cohesion (kPa)</th>
<th>Interface Friction Angle (Degrees)</th>
<th>Pullout Load (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>16</td>
<td>29.54</td>
<td>238.18</td>
</tr>
<tr>
<td>20%</td>
<td>19</td>
<td>25.33</td>
<td>213.68</td>
</tr>
<tr>
<td>30%</td>
<td>21</td>
<td>21.47</td>
<td>186.38</td>
</tr>
</tbody>
</table>

4. CONCLUSIONS

Pullout load (N) required to be applied on the GPAs for a given upward movement increased with decreasing water content or increasing periods of shrinkage. Interface friction angle (\( \phi’ \)) increased and interface cohesion (c’) decreased with shrinkage period. Pullout behaviour of GPAs subjected to shrinkage depends more on interface friction angle than on interface cohesion.

REFERENCES


