Uplift resistance of granular anchors in clay under undrained condition

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Content of presentation

• What are granular anchors?
• Experimental field tests in Dublin Boulder Clay
• Investigation of load–displacement behaviour and modes of failure
• Method of analysis for determination of ultimate pullout capacity for undrained (short-term) loading condition
• Summary
Experimental field tests in Dublin Boulder Clay

Test site: TCD Sports Grounds, Santry, Dublin
~1.8m depth Brown Dublin Boulder Clay (DBC) overlying Black DBC, groundwater level at ~1.8m depth

All of the anchors were installed in the Brown DBC formation

Table 1: Anchor installation details.

<table>
<thead>
<tr>
<th>Anchor number</th>
<th>Temporary casing required (Yes/No)</th>
<th>Borehole diameter (m)</th>
<th>Effective anchor length (m)</th>
<th>Anchor aspect ratio, L/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA1</td>
<td>Y</td>
<td>0.219</td>
<td>1.30</td>
<td>5.9</td>
</tr>
<tr>
<td>GA2</td>
<td>Y</td>
<td>0.219</td>
<td>0.96</td>
<td>4.4</td>
</tr>
<tr>
<td>GA3</td>
<td>N</td>
<td>0.200</td>
<td>0.50</td>
<td>2.5</td>
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<tr>
<td>GA4</td>
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<td>0.219</td>
<td>1.00</td>
<td>4.6</td>
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<tr>
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<td>0.168</td>
<td>1.47</td>
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<td>0.45</td>
<td>3.0</td>
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<td>GA8</td>
<td>Y</td>
<td>0.168</td>
<td>1.62</td>
<td>9.6</td>
</tr>
</tbody>
</table>

Fig. 1: Granular anchor construction

Boreholes formed using light cable-percussion drilling rig
Fig. 2: Schematic of TCD loading arrangement (Sivakumar et al., 2013)

Fig. 3: Load resistance and ground heave against axial displacement of anchors. P and H: pullout force and heave data plots respectively (O’Kelly et al., 2013)
• Short anchors: visual observation of surface of gravel backfill lifting in addition to substantial heave of surrounding ground => **failure in shaft resistance**

• For longer anchors (L/D > ~ 7), insignificant vertical displacement of ground surface even though anchors themselves had displaced by more than 100 mm => **failure by localised end bulging of column** (i.e. structural failure of column itself)

**PLAXIS 2D simulations:**

For bulging mechanism, enlargement in diameter at base of granular column ~10% of its original diameter at anchor displacement of D/2, with bulging zone over a length of 2–3xD (Sivakumar et al. 2013).
Method of analysis for the determination of ultimate pullout capacity of granular anchors presented by Sivakumar et al. (2013):

In analogue to rigid piles, ultimate resistance of granular anchor in *shaft resistance* given by

\[ T_F = \pi DL \alpha s_u + \frac{\pi D^2 L \gamma_g}{4} \]

\( \alpha \), adhesion factor; \( \gamma_g \), unit weight of granular backfill.

*Local bulging capacity* of granular column given by

\[ T_B = \frac{\pi D^2 \sigma_v}{4} \]

with \( \sigma_v = \left[ \frac{1 + \sin \phi'_g}{1 - \sin \phi'_g} \right] \left[ \sigma_{vc} + N^*_c s_u \right] \) (after Hughes and Withers (1974))

\( \sigma_{vc} \), overburden pressure caused by surrounding soil at point of bulging; \( \phi'_g \), angle of shearing resistance of granular column; \( N^*_c \), bearing capacity factor

with \( N^*_c = 1 + \log \frac{G}{s_u} \) (Gibson and Anderson, 1961)

\( G \), shear modulus of soil
\[ P^* = \frac{4P_{measured}}{\pi D^2 s_u} \]

Shaft friction capacity component \((\alpha = 0.9)\)

Local bulging capacity

Deviations accounted for by inherent variability/strength heterogeneity of the test area

Fig. 6: Non-dimensional ultimate pullout capacity against aspect ratio of anchor (O’Kelly et al. 2013).
Summary

• Granular anchors (GAs) having a larger surface area, achieved by increasing anchor length and (or) diameter, mobilized greater ultimate pullout capacity

• Short-term capacity mobilized in shaft resistance and localized end-bulging for short and deep GAs respectively

• New method of analysis for determination of ultimate pullout capacity presented and verified experimentally by Sivakumar et al. (2013), with dominant mode of failure controlled by L/D ratio.

• GAs having L/D > 7 fail by bulging and are particularly effective in transferring applied loads to strata at depth

• Advantages of granular anchors include short construction time, lower costs, as well as the ability to resist applied loading immediately after construction.
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References: