Uplift resistance of granular anchors in clay under undrained condition

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Workshop on Soil-Structure Interaction

22nd February 2013

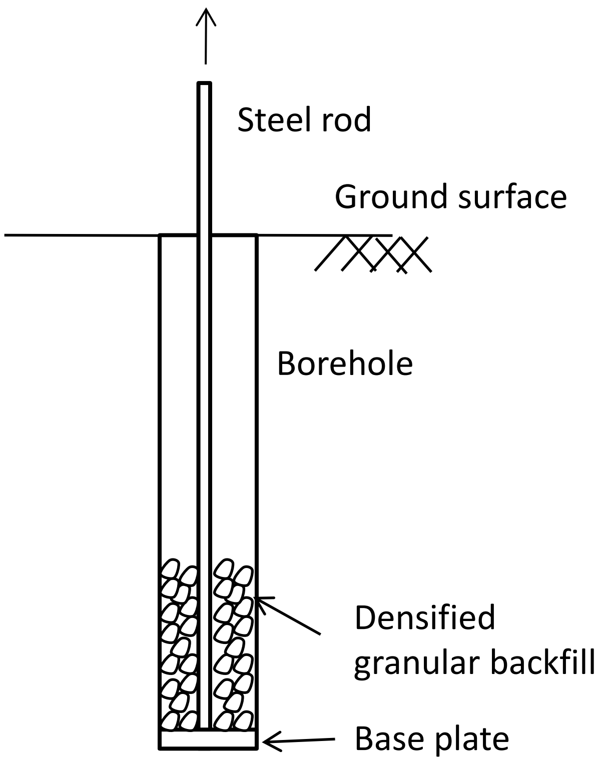
Trinity College Dublin

http://notesproject.webs.com/programme.htm

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

Fig. 1: Granular anchor construction



Boreholes formed using light cable-percussion drilling rig

Experimental field tests in Dublin Boulder Clay

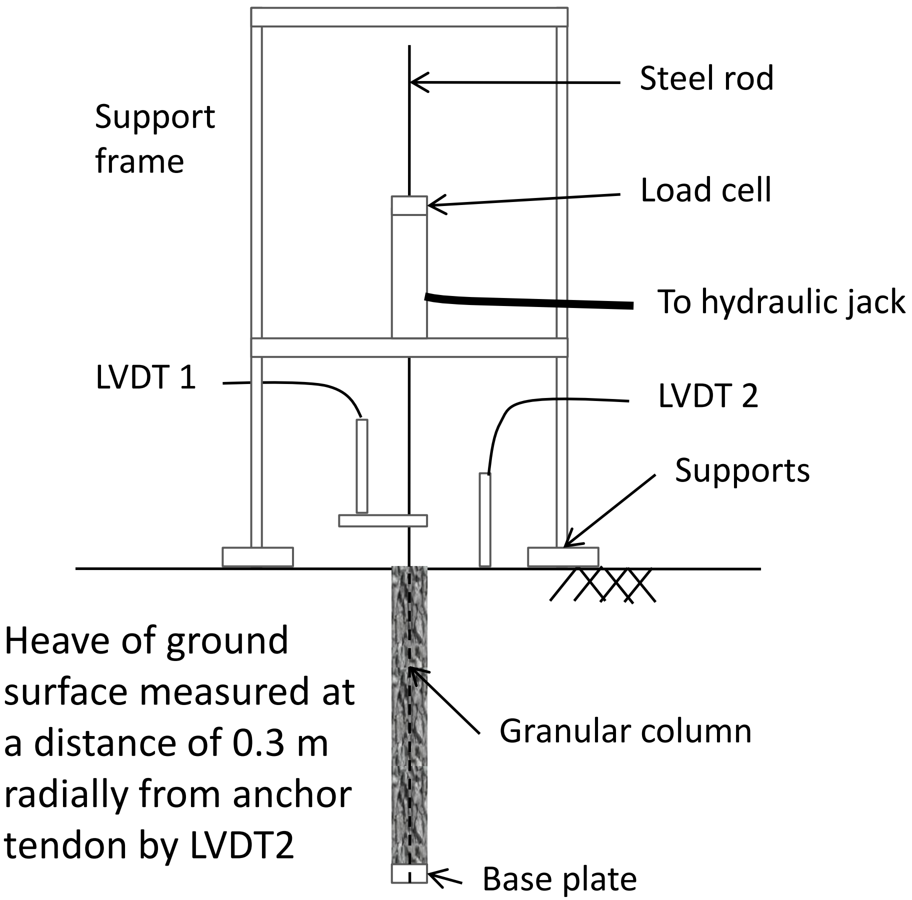
Test site: TCD Sports Grounds, Santry, Dublin
~1.8m depth Brown Dublin Boulder Clay (DBC) overlying Black DBC, groundwater level at ~1.8m depth

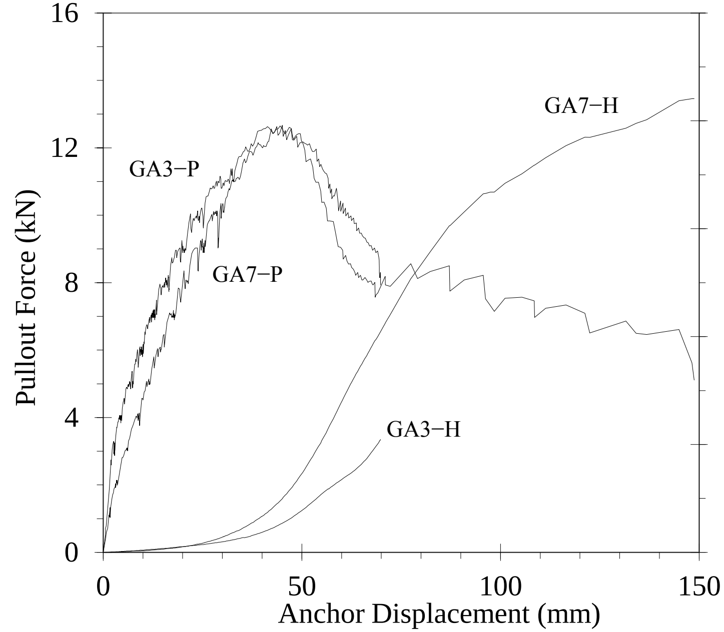
All of the anchors were installed in the Brown DBC formation

Table 1: Anchor installation details.

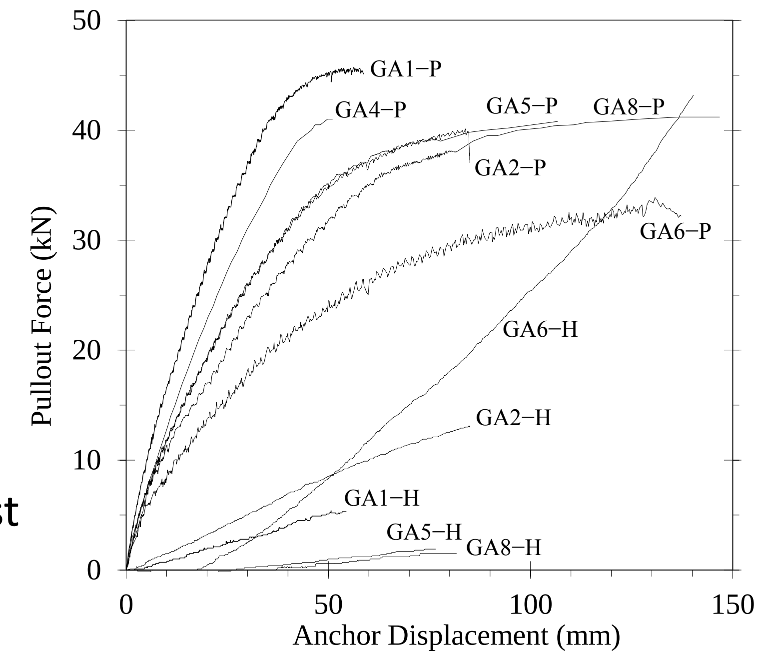
Anchor number	Temporary casing required (Yes/No)	Borehole diameter (m)	Effective anchor length (m)	Anchor aspect ratio, L/D
GA1	Y	0.219	1.30	5.9
GA2	Y	0.219	0.96	4.4
GA3	N	0.200	0.50	2.5
GA4	Y	0.219	1.00	4.6
GA5	Y	0.168	1.47	8.7
GA6	Y	0.168	0.80	4.8
GA7	N	0.150	0.45	3.0
GA8	Y	0.168	1.62	9.6

Fig. 2: Schematic of TCD loading arrangement (Sivakumar et al., 2013)





(a) Short anchors



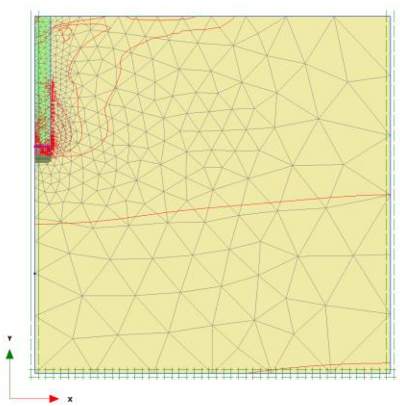
(b) Longer anchors

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**

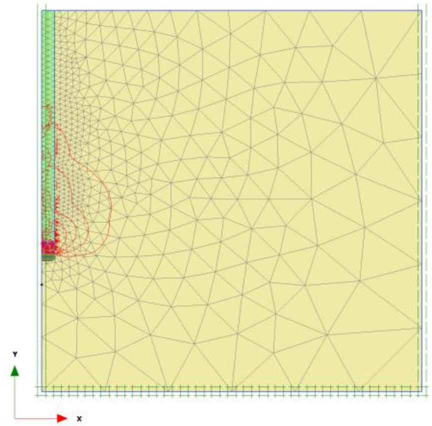
- For longer anchors (L/D > ~ 7), insignificant vertical displacement of ground surface even though anchors themselves had displaced by more than 100 mm => **failure by localised end bulging of column** (i.e. structural failure of column itself)

PLAXIS 2D simulations:



(a) GA4 (L/D = 4.6).

No increase in radial stress acting over upper half of column failing in end bulging



(b) GA8 (L/D = 9.6).

Fig. 4: Predicted radial stress contours at ultimate pullout capacity (O'Kelly et al. 2013)

Mohr-Coulomb points and tension-cutoff points indicated by solid and hollow boxes

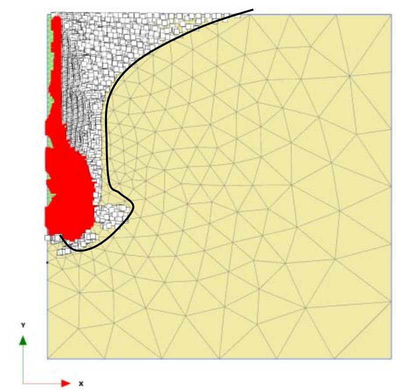


Fig. 5: Predicted extent of plastic zones at ultimate capacity (GA8, L/D = 9.6).

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

$$T_F = \pi D L \alpha\, s_{\mathrm{u}} + \frac{\pi D^2 L \gamma_g}{4}$$

α, adhesion factor; γ_{g}, unit weight of granular backfill.

Local bulging capacity of granular column given by $T_B = \frac{\pi D^2 \sigma_v}{4}$

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

σ_{vc}, overburden pressure caused by surrounding soil at point of bulging;
ϕ'_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

$$P^* = 4P_{measured} / \pi D^2 s_u$$

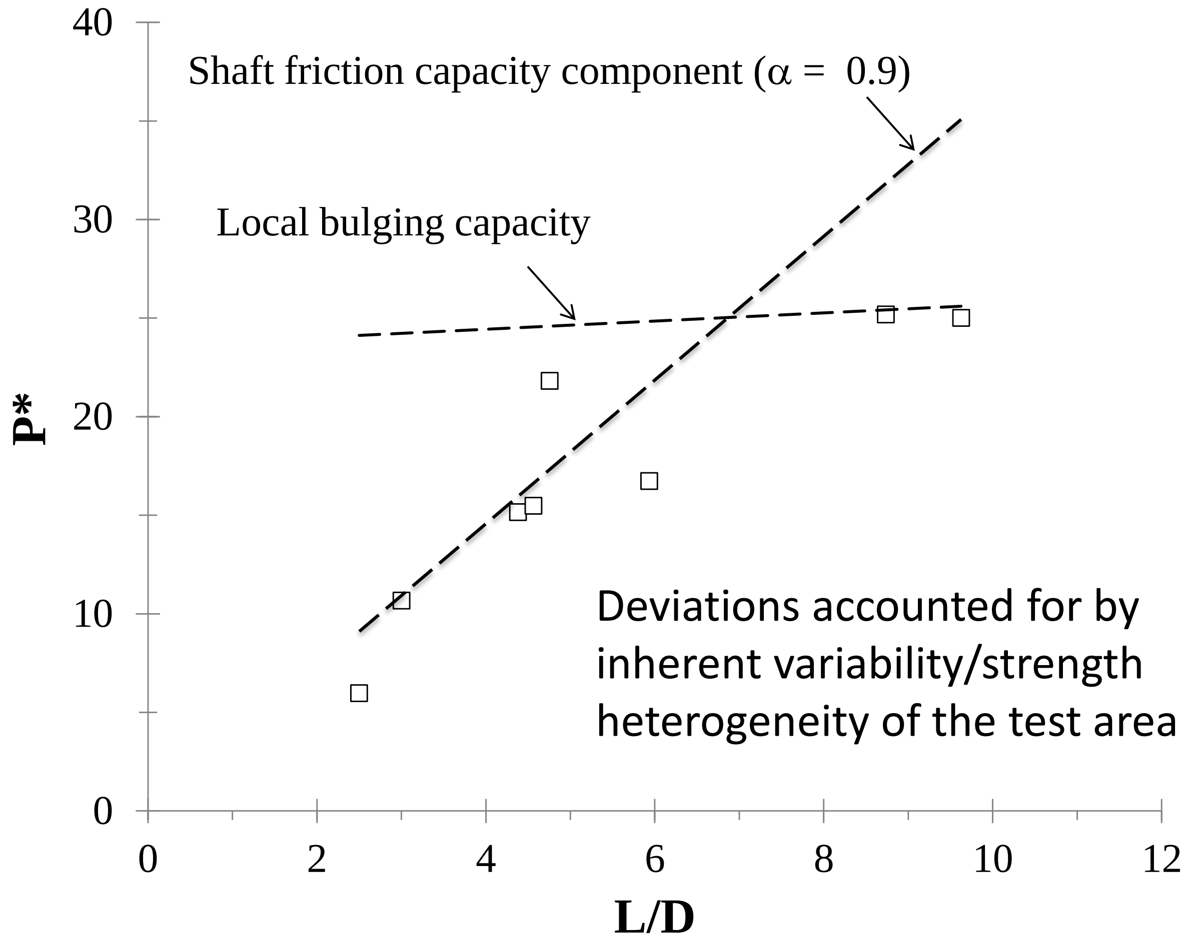


Fig. 6: Non-dimensional ultimate pullout capacity against aspect ratio of anchor (O'Kelly et al. 2013).

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.

THANK YOU

Acknowledgements:
The authors thank Martin Carney and Eoin Dunne (Department of Civil, Structural and Environmental Engineering, TCD) for their assistance in performing the anchor tests at the Santry test site. The numerical analysis element of the paper was performed under the Marie Curie IAPP project NOTES (Grant No. PIAP-GA-2008-230663)

References:

- O’Kelly B.C., Brinkgreve R.B.J. and Sivakumar V. 2013. Experimental and numerical studies of the vertical uplift resistance of granular anchors in clay under undrained condition. Currently under review with Soils and Foundations.
- Sivakumar V., O'Kelly B.C., Madhav M.R., Moorhead C. and Rankin B. (2013) Granular anchors under vertical loading – axial pull. Canadian Geotechnical Journal, 50(2): 123−132 . DOI 10.1139/cgj-2012-0203