Implementation of pile design in the UK

David Beadman
Byrne Looby Partners

Implementation of pile design in the UK

Pile design in the UK
Static load tests
Ground test results
- method of profiles
- alternative method
Alternative proposal
Conclusions
### Pile design in the UK

<table>
<thead>
<tr>
<th>Typical pile type</th>
<th>Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous flight auger piles (cfa)</td>
<td>300-1200mm</td>
</tr>
<tr>
<td>Bored piles</td>
<td>600-2400mm</td>
</tr>
<tr>
<td>Minipiles</td>
<td>140-600mm</td>
</tr>
<tr>
<td>Driven precast / driven cast-in-situ / driven tubes</td>
<td></td>
</tr>
</tbody>
</table>

Design largely by specialist contractors under competitive conditions
Piles designed for each different load to nearest 0.5m (occasionally to nearest 0.1m)
Pile design based on characteristic ground strength parameters

---

### Factors of Safety before Eurocode 7

<table>
<thead>
<tr>
<th>Preliminary Pile Load Test</th>
<th>Requirements for load testing of working piles (1.5 x working load)</th>
<th>Factor of Safety F</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No load testing on working piles</td>
<td>3.0</td>
</tr>
<tr>
<td>No</td>
<td>Load testing on 1% of working piles</td>
<td>2.5</td>
</tr>
<tr>
<td>Yes</td>
<td>Load testing on 1% of working piles</td>
<td>2.0</td>
</tr>
</tbody>
</table>

LDSA (1999) Table 1
Eurocode 7 in the UK

Pile design to Eurocode 7 and the UK National Annex
Andrew J. Bond and Brian Simpson (2009-10)


UK National Annex Design Approach 1

For axially loaded piles and anchors
Combination 1: A1 “+” M1 “+” R1
Combination 2: A2 “+” (M1 or M2) “+” R4

Combination 2
M1 - resistances of piles or anchors
M2 - unfavourable actions on piles
e.g. negative skin friction

We all had the opportunity to comment on these proposals – unfortunately most of us didn’t!

Why do we not factor the soil strength as for other structures?

Combination 1: A1 “+” M1 “+” R1
Combination 2: A2 “+” M2 “+” R1
National Annex Table A.NA.7

Partial resistance factors ($\gamma_R$) for bored piles for the STR and GEO limit states

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Symbol</th>
<th>Set</th>
<th>R4 without explicit verification of SLS$^A$</th>
<th>R4 with explicit verification of SLS$^A$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>$\gamma_b$</td>
<td>1.0</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Shaft (compression)</td>
<td>$\gamma_s$</td>
<td>1.0</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Total/combined (compression)</td>
<td>$\gamma_t$</td>
<td>1.0</td>
<td>2.0</td>
<td>1.7</td>
</tr>
<tr>
<td>Shaft in tension</td>
<td>$\gamma_{s,t}$</td>
<td>1.0</td>
<td>2.0</td>
<td>1.7</td>
</tr>
</tbody>
</table>

“Explicit verification of the SLS” - load tests (preliminary and/or working) carried out on more than 1% of the constructed piles to loads not less than 1.5 times the representative load for which they are designed.

Setting R1 factors to 1.0 means that Combination 1 is not critical for pile length.

Terminology ‘explicit verification of SLS’ is rather clumsy.

Static load tests 7.6.2.2 (7)P

$$R_{c,k} = \min\left\{(R_{c,m})_{\text{mean}}/\xi_1,(R_{c,m})_{\text{min}}/\xi_2\right\}$$

National Annex Table A.NA.9

Correlation factors ($\xi$) to derive characteristic values of the resistance of axially loaded piles from static pile load tests (n – number of tested piles)

<table>
<thead>
<tr>
<th>$\xi$ for n =</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\xi_1$</td>
<td>1.55</td>
<td>1.47</td>
<td>1.42</td>
<td>1.38</td>
<td>1.35</td>
</tr>
<tr>
<td>$\xi_2$</td>
<td>1.55</td>
<td>1.35</td>
<td>1.23</td>
<td>1.15</td>
<td>1.08</td>
</tr>
</tbody>
</table>

In the UK we have increased these correlation factors compared to Annex A.
Static load tests 7.6.2.2 (7)P

1. Rare to do more than one preliminary pile test on a site (these are assumed to be preliminary pile tests)
2. No guidance on how to compare piles of different diameter or different length
3. I (and others) have read this methodology as a means of determining the characteristic resistance from pile tests when the tests are used to confirm design using ground strength parameters. (I understand this is incorrect)
4. Piles are not generally ‘designed’ from pile tests alone. The pile test is used to confirm the design using ground strength parameters

THIS METHOD IS OF MINIMAL USE IN THE UK

Ground test results 7.6.2.3 (5)P

Method of profiles

\[ R_{c,k} = \left( R_{b,k} + R_{s,k}\right)/\xi = R_{c,cal} = \xi = \min\{(R_{c,cal})_{\text{mean}} \}, (R_{c,cal})_{\text{min}} \} \]

\[ \zeta_3 \]

\[ \zeta_4 \]

\[ \xi \]

National Annex Table A.NA.10

Correlation factors (\(\xi\)) to derive characteristic values of the resistance of axially loaded piles from ground test results (\(n\) – the number of profiles of tests)

<table>
<thead>
<tr>
<th>(\xi) for (n)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>7</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\xi_3)</td>
<td>1.55</td>
<td>1.47</td>
<td>1.42</td>
<td>1.38</td>
<td>1.36</td>
<td>1.33</td>
<td>1.30</td>
</tr>
<tr>
<td>(\xi_4)</td>
<td>1.55</td>
<td>1.39</td>
<td>1.33</td>
<td>1.29</td>
<td>1.26</td>
<td>1.20</td>
<td>1.15</td>
</tr>
</tbody>
</table>

• Does not involve the use of a characteristic design line
• I understand this method is for use with CPT profiles (this is not generally used in the UK)
• Potentially dangerous if a profile is adopted from limited SPT or \(c_u\) data
• It should be clearly stated as being limited for use with CPT profiles
Ground test results 7.6.2.3 (8)
Alternative Procedure (Eqn 7.9)

\[ R_{b;k} = A_{b}q_{b;k} \text{ and } R_{s;k} = \sum A_{s;i}q_{s;i;k} \]

National Annex A.3.3.2
...model factor should be 1.4, except that it may be reduced to 1.2 if the resistance is verified by a maintained load test taken to the calculated, unfactored ultimate load.

This is the way we are designing piles in the UK
Effectively four sets of partial factors
Risk is that the model factor is omitted and the pile design is unsafe

Proposed Amendment
For axially loaded piles and anchors
Combination 1: A1 “+” M1 “+” R1
Combination 2: A2 “+” M2 “+” R1
For piles only:
• Combination 1 is for STR
• Combination 2 is for GEO

Partial factors for soil parameters \((\gamma_w)\) for the STR and GEO limit state

<table>
<thead>
<tr>
<th>Soil parameter</th>
<th>Symbol</th>
<th>Set M1</th>
<th>Set M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of shearing resistance(^h)</td>
<td>(\gamma_f)</td>
<td>1.0</td>
<td>1.25</td>
</tr>
<tr>
<td>Effective cohesion</td>
<td>(\gamma_c)</td>
<td>1.0</td>
<td>1.25</td>
</tr>
<tr>
<td>Undrained shear strength</td>
<td>(\gamma_u)</td>
<td>1.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Unconfined strength</td>
<td>(\gamma_{qu})</td>
<td>1.0</td>
<td>1.4</td>
</tr>
</tbody>
</table>
Proposed Amendment Table A.NA.7 etc.

Partial resistance factors ($\gamma_R$) for bored piles for the STR and GEO limit states

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Symbol</th>
<th>R1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>$\gamma_0$</td>
<td>2.0</td>
</tr>
<tr>
<td>Shaft (compression)</td>
<td>$\gamma_0$</td>
<td>1.6</td>
</tr>
<tr>
<td>Total/combined (compression)</td>
<td>$\gamma_t$</td>
<td>2.0</td>
</tr>
<tr>
<td>Shaft in tension</td>
<td>$\gamma_{st}$</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Reduces the complication of R4 and two sets of R4 in each table

Proposed Amendment

Design Resistance factor ($\gamma_{Rd}$) for the GEO limit state

<table>
<thead>
<tr>
<th>Pile testing</th>
<th>$\gamma_{Rd}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pile testing</td>
<td>1.0</td>
</tr>
<tr>
<td>1% of working piles</td>
<td>0.85</td>
</tr>
<tr>
<td>(to 1.5 x representative load)</td>
<td></td>
</tr>
<tr>
<td>Preliminary and 1% of working piles</td>
<td>0.7</td>
</tr>
</tbody>
</table>

If $\gamma_{Rd}$ is omitted, design is safe

Ensures that both working pile testing and preliminary pile testing are encouraged with additional economy
Eurocode 7 - Ground test results
Alternative Procedure

Combination 2 for pile length
A2 “+” (M1 or M2) “+” R4

Proposed
A2 “+” M2 “+” R1

Action Factors
- 1.0 x Permanent Actions 1.0
- 1.3 x Variable Actions 1.3

Material Factors
- 1.0 (set M1) 1.25/1.4

Resistance Factors
(only for bored piles)
- 1.6/1.4 Shaft Factor 1.6
- 2.0/1.7 Base Factor 2.0

Model Factor
- 1.4/1.2 1.0/0.85/0.7

Eurocode 7 - Ground test results
Alternative Procedure

Combination 1 for pile structural design

Action Factors
- 1.35 x Permanent Actions
- 1.50 x Variable Actions

Material Factors
- 1.0 (set M1)

Resistance Factors
(only for bored piles)
- 1.6 Shaft Factor
- 2.0 Base Factor

(These resistance factors are not applied to structural design)
Alternative Method – Overall FOS Currently

Comparison between equivalent global factor from UK NA to EN 1997-1 and traditional UK practice, after Bond and Harris (2008)

Overall factor of safety – drained analysis

No testing
Working pile tests
Working and preliminary pile tests

10m deep pile – drained analysis

Angle of friction
Overall factor of safety – undrained analysis

Conclusions

• Current pile design method is inconsistent with the rest of the document
• Design from static load tests is rarely done in the UK without ground test results
• The method of profiles is not generally used in the UK
• The alternative method is used in the UK
• An alternative methodology for pile design and a set of partial factors have been proposed