Implementation of pile design in the UK

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

Alternative proposal
Conclusions

Pile design in the UK

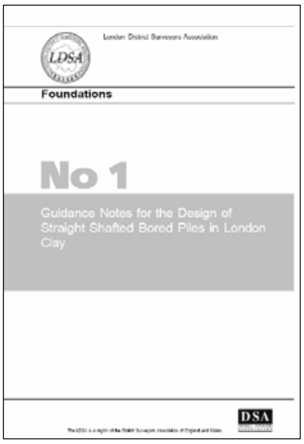
Typical pile type	Diameter
Continuous flight auger piles (cfa)	300-1200mm
Bored piles	600-2400mm
Minipiles	140-600mm
Driven precast / driven cast-in-situ / driven tubes	

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


London District Surveyors Association
LDSA
Foundations
No 1
Guidance Notes for the Design of Straight Shafted Bored Piles in London Clay

LDSA (1999) Table 1

Preliminary Pile Load Test	Requirements for load testing of working piles (1.5 x working load)	Factor of Safety F
No	No load testing on working piles	3.0
No	Load testing on 1% of working piles	2.5
Yes	Load testing on 1% of working piles	2.0

Eurocode 7 in the UK

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

Part 1: Eurocode 7, Ground Engineering, vol. 42, no 12, Dec 2009, pp27-31, London: Emap Inform
Part 2: UK National Annex, Ground Engineering, vol. 43, no 1, Jan 2010, pp28-31, London: Emap Inform.

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

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National Annex Table A.NA.7

Partial resistance factors (γ_R) for bored piles for the STR and GEO limit states				
Resistance	Symbol	Set		
		R1	R4 without explicit verification of SLS[A)]	R4 with explicit verification of SLS[A)]
Base	γ_b	1.0	2.0	1.7
Shaft (compression)	γ_s	1.0	1.6	1.4
Total/combined (compression)	γ_t	1.0	2.0	1.7
Shaft in tension	$\gamma_{s;t}$	1.0	2.0	1.7

"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

$$R_{c;k} = \mathrm{Min}\{(R_{c;m})_{mean}/\xi_1;(R_{c;m})_{min}/\xi_2\}$$

National Annex Table A.NA.9

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

ξ for n =	1	2	3	4	5
ξ_1	1.55	1.47	1.42	1.38	1.35
ξ_2	1.55	1.35	1.23	1.15	1.08

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

$$R_{c;k} = (R_{b;k} + R_{s;k}) = \frac{R_{b;cal} + R_{s;cal}}{\xi} = \frac{R_{c;cal}}{\xi} = \mathrm{Min}\left\{\frac{(R_{c;cal})_{mean}}{\xi_3}, \frac{(R_{c;cal})_{min}}{\xi_4}\right\}$$

National Annex Table A.NA.10

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

ξ for n=	1	2	3	4	5	7	10
ξ_3	1.55	1.47	1.42	1.38	1.36	1.33	1.30
ξ_4	1.55	1.39	1.33	1.29	1.26	1.20	1.15

- 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)

$R_{b;k} = A_b \cdot q_{b:k}$ and $R_{s;k} = \Sigma A_{s;i} \cdot q_{s;i;k}$

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 (γ_M) for the STR and GEO limit state

Soil parameter	Symbol	Set	
		M1	M2
Angle of shearing resistance[A)]	$\gamma_{\varphi'}$	1.0	1.25
Effective cohesion	$\gamma_{c'}$	1.0	1.25
Undrained shear strength	γ_{cu}	1.0	1.4
Unconfined strength	γ_{qu}	1.0	1.4

Proposed Amendment Table A.NA.7 etc.

Partial resistance factors (γ_R) for bored piles for the STR and GEO limit states		
Resistance	Symbol	**R1**
Base	γ_b	2.0
Shaft (compression)	γ_s	1.6
Total/combined (compression)	γ_t	2.0
Shaft in tension	$\gamma_{s;t}$	2.0

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

Proposed Amendment

Design Resistance factor (γ_{Rd})for the GEO limit state	
Pile testing	γ_{Rd}
No pile testing	**1.0**
1% of working piles (to 1.5 x representative load)	**0.85**
Preliminary and 1% of working piles	**0.7**

If γ_{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 “+” (M1or M2) “+” R4		Proposed A2 “+” M2 “+” R1
Action Factors	- 1.0 x Permanent Actions - 1.3 x Variable Actions	1.0 1.3
Material Factors	- 1.0 (set M1)	1.25/1.4
Resistance Factors (for bored piles)	- 1.6/1.4 Shaft Factor - 2.0/1.7 Base Factor	1.6 2.0
Model Factor	- 1.4/1.2	1.0/0.85/0.7

Eurocode 7 - Ground test results Alternative Procedure

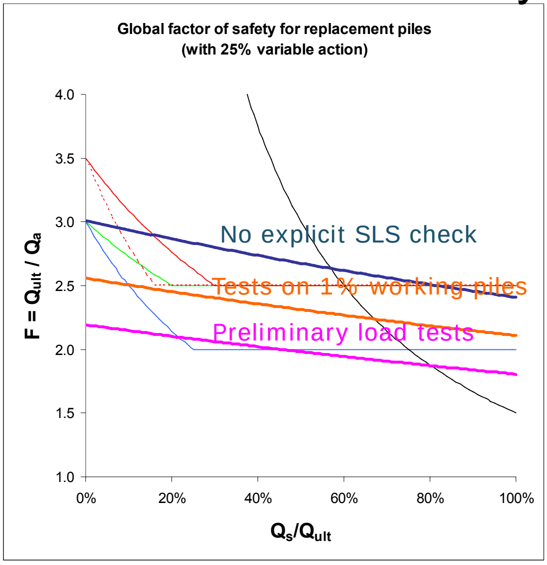
Combination 1 for pile structural design

Action Factors	- 1.35 x Permanent Actions - 1.50 x Variable Actions
Material Factors	- 1.0 (set M1)
Resistance Factors (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)



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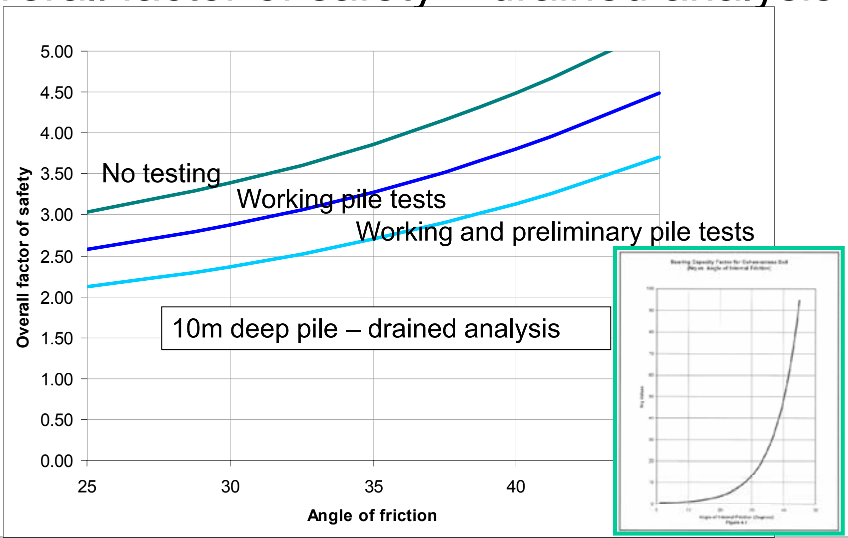
Overall factor of safety – drained analysis



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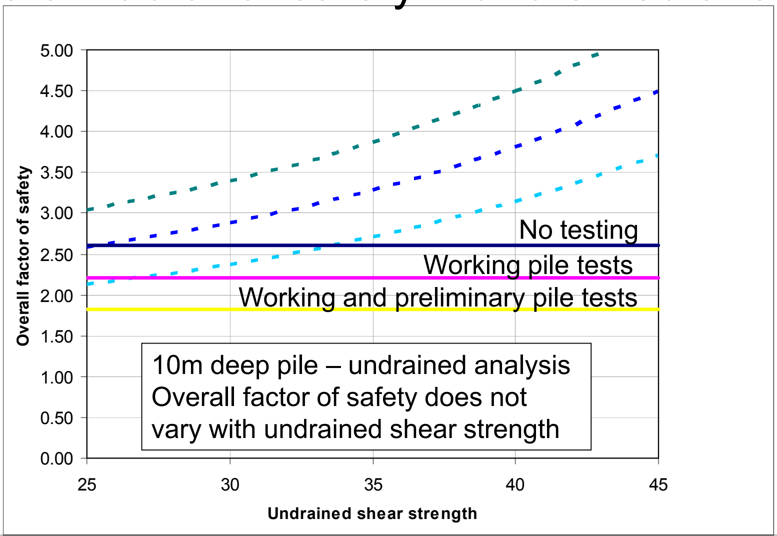
Overall factor of safety – undrained analysis



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