Evaluation of Eurocode 7
Example 2.3 – PILE IN CLAY
ETC 10

Adriaan van Seters
Fugro Ingenieurbureau BV
The Netherlands
Contents – Example 2.3 – Pile in Clay

- Introduction in example
- SLS–design – source of parameters
- Characteristic values of Cu – profile
- SLS – required pile length
- ULS – shaft friction / endbearing computation
- Design Approaches used
- Load/strength/resistance factors
- ULS – computed pile length
- Conclusions
Pile in Clay – Outline of problem

Soil data: boreholes 13, 14
SPT’s – borings 11, 12, 14 -17
CPT
Pressuremeter tests PM2, PM3
Triaxial UU – borings 11, 12, 14 -17
Soil Conditions

0 – 3 to 4 m  Man made ground, clayey sand, gravel
Below 3 to 4 m  London CLAY – Cu: 30 – 230 kPa
Below 34 m  SAND
Undrained shear strength based on UU-tests

All data - design profile

2nd International Workshop on Evaluation of Eurocode 7, Pavia, Italy, April 2010
Questions asked

1\textsuperscript{st} Question 17 Respondents from D, UK, PT, PL, IT:
- Permanent load 300 kN, variable load 150 kN downward
- SLS maximum settlement 20 mm
- SLS–State – required pile length?
- ULS–State – required pile length?

2nd Question – 7 Respondents:
- Repeat the exercise using the given Cu design values (red lines)
General Results

Observations:
- 13 (of 17) have designed more than 3 piles in clay
- 15 (of 17) are confident in a sound EC7 design
- 9 used an average of all tests
- 8 used nearest test results, took location into account
- 13 (of 14) assumed a linear/bilinear/stepped variation of Cu or E with depth
Where were the Parameters for SLS-design based on?

Parameters used for SLS-design

Qc-CPT  SPT-N  UU-Cu  Plim  Eund  E'drain  Poisson Nu

More than one answer was possible!

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Correlations for parameter assessment

- Relation $E_{\text{und}}$ and OCR, Duncan et al.
- $Cu = 4.5 \, N - \text{SPT}$, Stroud
- Adhesion factors, Tomlinson
- DIN 1054
- Correlations UU and $qc$, Kempfert
- Transform functions for bored piles, Gwizdala et al.
- EA Pfahle
- Correlation $Cu$ and Plasticity Index, Duncan et al.
- Relation $E'/N60$ (SPT), Stroud
**How did you derive at the characteristic values?**

<table>
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<tr>
<th>Answer</th>
<th>No</th>
<th>Comments</th>
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<tr>
<td>By eye</td>
<td>9</td>
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<td>Linear regression</td>
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<td>Other</td>
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</table>
Characteristic values for SPT–N, CPT–qc, Plim and Triaxial Cu

Questions 11–13 (qc, Plim, SPT–N) not answered
→ Only characteristic values CU-value (Q14)

Each participant converted test result back to Cu-value

Not many differences between countries
Variation $\sigma/\mu$: 0.2
Method of calculation – Pile settlement

• No method from the national Annex (Annex F is N.A.)
• German standard DIN 1054, Annex B
• EA-Pfahle, German method
• Wide range of handbooks, references:
  • Linear elastic solution
  • T–z, q–z curves, Fellenius
  • Transform functions method
  • T–z curves Reese & Wang (1990)
  • Poulos and Davis (1980)
  • Randolph and Clancy (1993)
  • Piglet, Randolph
  • Tomlinson
Q17 – Which length is needed in SLS – state?

- 12 Answers received
- Average pile length is 14 m
- Standard deviation of 2.8 m – variation 20 %
- All countries in the same range
Tests used for ULS Pile design

![Bar chart showing the number of participants for different soil tests:
- Qc-CPT: 10 participants
- SPT-N: 8 participants
- UU-Cu: 14 participants
- Plim: 2 participants
]
Correlations for ULS design

- **Wide range of correlations:**
  - DIN 1054
  - \( Cu = 4.5 \text{ N (SPT)} \) or \( f_1 \times \text{N (SPT)} \), Stroud
  - Tomlinson, adhesion factor \( a \) for piles
  - Kempfert et al, Correlation from UU-test to cone resistance
  - Polish piling code PN-B-02482
  - German code EA-Pfähle
  - Cone \( q_c = Cu \times N_c + \sigma_{v0} \)
  - CPT – \( cu \) correlation Meigh (1987, CIRIA)
  - DIN 4094–1: 2002–06 (CPT)
  - Baguelin et al, 1978 (pressuremeter)
Characteristic values of Unit Shaft Resistance

Q_{ shaft,k } at 7 \text{ m OD}

Countries:
D, I, PL, PT \rightarrow 55 \text{ kPa}
UK \rightarrow 80 \text{ kPa}
Characteristic values – Unit Base resistance

Q_{base,k} at \(-3\) m OD

Countries:
D, I, PL, PT \(\rightarrow\) 1750 kPa
UK \(\rightarrow\) 700 kPa

(UK applies a model factor of 1.4 in achieving at characteristic values)
Use of Design Approaches

Design Approaches - ULS Design

- DA1 - C1.1 + C1.2
- DA1 - C1.1
- DA1 - C1.2
- DA2/DA2*
- DA3

Number of participants

Others  Design approaches  Germany
Use of Partial Safety Factors in ULS–check

Load factors
- All participants: DA1 – Comb. 1, DA2 → $\gamma_G = 1.35 \quad \gamma_Q = 1.5$
- DA1 – Comb. 2 → $\gamma_G = 1.0 \quad \gamma_Q = 1.3$

Partial factors on strength
- Generally no partial factors on Cu (DA3) were applied
- Partial factors on shaft/base friction acc Nat Annexes:
  - DA1 – Comb. 1 → $\gamma_{\text{shaft}} = 1.0 \quad \gamma_{\text{base}} = 1.0$ (PL/PT: 1.25)
  - DA1 – Comb. 2 → $\gamma_{\text{shaft}} = 1.3/1.45/1.6 \quad \gamma_{\text{base}} = 1.6/1.7/2.0$
  - DA2 → $\gamma_{\text{shaft}} = 1.1/1.4 \quad \gamma_{\text{base}} = 1.1/1.4$
  - $\xi$–factors: $\xi_4$ (9x) → 1.135 to 1.7, $\xi_3$ (2x) → 1.45

Partial model factor
- UK / PT → partial model factor of 1.4 / 1.5 on Cu
Results of the Analyses – ULS Pile length

- 16 answers received
- Average pile length is 15.1 m (SLS 14.0 m)
- Standard deviation of 2.7 m (SLS 2.8 m)
- UK – pile length 12.5 m
- Italy – pile length 17.5 m
- Others – pile length ca. 15 m
Conclusions – Example bored pile in clay

• 17 participants from 5 countries!
• All answers translated soil data to Cu–value using many correlations!
• Variation of Characteristic values of Cu (no anomalies, below level + 7 m) within 10 %.
• Many SLS–methods, less ULS–methods (all based on Cu)
• Good agreement load factors + Design load (630 kN)
• Spread in $\gamma_{shaft}$ and $\gamma_{base}$ in DA1– Comb 2 (and DA2?)
• Use of partial model factor?
• Variation computed pile length (SLS and ULS) ca. 20 %

Thanks for all contributions!
Are we confident in Eurocode Design??