Assessment of Calculation Procedures for Piles in Clay based on Static Loading Tests

By

Anders Hust Augustesen
Agenda

- Presentation of calculation procedures
- Basis for the evaluation of the calculation procedures
- Database
- Results
- Conclusions
Design methods in consideration – API-RP2A

- Current API-method, long history (1969)
- \( \alpha \) – approach, \( \alpha = \alpha(OCR, s_u) \) for the skin friction
  \[
  \tau = \alpha \cdot s_u
  \]
  \[
  \alpha = 0.5 \cdot \psi^{-0.5}, \quad \psi \leq 1.0
  \]
  \[
  \alpha = 0.5 \cdot \psi^{-0.25}, \quad \psi > 1.0
  \]
  \[
  \psi = \frac{s_u}{P_0}
  \]
- \( \alpha \leq 1 \)
- High values of \( \psi \) => application with engineering judgement
- \( s_{uu} \) should be employed
Design methods in consideration – ICP

- Jardine and his co-workers (1996)
- $\beta = \beta (S_t, \delta_f, OCR, I_p, \text{tip conditions}, R, \Delta z)$:

$$\tau = 0.8 \cdot \sigma_{rc} \cdot \tan(\delta)$$

$$\sigma_{rc} = p_0 \left( 2.2 + 0.016 \cdot YSR - 0.87 \cdot \Delta I_{vy} \right) \cdot YSR^{0.42} \cdot \left( \frac{\Delta z}{R} \right)^{-0.2}$$

$$\Delta I_{vy} = \log_{10}(S_t)$$

Open piles: $R = \sqrt{R_{outer}^2 - R_{inner}^2}$

- Open/closed, tension/compression
- $s_{ciu}$ employed as reference strength
- End-bearing is function of $q_c$ and tip conditions
- Parameters not part of routine site investigations
PILCAP

- Assessment based on a database
- Focus on C/M-ratios
  - $\mu_{C/M}$ and $\sigma_{C/M}$
  - Distribution of skin friction
  - Characteristic values
- Interpretation of soil conditions
- Interpretation of loading tests
- PILCAP
  - Correction of $s_u$
  - Estimation of soil parameters
- Correction for time

\[ Q(t) = Q_0 \left[ 1 + \Delta_{10} \log_{10} \left( \frac{t}{t_0} \right) \right], \]

- \( t_0 = 100 \) days,
- \( \Delta_{10} = 0.24 \)

- Group action
- Pre-shearing effects
- Loading rate
Database

- Literature
- Norwegian and Danish companies
- All piles tested to failure
- Soil and pile ranking 0 - 4

- 253 static loading tests on 111 sites
- 199 compression and 54 tension tests
- 153 tests on steel piles, 65 on timber and 35 on concrete piles
- 95 “Super piles”

- $8\text{kPa} < s_{uu} < 600\text{kPa}$
- $0.10\text{m} < \text{Diameter} < 0.80\text{m}$
- Penetration depth of the longest pile exceeds 100m
Results

Assessment of Calculation Procedures for Piles in Clay based on Static Loading Tests

![Graphs showing C/M vs. Depth with API and ICP data for 253 data points.](image)

- **API**
  - Data = 253
  - $H_{C/M} = 1.03$
  - $\sigma_{C/M} = 0.40$

- **ICP**
  - Data = 253
  - $\mu_{C/M} = 0.89$
  - $\sigma_{C/M} = 0.44$
Results

Assessment of Calculation Procedures for Piles in Clay based on Static Loading Tests
Results

<table>
<thead>
<tr>
<th>Depth</th>
<th>No. of piles</th>
<th>API –RP2A $\mu_{C/M} / \sigma_{C/M}$</th>
<th>ICP $\mu_{C/M} / \sigma_{C/M}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 20</td>
<td>172</td>
<td>0.93 / 0.30</td>
<td>0.86 / 0.32</td>
</tr>
<tr>
<td>&gt;20</td>
<td>81</td>
<td>1.23 / 0.49</td>
<td>0.95 / 0.63</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>No. of piles</th>
<th>API-RP2A $\mu_{C/M} / \sigma_{C/M}$</th>
<th>ICP $\mu_{C/M} / \sigma_{C/M}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>All cases</td>
<td>253</td>
<td>1.03 / 0.40</td>
<td>0.89 / 0.44</td>
</tr>
<tr>
<td>Steel</td>
<td>153</td>
<td>0.97 / 0.43</td>
<td>0.82 / 0.49</td>
</tr>
<tr>
<td>Timber</td>
<td>65</td>
<td>1.11 / 0.27</td>
<td>0.94 / 0.32</td>
</tr>
<tr>
<td>Concrete</td>
<td>35</td>
<td>1.15 / 0.39</td>
<td>1.05 / 0.36</td>
</tr>
<tr>
<td>Super piles</td>
<td>95</td>
<td>0.90 / 0.49</td>
<td>0.87 / 0.58</td>
</tr>
</tbody>
</table>

The low average C/M-ratios provided by ICP may reflect that some input parameters are estimated based on relative uncertain correlations rather than a short-coming of the method.
Results

<table>
<thead>
<tr>
<th>Driving/Loading</th>
<th>No. of piles</th>
<th>API-RP2A $\mu_{C/M} / \sigma_{C/M}$</th>
<th>ICP $\mu_{C/M} / \sigma_{C/M}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open / TNS</td>
<td>24</td>
<td>0.97 / 0.27</td>
<td>0.92 / 0.31</td>
</tr>
<tr>
<td>Open / CMP</td>
<td>60</td>
<td>1.01 / 0.30</td>
<td>0.67 / 0.20</td>
</tr>
<tr>
<td>Closed / TNS</td>
<td>30</td>
<td>1.10 / 0.72</td>
<td>1.04 / 0.92</td>
</tr>
<tr>
<td>Closed / CMP</td>
<td>139</td>
<td>1.03 / 0.35</td>
<td>0.94 / 0.34</td>
</tr>
</tbody>
</table>

- API-RP2A provides overall a reasonable estimate of the capacity.
- ICP should **not** be used for piles driven open-ended and loaded in compression.
- ICP provide the better estimate of the capacities of piles loaded in tension.
- The large scatter associated with piles loaded in tension is mainly due to lack of capability to estimate the low shaft resistance measured in connection with piles in normally consolidated clay of low plasticity.
Results

Closed-ended: $0.25 < \psi < 0.5 \Rightarrow$ values lower than predicted by API-RP2A
$1.50 < \psi < 3.0 \Rightarrow$ values greater than predicted by API-RP2A
Conclusions

- Assessment of API-RP2A and ICP for piles in clay based on static loading tests

- Consistent treatment of available tests
  - Corrections for time and undrained shear strength
  - Failure criterion
  - Group action, preshearing effects and loading rate

- 253 pile tests distributed on 111 sites constitute the database

- Wide range of soil and pile conditions

- API-RP2A provides overall the better estimate of the capacity
Conclusions

- API-RP2A provides a skew distribution of C/M-ratios with penetration depth.
- For closed-ended piles there is a tendency that for low strength-ratios API-RP2A overestimate the $\alpha$-values whereas for high strength-ratios the $\alpha$-values are underestimated.
- ICP could preferable be applied to piles loaded in tension.
- Compared to API-RP2A the skew distribution of C/M-ratios with penetration depth provided by ICP is less significantly.
- ICP should not be used for piles driven open-ended and loaded in compression.

- Some input parameters for the ICP method have been estimated based on relatively uncertain correlations between geotechnical parameters.
The End

Thank you for your attention