DEEP FOUNDATIONS

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1. CLEAN SANDS - $\phi'$ only

The skin friction term

(LATERAL STRESS) $\times$ FRICTION COEFFICIENT

\[ f_s = (K_s \sigma'_v) (\tan \delta) \]
# KULHAWY (1984) – sand parameters

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>$\frac{K_s}{K_o}$</th>
<th>$\delta$ / $\phi'$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bored piles</td>
<td>0.7 to 1</td>
<td>1</td>
</tr>
<tr>
<td>Displacement piles</td>
<td>see below</td>
<td></td>
</tr>
<tr>
<td>- precast concrete</td>
<td>0.75 to 2</td>
<td>0.8 to 1</td>
</tr>
<tr>
<td>- smooth steel</td>
<td>0.75 to 2</td>
<td>0.5 to 0.7</td>
</tr>
</tbody>
</table>
END BEARING, $f_b$

Analogous to the surcharge term in bearing capacity analysis

$$f_b = (\sigma'_{vb_o})(N_q)$$
N_q for Piles in Sand

\[ N_q = fn \text{ (density & method of construction)} \]

Driven piling increases \( I_D \) and \( \phi' \), locally

[Meyerhof 1959]

NOTE: min. penetration into bearing stratum = 5B
Densification

\( \phi_o = 30^\circ \)

\( \phi = 47^\circ \)

\( \phi = 34^\circ \)

\( \phi_o = 30^\circ \)

5B Rule

Layer 1

Layer 2

5B
$N_q$ – typical values, driven piles [AS2159 (1978)]

<table>
<thead>
<tr>
<th>Sand Consistency</th>
<th>Density Index, $I_D$ (%)</th>
<th>$N_q$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOOSE</td>
<td>20-40%</td>
<td>60</td>
</tr>
<tr>
<td>MEDIUM DENSE</td>
<td>40-75%</td>
<td>100</td>
</tr>
<tr>
<td>DENSE</td>
<td>75-90%</td>
<td>180</td>
</tr>
</tbody>
</table>
Limiting (maximum) values of $f_s$ and $f_b$ for sands

\[ f_{s\text{ max}} = 110 \text{ kPa} \]

\[ f_{b\text{ max}} = 15 \text{ MPa} \]

After Tomlinson 1995
Method Based on Standard Penetration Test

\[ Q_u = 400 N A_b + 2 N_1 A_s \]

- \( Q_u \) = the ultimate pile load, kN
- \( N \) = the average standard penetration index at the pile tip elevation, blows/300 mm
- \( N_1 \) = the average standard penetration index along the pile shaft blows/300 mm with a maximum value of 50
- Minimum factor of safety of 4 should be applied to \( Q_u \).
CLAYS, SILTS

The skin friction OR side shear term…
- effective stresses and drained strength?
  **BUT** the pwp’s are uncertain
- Total stress analysis acceptable

“Adhesion” \[ f_s = F \alpha_p c_u = \alpha_p c_u \]

since \( F = \) pile flexibility factor
and \( F = 1 \) for \( L/B < 50 \)
Generally, $\alpha_p = 1.0$ for $c_u < 40$ kPa

$\alpha_p = 0.4$ for $c_u > 150$ kPa

Otherwise, Semple + Rigden (1984):

<table>
<thead>
<tr>
<th>$\alpha_p$</th>
<th>$(c_u) / (\sigma'_v)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt; 0.35</td>
</tr>
<tr>
<td>0.5</td>
<td>&gt; 0.8</td>
</tr>
</tbody>
</table>
End Bearing Term, $f_b$

Total Stress Analysis of Saturated NC Clay

$$f_b = 9c_u$$

- $N_c = 5.14$
- $d_cN_c = 8.4$ for infinitely deep footing
- $s_c d_c N_c = 9^+$ for a circular or square, deep footing
PILE PARAMETERS from CPT (field test)

CPT = Cone Penetration Test

OR electronic friction cone

- designed specifically for interpreting pile parameters
- 36 mm diameter cone (60°) is pushed into the soil at 2 cm/sec

⇒ 1.2 m in a minute
CPT provides a continuous record with time (= depth) of $q_c$ and $f_{sc}$
PILE PARAMETERS from CPT

(A) $f_s \Rightarrow f_{sc}$, directly from cone

Scale effect: small cone displaces less soil

⇒ conservative for sands!

CLAY SOILS ........ $f_s = f_{sc}$

SANDS .............. $f_s = 2f_{sc}$

(BUT $f_s = f_{sc}$ for H-piles)
PILE PARAMETERS from CPT

(B) \( f_b \text{ measured directly} \Rightarrow q_c \)

Interpretation of CPT for \( f_b \)

Various formulations exist, e.g.

ECP \quad \text{Av. } q_c \quad 6B \text{ above pile base level}

AND \quad 3B \text{ below}

\text{e.g. } 0.4 \text{ m dia. pile founded at } 10 \text{ m requires average } q_c \text{ between } 7.6 \text{ m and } 11.2 \text{ m}
Pile Capacity from CPT

For displacement piles:

\[ Q_{all} = \frac{1}{3} \alpha q_c \left( \frac{\pi d^2}{4} \right) + \frac{1}{2} f_c (\pi dL) \]

\( \alpha \): Scale factor = 0.70

\( q_c < 150 \text{kg/cm}^2 \)

\( f_c < 1.0 \text{kg/cm}^2 \)

**Notes:**
For bored piles:
estimated values should be reduced by 0.0 to 50%
Reinforcement details of piles

- Compression loading only
- No eccentricity of loads

- $A_{s_{\text{min}}} = 0.006A_g$
- Use $\Phi16$mm as minimum diameter.
- Length of reinforcement the largest of $6m$ or $3d$
- Spiral stirrups 8mm @ 15CM pitch
Tension Piles

Vertical tension loading:

ULTIMATE GEOTECHNICAL STRENGTH

- or capacity, $P_u$

$$P_u = f_s A_s + W_p$$
Pile Subjected to Eccentric Forces

\[ P_i = \frac{P_{F.L}}{n} \pm \frac{M_x}{\sum_{i=1}^{n} y_i^2} y_i \pm \frac{M_y}{\sum_{i=1}^{n} x_i^2} x_i \]

+ve: compression  
-ve: tension

\( P_i \): Load on Pile No. I  
\( n \): number of piles  
\( y_i, x_i \): co-ordinates of pile

\( M_x = P \cdot e_y \)
\( M_y = P \cdot e_x \)

Check Loads on piles:

\( P_i \) (max. comp.) < \( P_{all} \) comp.
\( P_i \) (max. ten.) < \( P_{all} \) ten.