Worked examples – design of pile foundations

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Worked example 1 –
design of pile foundations from load tests

DESIGN SITUATION
Design situation for a pile designed from static load test results

- Pile foundations are required to support the following loads from a building:
  - Characteristic permanent vertical load $G_k = 6.0$ MN
  - Characteristic variable vertical load $Q_k = 3.2$ MN

- It has been decided to use bored piles 1.2m in diameter and 15m long

- The pile foundation design is to determine how many piles are required
Pile load test results

- Load tests have been performed on site on four piles of the same diameter and same length.
- The results of load-settlement curves are plotted in Figure 1.
- Adopt settlement of the pile top equal to 10% of the pile base diameter as the "failure" criterion (7.6.1.1(3)).
Worked example 1 – design of pile foundations from load tests

SOLUTION
Measured pile resistances

- Adopting the pile load at a settlement of the top of the piles equal to 10% of the pile diameter as the ultimate resistance means using the measured resistances at a settlement of:
  \[ 12.0 \times (10/100) \times 10^3 = 120\text{mm} \]

- From the load-settlement graphs for each pile this gives:
  - Pile 1 \( R_m = 2.14 \text{ MN} \)
  - Pile 2 \( R_m = 1.96 \text{ MN} \)
  - Pile 3 \( R_m = 1.73 \text{ MN} \)
  - Pile 4 \( R_m = 2.33 \text{ MN} \)

- Hence the mean and minimum measured pile resistances are:
  \[ R_{m, \text{mean}} = 2.04 \text{ MN} \]
  \[ R_{m, \text{min}} = 1.73 \text{ MN} \]
Characteristic resistance

- The characteristic pile resistance is obtained by dividing the mean and minimum measured pile resistances by the correlation factors $\xi_1$ and $\xi_2$ and choosing the minimum value:

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

- For four load tests, recommended $\xi_1$ and $\xi_2$ values are:
  $$\xi_1 = 1.1 \quad \xi_2 = 1.0$$

- Hence the characteristic pile resistance:

$$R_{c,k} = \min \left\{ \frac{2.04}{1.1}, \frac{1.73}{1.0} \right\} = \min\{1.85;1.73\} = 1.73$$
Design Approach 1 partial factors

- Combinations of sets of partial factors
  - DA1.C1  A1 “+” M1 “+” R1
  - DA1.C2  A2 “+” M1 or M2 “+” R4

- Partial actions factors
  - A1  $\gamma_G = 1.35$  $\gamma_Q = 1.5$
  - A2  $\gamma_G = 1.0$  $\gamma_Q = 1.3$

- Partial material factors
  - M1 and M2 not relevant  ($\gamma_{\phi} = 1.0$ and not used)

- Partial resistance factors
  - R1  $\gamma_t = 1.15$ (Total/combined compression)
  - R4  $\gamma_t = 1.5$
Design Approach 1 - pile design

Design equation

\[ F_{c,d} \leq R_{c,d} \]

\[
\begin{align*}
\text{DA1.C1} & & F_{c,d} = 1.35 \, G_k + 1.5 \, Q_k & = 1.35 \times 6.0 + 1.5 \times 3.2 & = 12.9 \, \text{MN} \\
\text{DA1.C1} & & F_{c,d} = 1.0 \, G_k + 1.3 \, Q_k & = 1.0 \times 6.0 + 1.3 \times 3.2 & = 10.2 \, \text{MN} \\
\end{align*}
\]

For a single pile

\[
\begin{align*}
\text{DA1.C1} & & R_{c,d} = \frac{R_{c,k}}{\gamma_t} & = 1.73 / 1.15 & = 1.50 \, \text{MN} \\
\text{DA1.C2} & & R_{c,d} = \frac{R_{c,k}}{\gamma_t} & = 1.73 / 1.5 & = 1.15 \, \text{MN} \\
\end{align*}
\]

Assuming no pile group effect, for \( n \) piles, resistance = \( n \times R_{c,d} \)

Hence

\[
\begin{align*}
\text{DA1.C1} & & n \geq \frac{F_{c,d}}{R_{c,d}} & = 12.9/1.5 & = 8.6 \\
\text{DA1.C2} & & n \geq \frac{F_{c,d}}{R_{c,d}} & = 10.2/1.15 & = 8.9 \\
\end{align*}
\]

Therefore \( \text{DA1.C2} \) controls and no. piles required: \( n = 9 \)
Design Approach 2 partial factors

- Combination of sets of partial factors
  DA2 A1 “+” M1 “+” R2

- Partial actions factors
  A1 \( \gamma_G = 1.35 \quad \gamma_Q = 1.5 \)

- Partial material factors
  M1 not relevant \( (\gamma_{\phi'} = 1.0 \text{ and not used}) \)

- Partial resistance factor
  R2 \( \gamma_t = 1.1 \) (Total/combined compression)
Design Approach 2 - pile design

Design equation

\[ F_{c,d} \leq R_{c,d} \]

\[ F_{c,d} = 1.35 \, G_k + 1.5 \, Q_k = 1.35 \times 6.0 + 1.5 \times 3.2 = 12.9 \, \text{MN} \]

For a single pile

\[ R_{c,d} = \frac{R_{c,k}}{\gamma_t} = \frac{1.73}{1.1} = 1.57 \, \text{MN} \]

Assuming no pile group effect, for \( n \) piles, resistance = \( n \times R_{c,d} \)

Hence

\[ F_{c,d} \leq n \, R_{c,d} \]

Therefore no. piles required:

\[ n = \frac{F_{c,d}}{R_{c,d}} = \frac{12.9}{1.57} = 9 \, \text{piles} \]
Design Approach 3 partial factors

- Combination of sets of partial factors:
  \[ \text{DA3 A1} \ + \ + \ M1 \ + \ R3 \]

- Partial resistance factor:
  \[ R3 \ \gamma_t = 1.0 \ \text{(Total/combined compression)} \]

- Since the R3 recommended partial resistance factor is equal to 1.0, no safety margin on the resistance is provided if DA3 is used to calculate the design pile resistance from pile load test results.

- Hence piles should not be designed from load test results using Design Approach 3 and the recommended partial resistance factor.
Conclusions from pile worked example 1

- The same design number of piles, 9 is obtained for both DA1 and DA2
- Since the recommended partial resistance factors are 1.0 for DA3, this Design Approach should not be used for the design of piles from pile load test results unless the partial resistance factors are increased
Worked example 2 –
design of pile foundations from test profiles

DESIGN SITUATION
Design situation for a pile designed from a CPT test profile

• The piles for a building are each required to support the following loads:
  • Characteristic permanent vertical load $G_k = 300\, \text{kN}$
  • Characteristic variable vertical load $Q_k = 150\, \text{kN}$

• The ground consists of dense sand beneath loose sand with soft clay and peat to 16.5m as shown in figure on next slide

• It has been decided to use 0.45m diameter bored piles

• The pile foundation design involves determining the length of the piles
B’hole log/CPT profile

- 1 CPT was carried out
- Soil has upper 11m layer of loose sand, soft clay and some peat over 5.5m of clay with peat seams
  Cautious average $q_c = 2.5$ MPa
- Stronger layer of medium to dense sand starts at depth of 16.5m
  Cautious average $q_c = 12.5$ MPa
- Assume the soil above 16.5m provides no shaft resistance
Unit pile resistances

- The base and shaft pile resistances are calculated using Tables D.3 and D.4 of EN 1997-2 relating a single cautious average $q_c$ value in stronger soil to the unit base and shaft resistances, $p_b$ and $p_s$
- Assume the ULS settlement of the pile head, $s_g$ so that the normalised settlement is 0.1
- Interpret linearly between relevant $q_c$ values to obtain $p_b$ and $p_s$ from these tables:
  
  \[
  \begin{align*}
  p_b &= 2.5 \text{ MPa} \\
  p_s &= 0.1 \text{ MPa}
  \end{align*}
  \]

### Table D.3
Unit base resistance $p_b$ of cast in-situ piles in coarse soil with little or no fines

<table>
<thead>
<tr>
<th>Normalised settlement $s/D_s$, $s/D_b$</th>
<th>Unit base resistance $p_b$, in MPa, at average cone penetration resistance $q_c$ (CPT) in MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$q_c = 10$</td>
</tr>
<tr>
<td>0,02</td>
<td>0,70</td>
</tr>
<tr>
<td>0,03</td>
<td>0,90</td>
</tr>
<tr>
<td>0,10 (= $s_g$)</td>
<td>2,00</td>
</tr>
</tbody>
</table>

**NOTE** Intermediate values may be interpolated linearly.

In the case of cast in-situ piles with pile base enlargement, the values shall be multiplied by 0,75.

$s$ is the normalised pile head settlement

$D_s$ is the diameter of the pile shaft

$D_b$ is the diameter of the pile base

$s_g$ is the ultimate settlement of pile head

### Table D.4
Unit shaft resistance $p_s$ of cast in-situ piles in coarse soil with little or no fines

<table>
<thead>
<tr>
<th>Average cone penetration resistance $q_c$ (CPT)</th>
<th>Unit shaft resistance $p_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MPa</td>
<td>MPa</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0,040</td>
</tr>
<tr>
<td>10</td>
<td>0,080</td>
</tr>
<tr>
<td>$&gt; 15$</td>
<td>0,120</td>
</tr>
</tbody>
</table>

**NOTE** Intermediate values may be interpolated linearly
Worked example 2 –
design of pile foundations from test profiles

SOLUTION
Characteristic pile resistance

Pile diameter \( D = 0.45\,\text{m} \)
Pile base cross sectional area \( A_b = \pi \times 0.45^2 / 4 = 0.159\,\text{m}^2 \)
Pile shaft area per metre length \( A_s = \pi \times 0.45 = 1.414\,\text{m}^2 /\text{m} \)
Length of pile in stronger layer providing shaft resistance = \( L_s \)

Calculated compressive pile resistance for the one profile of test results:

\[
R_c;\text{cal} = R_b;\text{cal} + R_s;\text{cal} = A_b \times p_b + A_s \times L_s \times p_s \\
= (0.159 \times 2.5 + 1.414 \times L_s \times 0.10) \times 10^3\,\text{kN} \\
\]

\[
R_c;\text{cal} = 398 + 141 \times L_s \text{kN} \\
\]

Hence, applying the recommended correlation factors \( \xi_3 \) and \( \xi_4 \), which are both the same and equal to 1.4 for one profile of test results because the mean and minimum calculated resistances are the same so that \( \xi_3 \) and \( \xi_4 = \xi = 1.4 \) and the characteristic base and shaft compressive pile resistances are:

\[
R_b;\text{k} = R_b;\text{cal} / \xi = 398/1.4 = 284\,\text{kN} \\
R_s;\text{k} = R_s;\text{cal} / \xi = 141 \times L_s /1.4 = 101\,L_s \\
\]
Design Approach 1 partial factors

- Combinations of sets of partial factors:
  DA1.C1  A1 “+” M1 “+” R1
  DA1.C2  A2 “+” M1 or M2 “+” R4

- Partial actions factors:
  A1     $\gamma_G = 1.35$     $\gamma_Q = 1.5$
  A2     $\gamma_G = 1.0$     $\gamma_Q = 1.3$

- Partial material factors:
  M1 and M2 not relevant    ($\gamma_{\phi'} = 1.0$)

- Partial resistance factors:
  R1     $\gamma_b = 1.25$     $\gamma_s = 1.0$
  R4     $\gamma_b = 1.6$     $\gamma_s = 1.3$
Design Approach 1 - pile design

Design equation

\[ F_{c,d} \leq R_{c,d} \]

Design actions

\[
\begin{align*}
\text{DA1.C1} & \quad F_{c,d} = 1.35 G_k + 1.5 Q_k = 1.35 \times 300 + 1.5 \times 150 = 630 \text{ kN} \\
\text{DA1.C1} & \quad F_{c,d} = 1.0 G_k + 1.3 Q_k = 1.0 \times 300 + 1.3 \times 150 = 495 \text{ MN}
\end{align*}
\]

Design resistances

\[
\begin{align*}
\text{DA1.C1} & \quad R_{c,d} = R_{b,k} / \gamma_b + R_{s,k} / \gamma_s = 284 / 1.25 + 101 \times L_s / 1.0 \\
\text{DA1.C2} & \quad R_{c,d} = R_{b,k} / \gamma_b + R_{s,k} / \gamma_s = 284 / 1.6 + 101 \times L_s / 1.3
\end{align*}
\]

Equating actions and resistances

\[
\begin{align*}
\text{DA1.C1} & \quad 630 = 284 / 1.25 + 101 \times L_s / 1.0 \rightarrow L_s = 3.99 \text{ m} \\
\text{DA1.C2} & \quad 495 = 284 / 1.6 + 101 \times L_s / 1.3 \rightarrow L_s = 4.08 \text{ m}
\end{align*}
\]

Hence DA1.C2 controls and DA1 design pile length \( L = 16.5 + L_s = 21 \text{ m} \)
Design Approach 2 - pile design

Partial action factors same as for Example 1

Partial resistance factors:
\[ R_2 \quad \gamma_b = 1.1 \quad \gamma_s = 1.1 \]

Design equation
\[ F_{c,d} \leq R_{c,d} \]

Design action
\[ F_{c,d} = 1.35 \ G_k + 1.5 \ Q_k = 1.35 \times 300 + 1.5 \times 150 = 630 \ \text{kN} \]

Design resistance
\[ R_{c,d} = \frac{R_{b;k}}{\gamma_b} + \frac{R_{s;k}}{\gamma_s} = \frac{284}{1.1} + 101 \times \frac{L_s}{1.1} \]

Equating actions and resistances
\[ 630 = \frac{284}{1.1} + 101 \times \frac{L_s}{1.1} \quad \rightarrow \quad L_s = 4.05 \ m \]

Hence the DA2 design pile length \( L = 16.5 + L_s = 21 \ m \)
Design Approach 3 - pile design

- Combination of sets of partial factors:
  \[ \text{DA3 A1} \quad + \quad \text{M1} \quad + \quad \text{R3} \]

- Partial resistance factors:
  \[ R_3 \gamma_b = \gamma_s = 1.0 \]

- Since the R3 recommended partial resistance factors are both equal to 1.0, no safety margin is provided if these factors are used in DA3 to calculate the design pile resistance from a CPT test profile

- Hence piles should not be designed using the DA3 recommended partial resistance factors applied to the characteristic pile resistance obtained from a CPT test profile
Conclusions from pile worked example 2

• The same design pile length, 21m is required for both DA1 and DA2

• Since the recommended partial resistance factors are 1.0 for DA3, this Design Approach should not be used for the design of piles from profiles of ground test results unless the partial resistance factors are increased
Worked example 3 – design of pile foundations from soil parameters

DESIGN SITUATION
Design situation for a pile designed from soil parameters

• The piles for a proposed building in Dublin are each required to support the following loads:
  • Characteristic permanent vertical load \( G_k = 600 \text{ kN} \)
  • Characteristic variable vertical load \( Q_k = 300 \text{ kN} \)

• The ground consists of about 3m Brown Dublin Boulder Clay over Black Dublin Clay to great depth

• It has been decided to use 0.45m diameter driven piles

• The pile foundation design involves determining the length of the piles
Characteristic undrained shear strength

- Figure shows plot of SPT N values obtained plotted against depth
- Shaft resistance in Brown Dublin Boulder Clay is ignored
- Average N value in Black Dublin Boulder Clay = 57
- A cautious average N value = 45
- PI of the Dublin Boulder Clay = 14%
- From Stroud and Butler plot of $f_1$ vs. N
  - Adopt $f_1 = 6$
- Hence characteristic undrained shear strength $c_{u;k} = f_1 \times N = 6 \times 45 = 270 \text{ kPa}$
Pile resistances

Pile diameter \( D = 0.45 \text{m} \)

Pile base cross sectional area \( A_b = \pi \times 0.45^2 / 4 = 0.159 \text{ m}^2 \)

Pile shaft area per metre length \( A_s = \pi \times 0.45 = 1.414 \text{ m}^2 / \text{m} \)

Length of pile in Black Dublin Clay providing shaft resistance \( = L_s \)

The characteristic unit pile base and shaft resistances, \( q_{b;k} \) and \( q_{s;k} \) are obtained as follows:

\[
q_{b;k} = N_q \times c_u = 9 \times c_u
\]

\[
q_{s;k} = \alpha \times c_u = 0.4 \times c_u
\]

Characteristic base resistance

\[
R_{b;k} = A_b \times q_{b;k} = 0.159 \times 9 \times 270 = 386 \text{ kN}
\]

Characteristic shaft resistance

\[
R_{s;k} = A_s \times L_s \times q_{s;k} = 1.414 \times L_s \times 0.4 \times 270 = 153 \text{ L}_s
\]
Design Approach 1 partial and model factors

- Combinations of sets of partial factors:
  - DA1.C1: A1 “+” M1 “+” R1
  - DA1.C2: A2 “+” M1 or M2 “+” R4

- Partial actions factors:
  - A1: $\gamma_G = 1.35$ $\gamma_Q = 1.5$
  - A2: $\gamma_G = 1.0$ $\gamma_Q = 1.3$

- Partial material factors:
  - M1 and M2 not relevant (resistances factored not soil parameters)

- Partial resistance factors:
  - R1: $\gamma_b = 1.0$ $\gamma_s = 1.0$
  - R4: $\gamma_b = 1.3$ $\gamma_s = 1.3$

- Model factors:
  - $\gamma_{R;d} = 1.75$ (In Irish NA and applied to $\gamma_b$, $\gamma_s$ and $\gamma_t$)
Design Approach 1 - pile design to Irish NA

Design equation

\[ F_{c,d} \leq R_{c,d} \]

Design actions

\[
\begin{align*}
\text{DA1.C1} & \quad F_{c,d} = 1.35 \, G_k + 1.5 \, Q_k = 1.35 \times 600 + 1.5 \times 300 = 1260 \text{ kN} \\
\text{DA1.C1} & \quad F_{c,d} = 1.0 \, G_k + 1.3 \, Q_k = 1.0 \times 600 + 1.3 \times 300 = 990 \text{ kN}
\end{align*}
\]

Design resistances

\[
\begin{align*}
\text{DA1.C1} & \quad R_{c,d} = R_{b,k} / (\gamma_b \times \gamma_{R;d}) + R_{s,k} / (\gamma_s \times \gamma_{R;d}) \\
& = 386 / (1.0 \times 1.75) + 153 \times L_s / (1.0 \times 1.75) = 221 + 87.4 \, L_s \text{ kN} \\
\text{DA1.C2} & \quad R_{c,d} = R_{b,k} / (\gamma_b \times \gamma_{R;d}) + R_{s,k} / (\gamma_s \times \gamma_{R;d}) \\
& = 386 / (1.3 \times 1.75) + 153 \times L_s / (1.3 \times 1.75) = 170 + 67.3 \, L_s \text{ kN}
\end{align*}
\]

Equating actions and resistances

\[
\begin{align*}
\text{DA1.C1} & \quad 1260 = 221 + 87.4 \, L_s \quad \rightarrow \quad L_s = 11.9 \text{ m} \\
\text{DA1.C2} & \quad 990 = 170 + 67.3 \, L_s \quad \rightarrow \quad L_s = 12.2 \text{ m}
\end{align*}
\]

Hence DA1.C2 controls and the DA1 design pile length \( L = 3.0 + L_s = 15.5 \text{ m} \)
Design Approach 2 partial and model factors

- Combination of sets of partial factors
  DA2 A1 “+” M1 “+” R2

- Partial actions factors
  A1 $\gamma_G = 1.35 \quad \gamma_Q = 1.5$

- Partial material factors
  M1 not relevant ($\gamma_\phi = 1.0$)

- Partial resistance factor
  R2 $\gamma_b = 1.1 \quad \gamma_s = 1.1$

- Model factors:
  $\gamma_{R;d} = 1.75$ (In Irish NA and applied to $\gamma_b, \gamma_s$ and $\gamma_t$)
  $\gamma_{R;d} = 1.27$ (In German NA giving $\gamma_b = 1.1 \times 1.27 = 1.4, \gamma_s = 1.1 \times 1.27 = 1.4$)
Design Approach 2 - pile design to Irish NA

Design equation

\[ F_{c;d} \leq R_{c;d} \]

Design action

\[ F_{c;d} = 1.35 G_k + 1.5 Q_k = 1.35 \times 600 + 1.5 \times 300 = 1260 \text{ kN} \]

Design resistance

\[ R_{c;d} = \frac{R_{b;k}}{\gamma_{R;d}} + \frac{R_{s;k}}{\gamma_{R;d}} \]

\[ = \frac{386}{(1.1 \times 1.75)} + 153 \times L_s / (1.1 \times 1.75) = 201 + 79.5 L_s \text{ kN} \]

Equating design action and resistance

\[ 1260 = 201 + 79.5 L_s \]

\[ \rightarrow L_s = 13.3 \text{ m} \]

Hence the DA2 design pile length \( L = 3.0 + L_s = 16.5 \text{m} \)

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Design Approach 2 - pile design to German NA

Design equation

\[ F_{c;d} \leq R_{c;d} \]

Design action

\[ F_{c;d} = 1.35 \ G_k + 1.5 \ Q_k = 1.35 \times 600 + 1.5 \times 300 = 1260 \text{ kN} \]

Design resistance

\[ R_{c;d} = R_{b,k} / \gamma_b + R_{s,k} / \gamma_s \]

Note: R1 partial factors of 1.1 have been increased to 1.4, i.e. a model factor of 1.4/1.1 = 1.27 has been applied

\[ = 386 /1.4 + 153 \times L_s /1.4 = 276 + 109 \ L_s \text{ kN} \]

Equating design action and resistance

\[ 1260 = 276 + 109 \ L_s \]

\[ \rightarrow \ L_s = 9.0 \text{ m} \]

Hence DA2 design pile length \( L = 3.0 + L_s = 12.0 \text{ m} \)
Design Approach 3 partial and model factors

- Combination of sets of partial factors:
  \[ \text{DA3} \quad \text{A1}^* \text{ or A2}^+ \quad "+" \quad \text{M2} \quad "+" \quad \text{R3} \]
  * on structural actions
  † on geotechnical actions

- Partial actions factors:
  \[
  A1 \quad \gamma_G = 1.35 \quad \gamma_Q = 1.5 \\
  A2 \quad \gamma_G = 1.0 \quad \gamma_Q = 1.3 
  \]

- Partial material factor:
  \[
  M2 \quad \gamma_{cu} = 1.4 
  \]

- Partial resistance factors:
  \[
  R3 \quad \gamma_b = 1.0 \quad \gamma_s = 1.0 
  \]

- Model factor:
  \[
  \gamma_{R;d} = 1.75 \quad \text{(applied to } \gamma_b, \gamma_s \text{ and } \gamma_t) 
  \]
Design Approach 3 - pile design

Design equation
\[ F_{c,d} \leq R_{c,d} \]

Design action
\[ F_{c,d} = 1.35 G_k + 1.5 Q_k = 1.35 \times 600 + 1.5 \times 300 = 1260 \text{ kN} \]

Design resistance
\[ R_{c,d} = R_{b,d} + R_{s,d} \]
\[ = A_b x q_{b,d} + A_s x L_s x q_{s,d} \]
\[ = (A_b x N_q x c_{u,k} \gamma_{cu})/(\gamma_{R;d} \gamma_{b}) + (A_s x L_s x \alpha x c_{u,k} \gamma_{cu})/(\gamma_{R;d} \gamma_{s}) \]
\[ = (0.159 x 9 x 270/1.4)/(1.75 x 1.0) + (1.414 x L_s x 0.4 x 270/1.4)/(1.75 x 1.0) \]
\[ = 158 + 62.3 L_s \]

Equating design action and resistance
\[ 1260 = 158 + 62.3 L_s \]
\[ \rightarrow L_s = 17.7 \text{ m} \]

Hence the DA3 design pile length \( L = 3.0 + L_s = 21 \text{ m} \)
Conclusions from pile worked example 3

- The design pile lengths obtained from ground strength parameters using the alternative procedure and the model factor in the Irish and German National Annexes are:
  - DA1 (Irish NA) \( L = 15.5 \) m
  - DA2 (Irish NA) \( L = 16.5 \) m
  - DA3 (Irish NA) \( L = 21.0 \) m
  - DA2 (German NA) \( L = 12.0 \) m

- Application of the model factor of 1.75 as well as the material factor of 1.4 to obtain the design resistance when using DA3, results in DA3 providing a longer design pile length and hence the least economical Design Approach in Ireland.

- The longer design pile length of 16.5 m when using the Irish NA with DA2 compared to 12.0 m when using the German NA is because of the model factor of 1.75 in the Irish NA and 1.27 in the German NA.
Geotechnical design with worked examples

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