Safety Concepts and Calibration of Partial Factors in European and North American Codes of Practice

The Dutch approach on Geotechnical Design by Eurocode 7

Adriaan van Seters
Hein Jansen

Fugro GeoServices BV
The Netherlands

Contents

Typical Dutch…….
- Design Approach 3 – why??
- Piled structures – Cone resistance $q_c$ and EC7
- Shallow foundations
- Probabilistic Analyses for retaining structures
- Calculation method for retaining structures
- Slope stability
- Summary
Why Design Approach 3

- In 1970’s / 1980’s huge Water barriers in SW Holland
- Structures far outside the Technical State of the Art
- Extrapolation of knowledge was necessary
Why Design Approach 3

For those structures … Probabilistic design

- Top safety event distributed into chances of failure for sub systems
- Safety associated with uncertainty of loads and resistances
- Resistance related to strength of materials

From 1990 → probabilistic design in Dutch codes
Partial factors on loads and materials – based on probabilistic analyses
Pile foundations – Pile bearing capacity

- Pile bearing capacity based on CPT’s
  - Load tests in 1950’s
  - CPT is a “modelpile”
  - Tip and shaft resistance based on $q_c$ ($q_c = $ cone resistance)

- Tip resistance $q_b$, shaft resistance $q_s$
  \[ q_b = \alpha_p \cdot q_c, \quad q_s = \alpha_s \cdot q_c \]

- Different pile types → different $\alpha$-factors
  $\alpha_p$ - 0.6 to 1.0, $\alpha_s$ - 0.6 % to 1.4 %

- Partial factor $\gamma_f$, $\gamma_s$:t
  (same for all pile types)

- $\xi_3$, $\xi_4$ - values between 1.4 and 1.0
  (depend on no of CPT’s, since 1990)
### DA 3: Partial Factors $\gamma$

- **A on Loads**
- **M on Materials**

<table>
<thead>
<tr>
<th>Design Approach</th>
<th>Load/ Load effect</th>
<th>Material- Factor</th>
<th>Factor total Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>DA 1.1</td>
<td>$&gt; 1,0$</td>
<td>$= 1,0$</td>
<td>$= 1,0$</td>
</tr>
<tr>
<td>DA 1.2</td>
<td>$= 1,0$ $&gt; 1,0$ (q - last)</td>
<td>$&gt; 1,0$</td>
<td>$= 1,0$</td>
</tr>
<tr>
<td>DA 2</td>
<td>$&gt; 1,0$</td>
<td>$= 1,0$</td>
<td>$&gt; 1,0$</td>
</tr>
<tr>
<td>DA 3</td>
<td>$&gt; 1,0$</td>
<td>$&gt; 1,0$</td>
<td>$= 1,0$</td>
</tr>
</tbody>
</table>

**Piles in NL:** $q_c$ is material parameter material factor $\gamma$ on $q_c$ $\rightarrow$ **DA3**

**Alternatively:** factor on resistance $\rightarrow$ **DA2**
Pile factors $\alpha$

- Factors $\alpha$ are based on pile load tests in 1950’s – 1980’s

- Dutch buildings $\rightarrow$ CPT’s every 25 * 25 m

- 2011: Pile load testing – seldom executed, no standard routine

- Recent discussion
  - Underperformance of precast concrete piles
  - New – *untested* – pile types

- Pile testing campaign required for all manufacturers

- Ready by 2016, otherwise 33 % reduction in bearing capacity/factor $\alpha$
Shallow foundations

In NL – Not many shallow foundations!

Bearing capacity formula
\[ q = N_c * c_u + \gamma * d * N_q + 0,5 * B * \gamma * N_\gamma \]

DA3 → load and material factors

Factors based on Prob sums

Tabel A.4 - Partial factors (\( \gamma_M \))

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Symbol Set M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tan friction angle</td>
<td>( \gamma_\phi' )</td>
<td>1,25 EC-7 1,15 Nat.Annex</td>
</tr>
<tr>
<td>Effective cohesion</td>
<td>( \gamma_c' )</td>
<td>1,25 1,6</td>
</tr>
<tr>
<td>Undrained shear strength</td>
<td>( \gamma_{cu} )</td>
<td>1,4 1,35</td>
</tr>
<tr>
<td>Volume weight</td>
<td>( \gamma_\gamma )</td>
<td>1,0 1,0</td>
</tr>
</tbody>
</table>
Sheet piles - Design Approach 3

OB 3: partial factors on:
- A on Loads and Load effects
- M on Material strength
Material Factors applied to Sheetpiles

\[
\begin{align*}
(45-\phi'/2) & \quad \text{Characteristic values } \phi'_{\text{char}} \\
(45+\phi'/2) & \quad \text{Design values } \phi'_d \\
\tan\phi'_d &= \frac{\tan\phi'_{\text{char}}}{\gamma_\phi}
\end{align*}
\]
## Safety and Reliability in Eurocode 7

### Eurocode 0 (NEN-EN 1990)

<table>
<thead>
<tr>
<th>Class</th>
<th>$\beta$</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC1/RC1</td>
<td>3,3</td>
<td>Family house</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Buildings $&lt; 3$ stories</td>
</tr>
<tr>
<td>CC2/RC2</td>
<td>3,8</td>
<td>Offices, apartments</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic bridges</td>
</tr>
<tr>
<td>CC3/RC3</td>
<td>4,3</td>
<td>High rise buildings $&gt; 70$ m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stadions, Concert halls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Primary dikes, railway bridges</td>
</tr>
</tbody>
</table>

Distinction between CC/RC-Classes in Eurocode EN-1990 given by **LOADFACTORS** $\gamma_F$ (for Class CC2/RC2)

for:  
- CC1/RC1: $\gamma = 0,9 \times \gamma_F$
- CC3/RC3: $\gamma = 1,1 \times \gamma_F$
Eurocode EN 1990:

- Load factors to be used are according SET C
- Permanent loads $\gamma = 1.0$
- Variable loads $\gamma = 1.3$

**Main load** = soil weight $\rightarrow$ **both** stabilising and destabilising

$\Rightarrow$ Therefore $\gamma = 1.0$ is correct, but no difference for various CC/RC-Classes

$\Rightarrow$ In NL – Variation in Material Factors per CC/RC
Probabilistic Analyses in 1990 and 2005

Configurations analysed
Probabilistic Analyses – partial factors

Probabilistic analyses Level II and Level III (Monte Carlo)

- stochastic parameters (geometry, soil parameters)
- average value $\mu$ and standard deviation $\sigma$
  \[
  \text{(variation coefficient } V = \frac{\sigma}{\mu})
  
- Combined with Reliability index $\beta = 3,3 / 3,8 / 4,3$ (EN 1990)

Partial factor $\gamma$

\[
\gamma = \frac{1 - 1.64 \cdot V}{1 - \alpha \cdot \beta \cdot V}
\]

influence factors $\alpha$ follow from probabilistic analyses
Partial Factor for tan (\(\varphi'\))

General trend \(V = 0.1\) – assumed variation for tan (\(\varphi\))

\[
\begin{align*}
\text{gamma} & \quad 2.0 \\
\text{gamma} & \quad 1.9 \\
\text{gamma} & \quad 1.8 \\
\text{gamma} & \quad 1.7 \\
\text{gamma} & \quad 1.6 \\
\text{gamma} & \quad 1.5 \\
\text{gamma} & \quad 1.4 \\
\text{gamma} & \quad 1.3 \\
\text{gamma} & \quad 1.2 \\
\text{gamma} & \quad 1.1 \\
\text{gamma} & \quad 1.0 \\
\text{alfa} & \quad 0.0 \\
\text{alfa} & \quad 0.2 \\
\text{alfa} & \quad 0.4 \\
\text{alfa} & \quad 0.6 \\
\text{alfa} & \quad 0.8 \\
\text{alfa} & \quad 1.0
\end{align*}
\]

\(V = 0.1\)

\(\text{alfa} = 0.75\)

\(\beta = 3.3\)

\(\beta = 3.8\)

\(\beta = 4.2\)
Partial Factors for Retaining Walls (flexible)

<table>
<thead>
<tr>
<th>Soil parameter</th>
<th>Symbol</th>
<th>Set M2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reliability Class</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RC1 (β = 3,3)</td>
</tr>
<tr>
<td>Friction angle tan φ’</td>
<td>γφ'</td>
<td>1,15</td>
</tr>
<tr>
<td>Effective cohesion</td>
<td>γc'</td>
<td>1,15</td>
</tr>
<tr>
<td>Undrained Shear strength</td>
<td>γcu</td>
<td>1,5</td>
</tr>
<tr>
<td>Volume unit weight</td>
<td>γg</td>
<td>1,0</td>
</tr>
</tbody>
</table>

Geometric offsets:
- retaining height: 10 % extra, max 0.5 m (acc EC7)
- waterlevel: extra 0.25 m difference between both sides
Use Beam-Column method with linear soil springs

For each calculation phase – 5 calculations

• ULS - Vary spring stiffness (high/low) and vary waterlevel at excavation (high/low) – 4 calcs

• SLS-calculation
### CALCULATION SCHEME

<table>
<thead>
<tr>
<th>Phase</th>
<th><strong>Scheme A</strong></th>
<th><strong>Scheme B</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Always design values (d)</td>
<td>Design values (d) in applicable phase, but characteristic values (char) in previous phases</td>
</tr>
<tr>
<td>1</td>
<td>d ↓</td>
<td>char → d ↓</td>
</tr>
<tr>
<td>2</td>
<td>d ↓</td>
<td>char → d ↓</td>
</tr>
<tr>
<td>3</td>
<td>d ↓</td>
<td>char → d ↓</td>
</tr>
<tr>
<td>...</td>
<td>d ↓</td>
<td>char → d ↓</td>
</tr>
</tbody>
</table>

**Scheme A** → conservative  
**Scheme B** → enough safety based on PROB analyses
EXAMPLE

Phases
1. Excavate to NAP + 0.7 m
2. Install Anchor
3. Excavate to NAP -6.0 m (wet)
4. Underwater concrete
   + pump out water

- 10.0 m
- 6.0 m
FA + 1.0 m
NAP + 2.0 m
+ 0.5 m
10 kPa
AZ 18

Sand
Clay
Peat
Silt
Sand silty
Clay, sandy
Gravel
Sand
### EXAMPLE

<table>
<thead>
<tr>
<th>PHASE</th>
<th>SLS [char-values]</th>
<th>ULS – scheme A</th>
<th>ULS – scheme B</th>
<th>ULS = SLS x 1.2*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M_{rep}$</td>
<td>$F_{A;rep}$</td>
<td>$M_d$</td>
<td>$F_{A;d}$</td>
</tr>
<tr>
<td>1. Excavate to 0.7 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Install anchor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Excavate to – 6 m</td>
<td>139</td>
<td>116</td>
<td>260</td>
<td>149</td>
</tr>
<tr>
<td>4. Under water concrete + pumping</td>
<td>190</td>
<td>131</td>
<td>287</td>
<td>177</td>
</tr>
</tbody>
</table>

*) Factor on Load Effect
## EXAMPLE

<table>
<thead>
<tr>
<th>PHASE</th>
<th>SLS [char-values]</th>
<th>ULS – scheme A</th>
<th>ULS – scheme B</th>
<th>ULS = SLS x 1,2*)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( M_{\text{rep}} )</td>
<td>( F_{A;\text{rep}} )</td>
<td>( M_{d} )</td>
<td>( F_{A;d} )</td>
</tr>
<tr>
<td>1. Excavate to 0.7 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Install anchor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Excavate to – 6 m</td>
<td>139</td>
<td>116</td>
<td>260</td>
<td>149</td>
</tr>
<tr>
<td>4. Under water concrete + pumping</td>
<td>190</td>
<td>131</td>
<td>287</td>
<td>177</td>
</tr>
</tbody>
</table>

*) Factor on Load Effect
## EXAMPLE

<table>
<thead>
<tr>
<th>PHASE</th>
<th>SLS [char-values]</th>
<th>ULS – scheme A</th>
<th>ULS – scheme B</th>
<th>ULS = SLS x 1,2*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M_{rep}$</td>
<td>$F_{A;rep}$</td>
<td>$M_d$</td>
<td>$F_{A;d}$</td>
</tr>
<tr>
<td>1. Excavate to 0.7 m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Install anchor</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Excavate to – 6 m</td>
<td>139</td>
<td>116</td>
<td>260</td>
<td>149</td>
</tr>
<tr>
<td>4. Under water concrete + pumping</td>
<td>190</td>
<td>131</td>
<td>287</td>
<td>177</td>
</tr>
</tbody>
</table>

*) Factor on Load Effect
Slope Stability
# Partial Factors - Slopes

<table>
<thead>
<tr>
<th>SOIL PARAMETER</th>
<th>Symbol</th>
<th>Slope Stability Set M2</th>
<th>Default EC7</th>
<th>Reliability Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction angle tan $\varphi'$</td>
<td>$\gamma_\varphi$</td>
<td></td>
<td>1,25</td>
<td>RC1 RC2 RC3</td>
</tr>
<tr>
<td>Cohesion $c'$</td>
<td>$\gamma_c'$</td>
<td></td>
<td>1,25</td>
<td>1,2 1,25 1,3</td>
</tr>
<tr>
<td>Undrained shear strength $c_u$</td>
<td>$\gamma_{cu}$</td>
<td></td>
<td>1,4</td>
<td>1,5 1,75 2,0</td>
</tr>
<tr>
<td>Volume unit weight</td>
<td>$\gamma_g$</td>
<td></td>
<td>1,0</td>
<td>1,0 1,0 1,0</td>
</tr>
</tbody>
</table>

Material factors are based on PROB analyses in the 90’s
DUTCH FEATURES OF EC7 DESIGN - SUMMARY

- Since 1990 → Netherlands uses Design Approach 3 for all materials
  - Pile foundations – partial factor on cone resistance $q_c$
    - verification of pile factors $\alpha_p$, $\alpha_s$
  - Shallow foundations – Standard EC7 procedure, Partial factors deviate
  - Sheetpiles – design based on calculation scheme with SLS and ULS phases
    - material factors per Safety Class CC/RC
  - Slopes - material factors per Safety Class CC/RC
Thank You

a.vseters@fugro.nl