Geotechnical aspects of building design (EN 1997)

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1. General presentation of Eurocode 7 ‘Geotechnical design’
   Contents of Part 1 and 2
   Specific aspects of EN 1997-1
   3 ULS-Design Approaches (DAs)
   SLS and allowable movements of foundations
   Spread foundations
   Principles of embedded wall design

2. Application to building design
   Geotechnical data
   Column B2
     ULS-bearing capacity
     ULS-sliding
     SLS-settlement
GENERAL PRESENTATION OF EUROCODE 7

STRUCTURAL EUROCODES

EN 1990

EN 1991

EN 1992
EN 1993
EN 1994

EN 1995
EN 1996
EN 1999

Basis of Structural design

Actions on structures

«Material » resistance

Geotechnical and seismic design
Eurocode 7 – Geotechnical design


Section 1 General
Section 2 Basis of geot design
Section 3 Geotechnical data
Section 4 Supervision of construction, monitoring and maintenance
Section 5 Fill, dewatering, ground improv and reinfor
Section 6 Spread foundations *
Section 7 Pile foundations
Section 8 Anchorages
Section 9 Retaining structures *
Section 10 Hydraulic failure
Section 11 Site stability
Section 12 Embankments

> + number of Informative annexes with geotechnical models
Section 1 General
Section 2 Planning and reporting of ground investigations
Section 3 Drilling, sampling and gw measurements
Section 4 Field tests in soils and rocks
Section 5 Laboratory tests on soils and rocks
Section 6 Ground investigation report

> Also a number of Informative annexes
Clauses on:

- CPT(U), PMT, FDT, SPT, DP, WST, FVT, DMT, PLT

Objectives, specific requirements, evaluation of test results, use of test results and derived values

Annexes with examples on use of results and derived values for geotechnical design
preparation of soil specimens for testing
preparation of rock specimens for testing
tests for classif., identif. and description of soils
chemical testing of soils and groundwater
strength index testing of soils
strength testing of soils
compressibility and deformation testing of soils
compaction testing of soils
permeability testing of soils
tests for classification of rocks
swelling testing of rock material
strength testing of rock material
### Results of test standards

**EN 1997-2  Annex A**

#### Field test

<table>
<thead>
<tr>
<th>Field test</th>
<th>Test results</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPT/CPTU</td>
<td>( q_c, f_s, R_f ) (CPT) / ( q_t, f_s, u ) (CPTU)</td>
</tr>
<tr>
<td>Dynamic probing</td>
<td>( N_{10} ) (DPL, DPM, DPH); ( N_{10} ) or ( N_{20} ) (DPSH)</td>
</tr>
<tr>
<td>SPT</td>
<td>( N, E_r ) (SPT), soil description</td>
</tr>
<tr>
<td>Pressuremeters (PMT)</td>
<td>( E_M, p_f, p_{IM} ) (MPM); expansion curve (all)</td>
</tr>
<tr>
<td>Flexible dilatometer (FDT)</td>
<td>( E_{FDT} ), deformation curve</td>
</tr>
<tr>
<td>Field vane test (FVT)</td>
<td>( c_{fv}, c_{rv} ), torque-rotation curve</td>
</tr>
<tr>
<td>Weight sounding test (WST)</td>
<td>continuous record of penetration depth or ( N_b )</td>
</tr>
<tr>
<td>Plate loading test</td>
<td>( p_u )</td>
</tr>
<tr>
<td>Flta dilatometer test</td>
<td>( P_0, p_1, E_{DMT}, l_{DMT}, K_{DMT} ) (DMT)</td>
</tr>
</tbody>
</table>

#### Laboratory tests

**Soils**: \( w; \rho; \rho_s; \) grain size distribution curve ; \( w_P, w_L; \) \( e_{max}, e_{min}; l_D; C_{OM}; C_{CaCO3}; C_{SO4^{2-}}, C_{SO3^{2-}}; C_{cl}; \) pH ; compressibility, consolidation, creep curves, \( E_{oed}, \sigma'_p \) or \( C_s, C_c, \sigma'_p, C_\alpha; c_u \) (lab vane); \( c_u \) (fall cone); \( q_u, c_u \) (UU); \( \sigma-\varepsilon \) and \( u \) curves, \( \sigma-\)paths, Mohr circles; \( c', \varphi' \) or \( c_u', c_u=f(\sigma'c) \), \( E' \) or \( E_u \); \( \sigma-u \) curve, \( \tau-\sigma \) diagram, \( c', \varphi' \), residual parameters ; \( l_{CBR}; k \) (direct lab, field or oedometer)

**Rocks**: \( w; \rho \) and \( n \); swelling results ; \( \sigma_c, E \) and \( \nu \); \( l_{s50}; \) \( \sigma-u \) curve, Mohr diagram, \( c' \), \( \varphi' \), res par ; \( \sigma_T; \sigma-\varepsilon \) curve, \( \sigma-\)paths, Mohr circles ; \( c', \varphi', E \) and \( \nu \)
### Geotechnical properties

#### Type of test

- F = field
- L = laboratory

#### Correlations

<table>
<thead>
<tr>
<th>Test results and derived values</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 1997 -2</td>
</tr>
<tr>
<td>EN 1997 -1</td>
</tr>
</tbody>
</table>

#### Information from other sources on the site, the soils and rocks and the project

#### Cautious selection

#### Geotechnical model and characteristic value of geotechnical properties

#### Application of partial factors

#### Design values of geotechnical properties
Specific aspects of Eurocode 7-1

Characteristic values and design values
ULS Design Approaches
SLS and deformations of structures
The characteristic value of a geotechnical parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state.

If statistical methods are used, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of the limit state under consideration is not greater than 5%.
• **EQU**: loss of equilibrium of the structure
• **STR**: internal failure or excessive deformation of the structure or structural elements
• **GEO**: failure or excessive deformation of the ground
• **UPL**: loss of equilibrium due to uplift by water pressure (buoyancy) or other vertical actions
• **HYD**: hydraulic heave, internal erosion and piping caused by hydraulic gradients
Design values of geotechnical parameters

Design value of a parameter: \( X_d = X_k / \gamma_M \)

Design values of actions and resistances

fulfilling for STR/GEO ULS: \( E_d \leq R_d \)

\[
E_d = E \{ \gamma_F F_k ; X_k / \gamma_M \} \quad \text{and} \quad R_d = R \{ \gamma_F F_k ; X_k / \gamma_M \}
\]

(= “at the source”)

or

\[
E_d = \gamma_E E \{ F_k ; X_k \} \quad \text{and} \quad R_d = R \{ F_k ; X_k \} / \gamma_R
\]
EN1990 - Ultimate limit states
EQU and STR/GEO

\[ E_d < R_d \]

J.A Calgaro
**ULS - STR/GEO : 3 Design Approaches**

for persistent and transient design situations

<table>
<thead>
<tr>
<th>Approaches</th>
<th>Combinations</th>
</tr>
</thead>
</table>
| 1          | A1 “+” M1 “+” R1 &
|            | A2 “+” M2 “+” R1 |
| 2          | A1 “+” M1 “+” R2 |
| 3          | A1 or A2 “+” M2 “+” R3 |

**Format:** $E_d < R_d$

### Action ($\gamma_F$)

<table>
<thead>
<tr>
<th></th>
<th>Symbol</th>
<th>Set A1</th>
<th>Set A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td>$\gamma_G$</td>
<td>1,35</td>
<td>1,00</td>
</tr>
<tr>
<td>Unfavourable</td>
<td>$\gamma_G$</td>
<td>1,00</td>
<td>1,00</td>
</tr>
<tr>
<td>Favourable</td>
<td>$\gamma_G$</td>
<td>1,00</td>
<td>1,00</td>
</tr>
<tr>
<td>Variable</td>
<td>$\gamma_Q$</td>
<td>1,50</td>
<td>1,30</td>
</tr>
<tr>
<td>Unfavourable</td>
<td>$\gamma_Q$</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Favourable</td>
<td>$\gamma_Q$</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

### Soil parameter ($\gamma_M$)

<table>
<thead>
<tr>
<th></th>
<th>Symbol</th>
<th>Set M1</th>
<th>Set M2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle of shearing</td>
<td>$\gamma_\phi'$</td>
<td>1,00</td>
<td>1,25</td>
</tr>
<tr>
<td>resistance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Effective cohesion</td>
<td>$\gamma_c'$</td>
<td>1,00</td>
<td>1,25</td>
</tr>
<tr>
<td>Undrained shear</td>
<td>$\gamma_{cu}$</td>
<td>1,00</td>
<td>1,40</td>
</tr>
<tr>
<td>strength</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unconfined strength</td>
<td>$\gamma_{qu}$</td>
<td>1,00</td>
<td>1,40</td>
</tr>
<tr>
<td>Weight density</td>
<td>$\gamma_\gamma$</td>
<td>1,00</td>
<td>1,00</td>
</tr>
</tbody>
</table>

### Resistance ($\gamma_R$)

<table>
<thead>
<tr>
<th></th>
<th>Symbol</th>
<th>Set R1</th>
<th>Set R2</th>
<th>Set R3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearing capacity</td>
<td>$\gamma_{RV}$</td>
<td>1,00</td>
<td>1,4</td>
<td>1,00</td>
</tr>
<tr>
<td>Sliding</td>
<td>$\gamma_{Rh}$</td>
<td>1,00</td>
<td>1,1</td>
<td>1,00</td>
</tr>
</tbody>
</table>

$\gamma_R$ for Spread foundations
Verifications:

\[ E_d \leq C_d \]

\( C_d \) = limiting design value of the relevant serviceability criterion

\( E_d \) = design value of the effects of actions specified in the serviceability criterion, determined on the basis of the relevant combination

all \( \gamma_F \) and \( \gamma_M = 1.0 \)
settlement $s$, differential settlement $\delta s$, rotation $\theta$ and angular strain $\alpha$

relative deflection $\Delta$ and deflection ratio $\Delta/L$

$\omega$ and relative rotation (angular distortion) $\beta$

(after Burland and Wroth, 1975)
Foundations of buildings (Eurocode 7, 1994)

* Serviceability limit states (SLS) : $\beta_{\text{max}} \approx 1/500$
* Ultimate limit states (ULS) : $\beta_{\text{max}} \approx 1/150$

- $s_{\text{max}} \approx 50 \text{ mm}$
- $\delta_{s_{\text{max}}} \approx 20 \text{ mm}$

Foundations of bridges

Moulton (1986) for 314 bridges in the US and Canada :

* $\beta_{\text{max}} \approx 1/250$ (continuous deck bridges)
* $\beta_{\text{max}} \approx 1/200$ (simply supported spans)

- $s_{H_{\text{max}}} \approx 40 \text{ mm}$

In France, in practice :

ULS : $\beta_{\text{max}} \approx 1/250$
SLS : $\beta_{\text{max}} \approx 1/1000 \text{ à } 1/500$
Bearing resistance:

\[ V_d \leq R_d = R_k / \gamma_{R,v} \]

\( (R_k : \text{analytical – Annex D, semi-empirical – Annex E or prescriptive - Annex G}) \)

Sliding resistance:

\[ H_d \leq R_d + R_{p;d} \]

\[ [+ R_d \leq 0.4 V_d ] \]

- Drained conditions:

\[ R_d = V'_d \tan \delta_d \quad \text{or} \quad R_d = (V'_d \tan \delta_k) / \gamma_{R,h} \]

- Undrained conditions:

\[ R_d = A'c_{u;d} \quad \text{or} \quad R_d = (A'c_{u;k}) / \gamma_{R,h} \]
Overall stability

Large eccentricities: special precautions if:
\[ e/B > \frac{1}{3} \text{ (or 0,6 } \phi \text{)} \]

Structural failure due to foundation movement

Structural design of spread foundation:
see EN 1992
<table>
<thead>
<tr>
<th>Design approach</th>
<th>Actions on/from the structure $\gamma_F$</th>
<th>Geotechnical resistance $\gamma_R$ or $\gamma_M$ (at the source)</th>
</tr>
</thead>
</table>
| 1               | 1,35 and 1,5    | $\gamma_{R;v} = 1,0$  
|                 | 1,0 and 1,3     | $\gamma_{R;h} = 1,0$  |
|                 |                 | $\gamma_R = 1,0$  
| 2               | 1,35 and 1,5    | $\gamma_{R;v} = 1,4$  
|                 | 1,0 and 1,3     | $\gamma_{R;h} = 1,1$  |
| 3               | 1,35 and 1,5    | $\gamma_M = 1,25$ or $1,4$  |
Serviceability limit states (SLS)

Include both immediate and delayed settlements

Assess differential settlements and relative rotations

Check that limit values for the structure are not reached
Verifications methods

Direct method:
- check each limit states (ULS and SLS)
- check the settlement for the SLSs

Indirect method:
- only a SLS calculation based on experience

Prescriptive method:
- example of the presumed bearing resistance on rocks (Annex G)
Annex A  (normative) Safety factors for ultimate limit states

Informative annexes :

Annex D  A sample analytical method for bearing resistance calculation

Annex E  A sample semi-empirical method for bearing resistance estimation

Annex F  Sample methods for settlement evaluation

Annex G  A sample method for deriving presumed bearing resistance for spread foundations on rock

Annex H  Limiting foundation movements and structural deformation
“c-φ” model (Annex D)

\[ \frac{R}{A'} = c' \times N_c \times b_c \times s_c \times i_c \]

\[ + q' \times N_q \times b_q \times s_q \times i_q \]

\[ + 0.5 \times \gamma' \times B' \times N_\gamma \times b_\gamma \times s_\gamma \times i_\gamma \]

Pressuremeter model (annexe E)

\[ \frac{R}{A'} = \sigma_v + k \times p_{le}^* \]

Settlement of foundations (Annex F)

Adjusted elasticity: \( s = p \times b \times f / E_m \)
### Background and Applications

#### EN 1997-1 annex G

#### Bearing resistance on rocks

<table>
<thead>
<tr>
<th>Group</th>
<th>Type of rock</th>
</tr>
</thead>
</table>
| 1     | Pure limestones and dolomites  
Carbonate sandstones of low porosity |
| 2     | Igneous  
Oolitic and marly limestones  
Well cemented sandstones  
Indurated carbonate mudstones  
Metamorphic rocks, including slates and schist  
(flatt cleavage/foliation) |
| 3     | Very marly limestones  
Poorly cemented sandstones  
Slates and schists (steep cleavage/foliation) |
| 4     | Uncemented mudstones and shales |

5. Allowable bearing pressure not to exceed uniaxial compressive strength of rock if joints are tight or 50% of this value if joints are open,

6. Allowable bearing pressures: a) very weak rock, b) weak rock c) moderately weak rock  
d) moderately strong rock, e) strong rock  
Spacings: f) closely spaced discontinuities  g) medium spaced discontinuities  h) widely spaced discontinuities

For types of rock in each of four groups, see Table G.1. Presumed bearing resistance in hatched areas to be assessed after inspection and/or making tests on rock. (from BS 8004)
Informative annexes:

D.3 Example of a method to determine the settlement for spread foundations from CPT
D.4 Example of a correlation between the oedometer modulus and the cone penetration resistance from CPT
D.5 Examples of establishing the stress-dependent oedometer modulus from CPT results
E.1 Example of a method to calculate the bearing resistance of spread foundations from PMT
E.2 Example of a method to calculate the settlements for spread foundations from PMT
F.3 Example of a method to calculate the settlement of spread foundations from SPT
G.3 Example of establishing the stress-dependent oedometer modulus from DP results
J Flat dilatometer test (DMT)
K.4 Example of a method to calculate the settlement of spread foundations in sand from (PLT)
Gravity walls (in stone, concrete, reinforced concrete)

Embedded walls (sheet pile walls, slurry trench walls; cantilever or supported walls)

Composite retaining structures (walls composed of elements, double wall cofferdams, reinforced earth structures)
9.7.2 Overall stability (principles of section 11)

9.7.4 Rotational failure (lack of passive pressure)

9.7.5 Vertical failure (principles of sections 7)

9.7.6 Structural design (in accordance with EC 2, EC 3, EC 5 and EC 6)

9.7.7 Failure by pull-out of anchorages (in accordance with section 8)

9.7.1 (7) : Hydraulic failure (uplift, heave, etc.) (see section 10)
Overall stability (9.7.2):
Principles of section 11 apply

Rotational failure of embedded walls (9.7.4):
it shall be demonstrated that they have sufficient penetration into the ground, the design magnitude and direction of shear stress between the soil and the wall being consistent with the relative vertical displacement

Vertical failure of embedded walls (9.7.5):
The design magnitude and direction of shear stress between the soil and the wall shall be consistent with the check for vertical and rotational equilibrium

Failure by pull-out of anchorages (9.7.7): in accordance with section 8 (… under amendment !)
## Approaches

<table>
<thead>
<tr>
<th>Approaches</th>
<th>Combinations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A1 “+” M1 “+” R1 &amp; A2 “+” M2 “+” R1 (or A2 “+” M1 or M2 “+” R4)</td>
</tr>
<tr>
<td>2</td>
<td>A1 “+” M1 “+” R2</td>
</tr>
<tr>
<td>3</td>
<td>A1 or A2 “+” M2 “+” R3</td>
</tr>
</tbody>
</table>

### Action ($\gamma_F$)

<table>
<thead>
<tr>
<th>Permanent</th>
<th>Unfavourable</th>
<th>Favourable</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma_F$</td>
<td>1,35</td>
<td>1,00</td>
</tr>
</tbody>
</table>

### Soil parameter ($\gamma_M$)

| Angle of shearing resistance | $\gamma_F'$ | 1,00 | 1,25 |
| Effective cohesion           | $\gamma_c'$ | 1,00 | 1,25 |
| Undrained shear strength     | $\gamma_{cu}$ | 1,00 | 1,40 |

### Resistance ($\gamma_R$)

| Bearing capacity | $\gamma_R;v$ | 1,00 | 1,40 | 1,00 |
| Sliding resistance | $\gamma_R;h$ | 1,00 | 1,10 | 1,00 |
| Earth resistance   | $\gamma_R;e$ | 1,00 | 1,40 | 1,00 |

$\gamma_R$ for Retaining structures
Annex A (normative) Safety factors for ultimate limit states

Informative annexes:
Annex C Limit values of earth pressures on vertical walls
Annex H Limiting foundation movements and structural deformation
Active / Passive earth pressures

\[ \beta = -\varphi \\tan \theta + \varphi \]

\[ \delta = 0 ; \frac{2}{3}\varphi \text{ and } \varphi \]
EUROCODE 2
Background and Applications

Building design

SECTION 1

SECTION 2
For the sake of simplicity, in the present study, it is assumed that the whole building is founded on a very stiff clay:

- undrained shear strength (for total stresses analysis, short term) : \( c_u = 300 \text{ kPa} \)
- total unit weight : \( \gamma_k = 20 \text{ kN/m}^3 \)

The water-table is assumed to be at natural ground level.
### Example of column B2

#### Table 1. Forces and moments on the foundation of column B2 for ULS – Fundamental combinations (Curbach and Just, 2011)

<table>
<thead>
<tr>
<th>Combination: (1.35 \cdot G + 1.5 \cdot Q1 + 1.5 \cdot 2(\text{psi0} \cdot Q1))</th>
<th>Considered load cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>max My, accordingly N, V und Mz</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-4554.80</td>
<td>-3.56</td>
</tr>
<tr>
<td>-4837.96</td>
<td>0.24</td>
</tr>
<tr>
<td>max Vy, acc. N, V und My</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-4990.35</td>
<td>0.48</td>
</tr>
<tr>
<td>max Vz, acc. N, V und Vy</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-4985.91</td>
<td>-2.81</td>
</tr>
<tr>
<td>max N, acc. V und M</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-4491.62</td>
<td>-1.83</td>
</tr>
<tr>
<td>min My, acc. N, V und Mz</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-5435.54</td>
<td>-3.83</td>
</tr>
<tr>
<td>min Mz, acc. N, V und My</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-5359.70</td>
<td>1.26</td>
</tr>
<tr>
<td>min Vy, acc. M, N und Vz</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-5359.70</td>
<td>1.26</td>
</tr>
<tr>
<td>min Vz, acc. M, N und Vy</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-4502.78</td>
<td>-3.18</td>
</tr>
<tr>
<td>min N, acc. V und M</td>
<td>(Q1)</td>
</tr>
<tr>
<td>-5780.18</td>
<td>-4.53</td>
</tr>
</tbody>
</table>
Table 2. Forces and moments on the foundation of column B2 for SLS (Curbach and Just, 2011)

<table>
<thead>
<tr>
<th>Combination</th>
<th>1,00 * G + 1,00 * Σ(ψi2 * Qi)</th>
<th>Considered load cases Qi</th>
</tr>
</thead>
<tbody>
<tr>
<td>max My, accordingly N, V und Mz</td>
<td>-3365,83 -2,75 0,83 -1,24 -2,61 10101</td>
<td>10011</td>
</tr>
<tr>
<td>max Mz, acc. N, V und My</td>
<td>-3434,58 -1,95 0,70 -1,18 -1,89 10011</td>
<td></td>
</tr>
<tr>
<td>max Vy, acc. M, N und Vz</td>
<td>-3434,58 -1,95 0,70 -1,18 -1,89 10011</td>
<td></td>
</tr>
<tr>
<td>max Vz, acc. M, N und Vy</td>
<td>-3506,91 -3,02 0,84 -1,25 -2,86 10121, 1356, 10001</td>
<td></td>
</tr>
<tr>
<td>max N, acc. V und M</td>
<td>-3473,34 0,65 0,69 -1,13 -0,68 1366, 10001, 10111</td>
<td></td>
</tr>
<tr>
<td>min My, acc. N, V und Mz</td>
<td>-3603,82 -3,03 0,87 -1,31 -2,90 10121, 10031, 1356</td>
<td></td>
</tr>
<tr>
<td>min Mz, acc. N, V und My</td>
<td>-3585,31 -0,66 0,72 -1,19 -0,72 10111, 10031, 1336</td>
<td></td>
</tr>
<tr>
<td>min Vy, acc. M, N und Vz</td>
<td>-3585,31 -0,66 0,72 -1,19 -0,72 10111, 10031, 1336</td>
<td></td>
</tr>
<tr>
<td>min Vz, acc. M, N und Vy</td>
<td>-3585,31 -0,66 0,72 -1,19 -0,72 10111, 10031, 1336</td>
<td></td>
</tr>
<tr>
<td>min N, acc. V und M</td>
<td>-3618,11 -3,03 0,87 -1,31 -2,90 10121, 10031, 1336</td>
<td></td>
</tr>
</tbody>
</table>
Example of column B2

- ULS – Bearing capacity
- ULS – Sliding resistance
- SLS – Settlement check
Resultant actions: most unfavourable case in permanent and transient design situation – see table 1 (to be checked):

- \( N_d = -5.78 \ \text{MN} \)
- \( V_{yd} = -4.53 \times 10^{-3} \ \text{MN} \)
- \( V_{zd} = -1.54 \times 10^{-3} \ \text{MN} \)
- \( M_{yd} = -2.36 \times 10^{-3} \ \text{MN.m} \)
- \( M_{zd} = -4.49 \times 10^{-3} \ \text{MN.m} \)
- \( H_d = 4.78 \times 10^{-3} \ \text{MN.m} \)

Note that horizontal loads and moments on this foundation are negligible.
Geotechnical resistance (bearing capacity) – see Annex D of EN 1997-1 (CEN, 2004)

\[
R = A' (\pi+2) c_u \ s_c \ i_c
\]

(4)

with\[
A' = B' L' = (B-2e_B).(L-2e_L)
\]

and\[
s_c = 1+0.2 \ B'/L'
\]

with H being the resultant horizontal force (resultant of \(V_y\) and \(V_z\))

Eccentricity, is calculated by :

- in the transversal (B) direction : \(e_B = M_y/N\)
- in the longitudinal (L) direction : \(e_L = M_z/N\)

Note the dependance on the actions, thus on the design approach….
For **DA1-1, DA2 and DA3**, $e_B = 4.1 \times 10^{-4} \text{ m}$ (!)

$e_L = 7.8 \times 10^{-4} \text{ m}$ (!), $B' \approx B$ and $L' \approx L$ and $s_c = 1.2$

For **DA1-2**, the loads are divided by a factor somewhere between 1.15 and 1.35, depending on the proportion of permanent and variable loads.

Correction factor $s_c$, and the total resistance $R$ also depend on the Design Approach through $\gamma_M$ and $\gamma_{R;v}$ (see tables for spread foundations).
Design Approach 1

- combination DA1-1: \( \gamma_M = 1,0 ; \gamma_{R;v} = 1,0 \)
  Thus: \( c_{ud} = 300 \text{ kPa} ; s_c \approx 1,2 , i_c \approx 1 \)
  and \( R_d = 4 \times 5.14 \times 1.2 \times 1 \times 300 \times 10^{-3} / 1.0 = 7.4/1.0 \)
  \( = 7.4 \text{ MN} \) and \( N_d \leq R_d \) is verified.

- combination DA1-2: \( \gamma_M = 1,4 ; \gamma_{R;v} = 1,0 \)
  Thus: \( c_{ud} = 300/1,4 = 214 \text{ kPa} ; s_c \approx 1,2 , i_c \approx 1 \)
  and \( R_d = 4 \times 5.14 \times 1.2 \times 1 \times 214 \times 10^{-3} / 1.0 = 5.28/1.0 \)
  \( = 5.28 \text{ MN} \)

Let us assume that \( N_d \) is equal to \( N_d \) for DA1-2 divided by 1.25, thus \( N_d = 4.62 \text{ MN} \) and \( N_d \leq R_d \) is verified.
Design Approaches 2 and 3

They yield the same safety, because one of the values for the factors $\gamma_M$ and $\gamma_{R;v}$ is equal to 1.4 and the other one is equal to 1.0.

Thus: $R_d = 4 \times 5.14 \times 1.2 \times 1 \times 300 \times 10^{-3} / 1.4 = 5.28$ MN.

and $N_d \leq R_d$ is not verified.

The size of the footing should be around:

$A' = 1.4 \times N_d / (\pi + 2) c_u s_c i_c \approx 4.37$, that is, say: $B = L = 2.1$. The difference is small...
Dissemination of information for training – Brussels, 20-21 October 2011

**EUROCODE 2**

Background and Applications

Column B2 – ULS Sliding resistance

\[ H_d \leq R_d + R_{p;d} \]

where

- \( H_d \) is the horizontal component in the longitudinal direction
- \( R_d \) is the sliding resistance on the base area of the foundation
- \( R_{p;d} \) is the passive earth force in front of the spread foundation (will be neglected here).

For undrained conditions: \( R_d = \left( \frac{A'c_u}{\gamma M} \right)/\gamma R_h \)

where

- \( A' = B' L' = (B-2e_B).(L-2e_L) \)
- \( c_u = 300 \) kPa is the undrained shear strength of the stiff clay
Resultant actions: most unfavourable case in permanent and transient design situation – see table 1 (to be checked):

\[
\begin{align*}
N_d &= -4.50 \text{ MN} \\
V_{yd} &= -3.18 \times 10^{-3} \text{ MN} \\
V_{zd} &= -4.01 \times 10^{-3} \text{ MN} \\
M_{yd} &= -4.1 \times 10^{-3} \text{ MN.m} \\
M_{zd} &= -3.5 \times 10^{-3} \text{ MN.m} \\
H_d &= 5.12 \times 10^{-3} \text{ MN.m}
\end{align*}
\]

Note that horizontal loads and moments on this foundation are negligible and \(e_B\) and \(e_L\) remain negligible and \(B' \approx B\), \(L' \approx L\) and \(A' \approx BL \approx 4m^2\).
Design Approach 1

- combination DA1-1: $\gamma_M = 1,0 \; ; \; \gamma_{R;h} = 1,0$

Thus, $c_{ud} = 300$ kPa and $R_d = 4 \times 0.300 / 1.0 = 1.2$ MN

and $H_d \leq R_d$ is largely verified.

- combination DA1-2: $\gamma_M = 1,4 \; ; \; \gamma_{R;h} = 1,0$

Thus, $c_{ud} = 300 / 1.4 = 214$ kPa

and $R_d = 4 \times 0.214 / 1,0 = 0.86$ MN,

with $H_d < 5.12$ kN. $H_d \leq R_d$ is largely verified.

According to DA1, the foundation is safe with regard to sliding.
\textbf{Design Approach 2} : \( \gamma_M = 1,0 \); \( \gamma_{R;h} = 1,1 \)

Thus, \( c_{ud} = 300 \text{ kPa} \)
\[
R_d = 4 \times 0.300 / 1.1 = 1,09 \text{ MN}
\]
and \( H_d \leq R_d \) is largely verified.

\textbf{Design Approach 3} : \( \gamma_M = 1,4 \); \( \gamma_{R;h} = 1,0 \)

Thus, \( c_{ud} = 300 / 1.4 = 214 \text{ kPa} \)
\[
R_d = 4 \times 0.214 / 1.0 = 0.86 \text{ MN}
\]
and \( H_d \leq R_d \) is largely verified.
Column B2 – SLS Settlement check

\[ s_d < C_d \]

\( s_d \) - Determine the settlement(s)
- Compensated foundation: no settlement (?)
- Empirical Ménard pressuremeter calculation (Informative Annex D2 of EN 1997-2)
- Adjusted elasticity approach (Informative Annex F of EN 1997-1)

\( c_d \) - Check the results against … limiting values \( c_d \) provided for by the structural engineer!
Settlements are usually derived for SLS-QP combination

For column B2, from Table 2:

\[ N_d = 3.6 \text{ MN} \]

which corresponds to the applied pressure on the ground:

\[ q = \frac{N_d}{BL} = \frac{3.6}{2 \times 2} = 0.9 \text{ MPa} \]
Ménard formula: 
\[ s = (q - \sigma_{v0}) \times \left[ \frac{2B_0}{9E_d} \times \left( \frac{\lambda_d B}{B_0} \right)^a + \frac{\alpha \lambda_c B}{9E_c} \right] \]

- \( \sigma_{v0} = 0 \), as if the soil is loaded from its initial natural level (pessimistic assumption)
- square foundation: \( B_0 = 0.6\text{m}; \lambda_d = 1.12 \) and \( \lambda_c = 1.1 \)
- overconsolidated clay: \( \alpha = 1 \)
- \( E_M \approx 150 \text{ c_u} = 45 \text{ MPa}; \) thus, \( E_d = E_c = 45 \text{ MPa} \)

Finally, \( s_{B2} \)
\[
= (0.9-0.00)[1.2(1.12\times2/0.6)^{1/(9\times45)}+ 1\times1.1\times2/(9\times45)]
\]
\[
= 0.9 [0.011 + 0.0054] = 0.015 \text{ m} = 15 \text{ mm}.
\]
Adjusted elasticity (pseudo-elastic) approach (Annex F)

\[ s = q \times B \times f / E_m \]

but how to evaluate \( E_m \) ???

Here, it is assumed that \( E_m \approx E_u \approx 500 \text{ MPa} \)
(from Mair, 2011, Singapore clay matrix, \( c_u > 150 \text{ kPa} \), back-analysis of settlements of buildings on rafts):

\[ s_{B2} = 0.9 \times 2.0 \times 0.66 / 500 = 0.0023 = 2.3 \text{ mm} \]
Allowable relative rotation?

If \( \delta s \approx \frac{s_{B2}}{2}, \ L = 6 \ m \)

the relative rotation is for:

\[ \beta = \frac{s_{B2}}{2L} = 1.2 \times 10^{-3} \text{ and } 0.109 \times 10^{-3} \]

respectively

Annex H of EN 1997-1 (Informative) states that a relative rotation \( \beta = 1/500 = 2 \times 10^{-3} \) is quite acceptable
and to conclude, a nice sentence from En 1997-1:

It should be considered that knowledge of the ground conditions depends on the extent and quality of the geotechnical investigations. Such knowledge and the control of workmanship are usually more significant to fulfilling the fundamental requirements than is precision in the calculation models and partial factors.
Thank you for your kind and patient attention!