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PART 1 – BASIC ASSUMPTIONS

GENERAL
The following calculations of anchorage of the units and the corresponding reinforcement must be considered as an example illustrating the design model.

It must always be checked that the forces from the anchorage reinforcement can be transferred to the main reinforcement of the concrete components. The recommended reinforcement includes only the reinforcement necessary to anchor the unit to the concrete.

In the vicinity of the unit the element must be designed for the force $R_1$.

STANDARDS
The calculations are carried out in accordance with:

For all NDPs (Nationally Determined Parameter) in the Eurocodes the recommended values are used.

NDPs are as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\gamma_c$</th>
<th>$\gamma_s$</th>
<th>$\alpha_{cc}$</th>
<th>$\alpha_{cf}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended value</td>
<td>1.5</td>
<td>1.15</td>
<td>1.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*Table 1: NDP-s in EC-2.*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\gamma_{M0}$</th>
<th>$\gamma_{M1}$</th>
<th>$\gamma_{M2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recommended value</td>
<td>1.0</td>
<td>1.0</td>
<td>1.25</td>
</tr>
</tbody>
</table>

*Table 2: NDP-s in EC-3.*
QUALITIES

Concrete grade C35/45:

\[ f_{ck} = 35.0 \text{ MPa} \quad \text{EC2, Table 3.1} \]

\[ f_{cd} = \alpha_{fc} f_{ck} / \gamma_c = 1.35/1.5 = 23.3 \text{ MPa} \quad \text{EC2, Pt.3.15} \]

\[ f_{cd} = \alpha_{fc} f_{ck,0.05} / \gamma_c = 1.20/1.5 = 1.46 \text{ MPa} \quad \text{EC2, Pt.3.16} \]

\[ f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 f_{cd} = 2.25 \cdot 0.7 \cdot 1.0 \cdot 1.46 = 2.3 \text{ MPa} \quad \text{EC2, Pt.8.4.2} \]

Reinforcement 500C (EN 1992-1-1, Annex C):

\[ f_{yd} = f_y / \gamma_s = 500/1.15 = 435 \text{ MPa} \quad \text{EC2, Clause 3.2.7} \]

Note: Reinforcement steel of different ductility grade may be chosen provided that the bendability is sufficient for fitting the vertical suspension reinforcement to the half round steels in front of the unit.

Structural steel S355:

Tension: \[ f_{yd} = f_y / \gamma_{M0} = 355/1.0 = 355 \text{ MPa} \]
Compression: \[ f_{yd} = f_y / \gamma_{M0} = 355/1.0 = 355 \text{ MPa} \]
Shear: \[ f_{sd} = f_y / (\gamma_{M0} \cdot v^3) = 355/(1.0 \cdot v^3) = 205 \text{ MPa} \]

DIMENSIONS

Inner tube: HUP 70x40x4, Cold formed, S355
Outer tube: HUP 80x50x4, Cold formed, S355

LOADS

Vertical ultimate limit state load = \( F_V = 40 \text{kN} \).
PART 2 - REINFORCEMENT

**EQUILIBRIUM**

*Figure 1: Forces acting on the unit.*

\[ F_V \] = External force on the inner tube

\[ R_{d1}, R_{d2} \] = Internal forces between the inner and the outer tubes.

\[ R_1, R_2, R_3 \] = Support reaction forces of the outer tube.

\[ g \] = distance to the middle plane of the anchoring stirrups in front of the unit.
1) Equilibrium inner tube:

![Equilibrium inner tube diagram]

**Figure 2: Forces acting on the inner tube.**

Equilibrium equations of the inner tube:

1): $\Sigma M=0$:  
\[ F_v(L_1-b-e) - R_{1i}(L_1-b-a-g-e)=0 \]  
\[ \text{(1)} \]

2): $\Sigma F_y=0$:  
\[ F_v - R_{1i} - R_{2i}=0 \]  
\[ \text{(2)} \]

Assuming nominal values:

- $L_1=275\text{ mm}$, $a=75\text{ mm}$, $b=35\text{ mm}$, $g=35\text{ mm}$, $e=10\text{ mm}$

Solving $R_{1i}$ from eq. 1:

\[ R_{1i} = \frac{F_v \cdot (L_1 - b - e)}{(L_1 - b - a - g - e)} \]  
\[ \text{(3)} \]

Solving $R_{2i}$ from eq. 2:

\[ R_{2i} = R_{1i} - F_v \]  
\[ \text{(4)} \]

Results:

\[ R_{1i} = \frac{40\text{kN} \cdot (275 - 35 - 10)\text{mm}}{(275 - 35 - 75 - 35 - 10)\text{mm}} = 76.7\text{kN} \]

\[ R_{2i} = 76.7\text{kN} - 40\text{kN} = 36.7\text{kN} \]
II) Equilibrium outer tube:

Figure 3: Forces acting on the outer tube.

Exact distribution of forces depends highly on the behavior of the outer tube. Both longitudinal bending stiffness and local transverse bending stiffness in the contact points between the inner and the outer tubes affects the equilibrium. Two situations are considered:

1) Rigid outer tube.

Outer tube rotates as a stiff body. This assumption gives minimum reaction force at $R_1$, and maximum reaction force at $R_6$. $R_3$ is assumed zero. (The force $R_3$ will actually be negative, but since no reinforcement to take the negative forces is included at this position, it is assumed to be zero.)

Equilibrium equations of the outer tube:

1): $\Sigma M=0$: $(R_1i-R_1)(L-3g-d)-(R_3-R_6)(L-3g-c-d)=0$  \hspace{1cm} (5)

2): $\Sigma F_y=0$: $R_2+R_3+R_1- R_6-R_6=0$ \hspace{1cm} (6)

Assuming nominal values:

$L=320\text{mm}, c=120\text{mm}, g=35\text{mm}, e=10\text{mm}, d=10\text{mm}; (c=L_1-b-a-g-e=275-35-75-35-10=120\text{mm})$

Solving $R_1$ from eq. 5:

$\left(R_{1i}-R_1\right)\cdot(L-g-d)-(R_{2i}-R_1)\cdot(L-g-c-d) = 0$

$(76.7-R_{1i})\cdot(320-35-10)-(36.7-0)\cdot(320-35-120-10)=0$

$21092 - 275R_{1i} = 5688 = 0$

$R_1 = \frac{15404}{275} = 56.0\text{kN}$

Solving $R_2$ from eq. 6:

$R_2 = R_1 + R_{2i} - R_{1i} = 56.0 + 36.7 - 76.7 = 16.0\text{kN}$
2) Outer tube without bending stiffness. No forces transferred to outer tube at the back of inner tube.

This assumption gives maximum reaction forces $R_1$ and $R_3$. $R_2$ becomes zero. The forces follow directly from the assumption: $R_1 = R_{1i}$, $R_3 = R_{2i}$, and $R_2 = 0$

\[
R_1 = 76.7\text{kN} \\
R_2 = 0\text{kN} \\
R_3 = 36.7\text{kN}
\]

The magnitude of the forces will be somewhere in between the two limits, and the prescribed reinforcement ensures integrity for both situations. Reinforcement is to be located at the assumed attack point for support reactions.

**Reinforcement for $R_1$, $R_2$ and $R_3$:**

![Diagram of forces](image)

**Figure 4: Forces.**

**Reinforcement necessary to anchor the unit to the concrete:**

Reinforcement $R_1$: $A_{s1} = \frac{R_1}{f_{sd}} = \frac{76.7\text{kN}}{435\text{MPa}} = 176\text{ mm}^2$

Select 2-Ø8 = 2×2×50 = 200 mm²

Capacity selected reinforcement: $R = 200\text{ mm}^2 \cdot 435\text{MPa} = 87\text{kN}$

Reinforcement $R_3$: $A_{s3} = \frac{R_3}{f_{sd}} = \frac{36.7\text{kN}}{435\text{MPa}} = 84\text{ mm}^2$

Select 1-Ø8 = 1×2×50 = 100mm²

Capacity selected reinforcement: $R = 100\text{ mm}^2 \cdot 435\text{MPa} = 43.5\text{kN}$

Reinforcement $R_2$: $A_{s2} = \frac{R_2}{f_{sd}} = \frac{16.0\text{kN}}{435\text{MPa}} = 37\text{ mm}^2$

Select 1-Ø8 = 1×2×50 = 100mm²

Capacity selected reinforcement: $R = 100\text{ mm}^2 \cdot 435\text{MPa} = 43.5\text{kN}$
Tolerances on the positioning of the reinforcement:

Due to the small internal distances, the magnitude of the forces will change when changing the position of the reinforcement. Thus, strict tolerances are required.

Alt 1)

Assume:
Li=275mm, a=75mm, b=35mm, g=35+5=40mm, e=10mm

Gives:

\[ R_1 = \frac{40kN \cdot (275 - 35 - 10)mm}{(275 - 35 - 75 - 40 - 10)mm} = 80.0kN \]

\[ R_2 = 80.0kN - 40kN = 40.0kN \]

Alt 2)

Assume:
Li=275mm, a=75mm, b=35mm, g=35+5=40mm, e=10+5mm.

Gives:

\[ R_1 = \frac{40kN \cdot (275 - 35 - 15)mm}{(275 - 35 - 75 - 40 - 15)mm} = 81.8kN \]

\[ R_2 = 81.8kN - 40kN = 41.8kN \]

Conclusion tolerances: Alt 2 represents the most unfavorable position of reinforcement allowed without exceeding the reinforcement capacity. Thus, the assembling tolerances for P1, P2 and P4 should be ±5mm. For recommended reinforcement pattern, see Memo 55c.

Transverse reinforcement:

- One transverse bar with the same diameter as the anchorage bar to be placed in the bend of every anchoring bar.
Design
MEMO 54c
Reinforcement design for TSS 41

Figure 5: Anchoring reinforcement.
### REVISION HISTORY

<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.10.2011</td>
<td>Updated.</td>
</tr>
<tr>
<td>07.01.2016</td>
<td>Included revision history table. Included note on reinforcement ductility grade. Reduced number of values in Table 2.</td>
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