BSF – DESIGN OF REINFORCEMENT, T-CONNECTION BEAM-BEAM

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PART 1 BASIC ASSUMPTIONS

1.1 GENERAL

This memo deals with BSF used in beam-beam connections where a secondary beam is connected to the side of a main beam. Standard beam-box is embedded in the side of the main beam. Reinforcement of the secondary beam with the BSF knife is found in Memo 521. Therefore, only reinforcement related to the BSF beam-box is discussed.

Cross sections of the two connected beams, and the point along the main beam where the secondary beam is connected, will vary. This may lead to different load bearing mechanisms in the main beam. Thus, the final load bearing mechanism is to be evaluated in each case. The mechanism will depend upon the geometry in the connection, and there may be issues with the local force transfer that is not covered by the examples given in this Memo.

Therefore, the following selected load bearing model, calculations on anchorage of the unit, and the resulting reinforcement is only examples meant to illustrate one possible load bearing model and one way to arrange the reinforcement.

If other reinforcement arrangements are used, observe the following:

- The number and size of vertical anchoring bars must be as indicated in this memo.
- The position of bars at the point of contact with the bearing block on the BSF BB unit must be as indicated in this memo. This to ensure the centre of gravity of the bars is identical to the centre of the load from the knife onto the bearing block.
- Bars should be detailed so as to transfer load from the bearing block up to the upper part of the beam.
- At the upper end, anchorage and bends should comply with National Regulations to ensure full anchorage.

Beyond these observations, EC2 shall as always be applied as the governing design document when detailing the beam reinforcement. The information found here and in the memos assumes that the design of the elements and the use of the units in structural elements are carried out under the supervision of a structural engineer with knowledge about both the relevant standards, and the structural behavior of concrete and steel structures.
1.2 STANDARDS

The calculations are in accordance with:


The selected values for the NDP’s in the following calculations are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\gamma_c$</th>
<th>$\gamma_s$</th>
<th>$\alpha_{cc}$</th>
<th>$\alpha_{ct}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>1,5</td>
<td>1,15</td>
<td>0,85</td>
<td>0,85</td>
</tr>
</tbody>
</table>

*Table 1: NDP-s in EC2.*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$\gamma_{M0}$</th>
<th>$\gamma_{M1}$</th>
<th>$\gamma_{M2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>1,1</td>
<td>1,1</td>
<td>1,25</td>
</tr>
</tbody>
</table>

*Table 2: NDP-s in EC3.*

1.3 QUALITIES

Concrete C35/45: $f_{ck} = 35,0$ MPa

- $f_{cd} = \alpha_{cc} \times f_{ck} / \gamma_c = 0,85 \times 35/1,5 = 19,8$ MPa
- $f_{cd} = \alpha_{ct} \times f_{ck,0,05} / \gamma_c = 0,85 \times 2,2/1,5 = 1,24$ MPa
- $f_{bd} = 2,25 \times \eta_1 \times \eta_2 \times f_{cd} = 2,25 \times 1,0 \times 1,0 \times 1,24 = 2,79$ MPa

*Note: For simplicity, good bond conditions are assumed when calculating $f_{bd}$. This assumption may not be correct in all situations and has to be evaluated in each case. EC2 indicates poor bond conditions for anchoring in top of the beam.*

Reinforcement 500C (EN 1992-1-1, Annex C): $f_{yd} = f_y / \gamma_s = 500/1,15 = 435$ MPa

*Note: Reinforcement steel of different qualities may be chosen provided that the calculations take into account the actual yield strength ($f_y \leq 500$ MPa) and that the bendability is sufficient for fitting the vertical suspension reinforcement to the half round steel.*

Steel Sxxx (EN 10025-2):

Steel S355: Tension: $f_{td} = f_y / \gamma_{M0} = 355/1,1 = 322$ MPa
Compression: $f_{cd} = f_y / \gamma_{M0} = 355/1,1 = 322$ MPa
Shear: $f_{sd} = f_y / (\gamma_{M0} \times \sqrt{3}) = 355/(1,1 \times \sqrt{3}) = 186$ MPa
Weld S355: 
\[ f_{w,d} = \frac{f_u}{\gamma_M} \sqrt{\frac{3}{\beta_w}} \times \frac{1}{1,25 \times \sqrt{3}} \times \frac{1}{0,9} = 262 MPa \]

Threaded bars/nut:
8.8 quality steel: 
\[ f_{yd} = 0,9 \times \frac{f_u}{\gamma_M} = 0,9 \times 800/1,25 = 576 MPa \]

1.4 DIMENSIONS AND CROSS-SECTION PARAMETERS

<table>
<thead>
<tr>
<th>UNIT</th>
<th>HALF ROUND STEEL</th>
<th>HORIZONTAL ANCHORING¹</th>
<th>INTERNAL OPENING BEAM BOX (WIDTH×HEIGHT×DEPTH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BSF225 BEAM BOX</td>
<td>Ø76 100 S355</td>
<td>2×M12, 8.8+ nut, L=to be decided &amp; st.pl.50×50×8, S355</td>
<td>30mm×215mm×80mm</td>
</tr>
<tr>
<td>BSF300 BEAM BOX</td>
<td>Ø76 100 S355</td>
<td>2×M12, 8.8+ nut, L= to be decided &amp; st.pl.50×50×8, S355</td>
<td>30mm×255mm×80mm</td>
</tr>
<tr>
<td>BSF450 BEAM BOX</td>
<td>Ø76 100 S355</td>
<td>1×M20, 8.8+ nut, L= to be decided &amp; st.pl.90×90×12, S355</td>
<td>40mm×270mm×92,5mm</td>
</tr>
<tr>
<td>BSF700 BEAM BOX</td>
<td>Ø175 140 S355</td>
<td>2×M20, 8.8+ nut, L= to be decided &amp; st.pl.160×90×12, S355</td>
<td>50mm×310mm×105mm</td>
</tr>
</tbody>
</table>

Table 3: Dimensions – BSF beam box.

¹ See also Table 4. Note: The steel plate anchoring both the M20 bars for the BSF700 is designed only for the actual design force of 210kN, not the tensile capacity of two M20 bars.
Table 4: Dimensions - threaded bars and anchoring steel plates.

<table>
<thead>
<tr>
<th>NOMINAL DIAMETER</th>
<th>M12</th>
<th>M16</th>
<th>M20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent diameter:</td>
<td>10,4</td>
<td>14,1</td>
<td>17,7</td>
</tr>
<tr>
<td>$\phi_{eq}$ [mm]</td>
<td>84</td>
<td>157</td>
<td>245</td>
</tr>
<tr>
<td>Stress area:</td>
<td>48</td>
<td>90</td>
<td>141</td>
</tr>
<tr>
<td>$A_s$ [mm²]</td>
<td>19</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Tensile capacity (8.8):</td>
<td>10,4 14,1 17,7</td>
<td>84 157 245</td>
<td>48 90 141</td>
</tr>
<tr>
<td>$F_{cap} = f_{ye} \times A_s$ [kN]</td>
<td>19</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>With across flats:</td>
<td>19</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>NV [mm]</td>
<td>19</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>Required dim. of square steel plate anchoring $F_{cap}$</td>
<td>≈50,4</td>
<td>69</td>
<td>86</td>
</tr>
<tr>
<td>$b_{req} \geq [F_{cap} / f_{yd} \times \phi_{nom}/4]^{0.5}$ [mm]</td>
<td>Select 50×50</td>
<td>Select 70×70</td>
<td>Select 90×90</td>
</tr>
<tr>
<td>Net area for compression anchorage:</td>
<td>2387</td>
<td>4699</td>
<td>7786</td>
</tr>
<tr>
<td>$A_{net} = A_{steel \ plate} - \pi \times \phi_{nom}/4$ [mm²]</td>
<td>2387</td>
<td>4699</td>
<td>7786</td>
</tr>
<tr>
<td>Concrete stress:</td>
<td>20,1</td>
<td>19,1</td>
<td>18,1</td>
</tr>
<tr>
<td>$\sigma_c = F_{cap} / A_{net}$ [MPa]</td>
<td>20,1</td>
<td>19,1</td>
<td>18,1</td>
</tr>
<tr>
<td>Required thickness of steel plate, S355:</td>
<td>a=25.9</td>
<td>a=37.5</td>
<td>a=48.6</td>
</tr>
<tr>
<td>$c=b/2-NV/2$</td>
<td>t₁=6.5</td>
<td>t₂=9.1</td>
<td>t₁=11.5</td>
</tr>
<tr>
<td>$t₁ \geq a \times (\sigma_c / f_{yd})^{0.5}$ [mm]</td>
<td>t₂=6.7</td>
<td>t₂=9.7</td>
<td>t₂=12.3</td>
</tr>
<tr>
<td>Select t=8mm</td>
<td>Select t=10mm</td>
<td>Select t=12mm</td>
<td></td>
</tr>
<tr>
<td>Standard height of nut:</td>
<td>10,0</td>
<td>13,0</td>
<td>16,0</td>
</tr>
<tr>
<td>(H) [mm]</td>
<td>18mm</td>
<td>24mm</td>
<td>30mm</td>
</tr>
<tr>
<td>Required thread length in blind holes:</td>
<td>S355</td>
<td>S355</td>
<td>S355</td>
</tr>
</tbody>
</table>

---

$^2$ An illustration, and background for the formulas, can be found in the Memo “BSF-Design of steel units”. The listed dimensions are based on the concrete quality and parameters given in Section 1.2 and Section 1.3.

Note: The steel plate anchoring both the M20 bars for the BSF700 is designed only for the actual design force of 210kN, not the tensile capacity of two M20 bars.
1.5 LOADS

Vertical ultimate limit state load: \( F_V = \) According to Table 5.
Horizontal ultimate limit state load - in axial direction: \( F_{H\text{a}} = 0\,\text{kN} \) (see notes below)
Horizontal ultimate limit state load - in transverse direction: \( F_{H\text{t}} = 0\,\text{kN} \)

*Note on loads:
- The BSF beam box is a product designed to transfer primarily vertical load.

- Significant horizontal loading on the unit may also occur if imposed deformation (shrinkage, temperature differences etc.) in the pre-cast element is resisted. When the occurring horizontal force exceeds the potential friction force the knife will slide and the force will be partly relieved. The static friction factor steel-steel at support is assumed to be within the range \((0.2-0.5)\). The maximum friction force due to gradually increasing imposed deformations will however be associated with vertical service loads. The steel parts of the unit, and anchoring of these parts into the concrete are designed for the following unfavorable load combination:

\[
\text{Vertical force } 1.0F_v + \text{Horizontal force } 0.3F_v
\]

- In some cases transfer of static global horizontal load via the unit may be requested. The magnitude of this force would be limited by the minimum friction factor at the support and vertical load present at the same time. This will imply uncertainty in resistance, and it’s recommended to transfer the horizontal forces by proper reinforcement through the joint. In case of dynamic loads, the horizontal resistance should always be assumed to be zero.

- Horizontal anchoring of the steel parts assumes minimum concrete grade C35 in column and beam.

<table>
<thead>
<tr>
<th>UNIT</th>
<th>VERTICAL ULTIMATE LIMIT STATE LOAD ( F_v ) [kN]</th>
<th>LOAD BEAM BOX</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( 1.0F_v ) [kN]</td>
<td>( 0.3F_v ) [kN]</td>
</tr>
<tr>
<td>BSF225</td>
<td>225</td>
<td>67.5</td>
</tr>
<tr>
<td>BSF300</td>
<td>300</td>
<td>90</td>
</tr>
<tr>
<td>BSF450</td>
<td>450</td>
<td>135</td>
</tr>
<tr>
<td>BSF700</td>
<td>700</td>
<td>210</td>
</tr>
</tbody>
</table>

*Table 5: Design loads*
1.6 TOLERANCES

The design nominal gap between two beams is 20mm, with a tolerance of ±10mm. The tolerances are handled with the cantilevering of the knife from the beam. If the gap is 30mm, the knife is pushed out an extra 10mm and vice versa if the gap is only 10mm. Thus, the load point in the beam box will always be the same. The knife shall always be pushed out until it bottoms against the back of the beam box. The tolerance on location of the reinforcement for the beam box is ±2mm.

*Figure 1: Tolerances.*
PART 2 PRINCIPAL DESIGN OF REINFORCEMENT - BSF BEAM BOX

2.1 BEAM BOX - EQUILIBRIUM

Figure 2: Equilibrium.
The assumed flow of forces is illustrated in Figure 2:

1) Vertical force: Suspension reinforcement designed for the load is to be placed at the load point ⇒ \( R_v = F_v \).
   The suspension reinforcement is anchored both inwards in the cross section, and in the longitudinal direction of the main beam.
   Horizontal force: Anchored with threaded bars. The bending moment associated with the small vertical shift in the horizontal force is neglected. The length of the threaded bar is to be decided in each case. Proper depth of the anchoring must be ensured.

2) The assumed flow of forces for the beam section in order to transfer the load \( F_v \) into the shear center of the beam (drawing two in fig. 2) shows a compression strut (T1) directed from the upper left corner towards the center of the beam. Proper reinforcement in order to take the horizontal force \( S \) in this strut is required at the bottom of the beam. Reasonableness of this force model must be controlled in each case. In normal beams, the horizontal force will be less than the vertical force. However, in low/wide beams the horizontal force will exceed the vertical force and the strut and tie model should be revised. Depending on the ratio of suspension reinforcement anchored inwards in the cross section, an equal ratio of the compression strut (T1) will be anchored towards the bend of these bars. Thus, the anchor length for the suspension reinforcement bent inwards shall be measured from the end of the upper left bend. The remaining part of the diagonal force will be anchored towards the bend of the shear stirrups.

3) Suspension reinforcement anchored in the longitudinal direction of the beam will cause a compression strut (T2). Sufficient vertical reinforcement \( A_s2 \) within a distance, a, to each side of the beam must be ensured. Normally the shear stirrups designed for the occurring shear force in the beam will be sufficient for this purpose.

4) In high beams a part of the vertical force may spread into the concrete below the unit. Stirrups within a distance \( 2/3H \) (\( H \)=height below unit) to both sides of the unit will contribute to collect this force. (Note: only one leg per stirrup is active). Alternatively, a stirrup shaped as illustrated red in the figure may be used.

Based on the issued mentioned in above clauses 2-4 it is recommended to always include extra stirrups close to the unit. These stirrups shall have a total cross-section (Note: only on leg per stirrup to go into the summation) equal to the calculated required amount of suspension reinforcement. The reinforcement is to be placed with one half on each side of the unit.

Use of horizontal stirrups and longitudinal reinforcement to safeguard splitting forces below the unit must be considered.
2.2 BEAM BOX – ANCHORING REINFORCEMENT

1) Required cross section area of suspension reinforcement (and stirrups close to the unit):

\[ A_x = \frac{F_v}{f_{yd}} \]

2) Mandrel diameter – Bending of reinforcement - EC2, clause 8.3:

\[ \Omega = F \times \left[ \frac{1}{a_s} + \frac{1}{(2\Omega)} \right] \]

Reinforcement anchored inwards in the cross section: \( \Omega = F \times \left[ \frac{1}{a_s} + \frac{1}{(2\Omega)} \right] \)

Reinforcement anchored in the longitudinal direction: \( \Omega_2 = F \times \left[ \frac{1}{a_s} + \frac{1}{(2\Omega_2)} \right] \)

In addition: EC2, clause 8.3: \( \Omega_{\text{min}} = 64\text{mm} \) for \( \Omega_{16\text{mm}} \) og 175mm for \( \Omega_{>25\text{mm}} \)

⇒ Select mandrel diameter

3) Anchoring of reinforcement - EC2, clause. 8.4.3 and 8.4.4:

\[ l_{bd} \]

\[ l_{bd} \]

Figure 3: Bending of reinforcement.

Figure 4: Anchoring of reinforcement
\[ l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b, reqd} \geq l_{b, min} \]

Assume: \( \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 = 1,0 \)

\[ l_{bd} = l_{b, reqd} = \frac{f_{bd}}{4} \times \frac{\sigma_{sd}}{f_{bd}} \]

For the reinforcement anchored inwards in the cross-section, the anchoring length is: \( l_{bd} = c + b + d \), see Figure 4 and the evaluations in section 2.1. Transverse reinforcement in the anchoring zone must be specified in accordance with EC2.

### 2.3 BEAM BOX – HORIZONTAL ANCHORING

The beam box is anchored for a total horizontal load of \( F_H = 0,3F_V \). The knife will be in contact with the half round steel and the horizontal force is transferred by friction between the two steel parts. The half round steel is anchored with threaded bars.

The required dimension of threaded bar and machined thread lengths in the half round steel is found from Table 4. The length of the threaded bars shall be adapted to the width of the beam. Proper depth of the anchoring must be ensured.

### 2.4 MAIN BEAM - TORSION

Due to the short length of the beam box, the secondary beam will probably never transfer the load to the center of gravity of the main beams cross section. Thus, it is recommended to always establish connections between the main- and the secondary beam to lock the torsion caused by the eccentric loading. If this is not done, the main beam and its supports have to be designed for the torsion. In addition, the force must be followed all the way through the rest of the construction.

The required tension/compression force in the joint between the secondary and main beam to lock the torsion becomes (see Figure 5):

\[ S = T = F_v \times a/h \]

Detailing of the connections must be done in each case based on the geometry and magnitude of the forces. There are several possible solutions. Figure 5 illustrates a solution with steel plates embedded in both beams, connected with a welded steel plate. The compression force at top of the beam goes through the concrete in the joint. (Note: The figure is an illustration, no calculations has been carried out)
Figure 5: Lock of torsion –main beam.

Note:

- The theoretical span for the secondary beam increases when the lock of torsion is included. The span will continue to the center of the main beam. Alternatively, a bending moment may be applied to the end of the secondary beam in the calculations, see Figure 5: $M = F_v \times a$

- Following from the first note: The anchoring in the main reinforcement in every point (x) along the secondary beam, shall be designed for a tension force, see Figure 5: $S = M/z = F_v \times L/z$ (not only $F_v \times b/z$)

(Example of anchoring of reinforcement for the normal situation is found in Memo 521.)
PART 3 BSF 225

3.1 BEAM BOX – ANCHORING REINFORCEMENT

1) Required cross section for reinforcement:

\[ A_s = \frac{F_y}{f_{cd}} = \frac{225kN}{435MPa} = 517mm^2 \]

2Ø16 stirrups = 201mm² x 4 = 804mm²

Capacity of selected reinforcement: 804mm² x 435MPa = 349kN

Compression strut T1:

\[ A_{s1} = A_s \]

Extra stirrups in the main beam close to the unit: 3+3 stirrups Ø12 = 113mm² x 6 = 678mm²

Compression strut T2:

\[ A_{s2} = \frac{F_y}{4} = \frac{225kN}{435MPa \times 4} = 130mm^2 \]

Control: shear reinforcement within distance a > 130mm²

2) Mandrel diameter – Bending of reinforcement - EC2, clause 8.3:

Reinforcement anchored inwards in the cross section:

\[ \varnothing = F \times \left[ \frac{1}{(s/2)} + \frac{1}{(2\varnothing)} \right] = 225000N/4 \times \left[ \frac{1}{(96/2)} + \frac{1}{(2\times16)} \right] = 148mm \]

Minimum: 4×Ø=4×16=64mm

⇒ Select: Ø=80mm and bend around reinforcement in top of beam (minimum Ø16 in top of beam)

Reinforcement anchored in the longitudinal direction of the beam:

\[ \varnothing_2 = F \times \left[ \frac{1}{a_b} + \frac{1}{(2\varnothing)} \right] = 225000N/4 \times \left[ \frac{1}{70} + \frac{1}{(2\times16)} \right] = 130mm \]

⇒ Select: Ø₂=200mm

3) Anchoring of reinforcement, EC2 clause 8.4.3 and 8.4.4:

\[ l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min} \]
\[ l_{b,\text{reqd}} = \frac{\phi}{4} \times \frac{\sigma_{sd}}{f_{bd}} \]

Stress in reinforcement: \( \sigma_{sd} = \frac{225kN}{804mm^2} = 280MPa \)

\[ l_{b,\text{reqd}} = \frac{16 \times 280}{4 \times 2.79} = 401mm \]

\[ l_{b,\text{min}} = \max(0,3 \times l_{b,\text{reqd}}, 10 \times \phi, 100mm) = 160mm \]

\[ l_{bd} = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 401mm = 401mm \]

⇒ Reinforcement bent in longitudinal direction: Select: \( l = 400mm \)

⇒ Reinforcement bent inwards: 220mm + 141mm + 385mm = 746mm > 401mm ⇒ OK!

Figure 6: Illustration.
Note: The figure illustrates only the calculated suspension reinforcement and the extra stirrups close to the unit. The beam shall of cause have proper shear reinforcement/stirrups in every point, also in-between the illustrated stirrups. The other issues mentioned in chapter 2.1 (transverse reinforcement, stirrups below the unit, longitudinal reinforcement along beam edge, etc.) has not been evaluated. These issues must be addressed in each case by qualified engineer.

3.2 BEAM BOX – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel: $R_u = 0.3 \times f_y = 67.5\text{kN}$:

Select: $2 \times M12$ threaded bars, 8.8 with nut & steel plate = $48\text{kN} \times 2 = 96\text{kN}$

Proper anchoring depth to avoid tearing of concrete cone must be ensured.

PART 4 BSF 300

4.1 BEAM BOX – ANCHORING REINFORCEMENT

1) Required cross section for reinforcement:

$$A_s = \frac{F_y}{f_{yd}} = \frac{300\text{kN}}{435\text{MPa}} = 689\text{mm}^2$$

$2 \times 16$ stirrups = $201\text{mm}^2 \times 4 = 804\text{mm}^2$

Capacity of selected reinforcement: $804\text{mm}^2 \times 435\text{MPa} = 349\text{kN}$

Compression strut $T_1$:

$$A_{s1} = A_s$$

Extra stirrups in the main beam close to the unit: $3 + 3$ stirrups $\phi 12 = 113\text{mm}^2 \times 6 = 678\text{mm}^2$ ($\approx 689\text{mm}^2$)

ok

Compression strut $T_2$:

$$A_{s2} = \frac{F_y}{4} / f_{yd} = \frac{300\text{kN}}{435\text{MPa} \times 4} = 172\text{mm}^2$$

Control: shear reinforcement within distance $a > 172\text{mm}^2$

2) Mandrel diameter – Bending of reinforcement - EC2, clause 8.3:

Reinforcement anchored inwards in the cross section:
\[
\varnothing = F_y \times \left[ \frac{1}{f_{cd}} \left( \frac{1}{2} + \frac{1}{2\varnothing} \right) \right] = 300000 \frac{N}{4} \times \left[ \frac{1}{96/2} + \frac{1}{2\times16} \right] = 197 mm
\]

Minimum: \(4\varnothing = 4\times16 = 64 mm\)
⇒ Select: \(\varnothing = 80 mm\) and bend around reinforcement in top of beam (minimum \(\varnothing 16\) in top of beam)

Reinforcement anchored in the longitudinal direction of the beam:
\[
\varnothing_2 = F_y \times \left[ \frac{1}{a_b} + \frac{1}{2\varnothing} \right] = 300000 \frac{N}{4} \times \left[ \frac{1}{70} + \frac{1}{2\times16} \right] = 174 mm
\]
⇒ Select: \(\varnothing_2 = 200 mm\)

3) Anchoring of reinforcement, EC2 clause 8.4.3 and 8.4.4:
\[
\varnothing_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times \alpha_5 \times l_{b,reqd} \geq l_{b,min}
\]
\[
l_{b,reqd} = \frac{\varnothing}{4} \times \frac{\sigma_{sd}}{f_{bd}}
\]

Stress in reinforcement: \(\sigma_{sd} = \frac{300 kN}{804 mm^2} = 373 MPa\)
\[
l_{b,reqd} = \frac{16}{4} \times \frac{373}{2.79} = 535 mm
\]
\[
l_{b,min} = \max(0.3 l_{b,reqd}, 10 \times \varnothing; 100 mm) = 160 mm
\]
\[
l_{bd} = 1,0 \times 1,0 \times 1,0 \times 1,0 \times 1,0 \times 535 mm = 535 mm
\]
⇒ Reinforcement bent in longitudinal direction: Select: \(l=550 mm\)
⇒ Reinforcement bent in longitudinal direction: \(220 mm + 141 mm + 385 mm = 746 mm > 535 mm \Rightarrow OK!\)
Figure 7: Illustration.

Note: The figure illustrates only the calculated suspension reinforcement and the extra stirrups close to the unit. The beam shall of cause have proper shear reinforcement/stirrups in every point, also in-between the illustrated stirrups. The other issues mentioned in chapter 2.1 (transverse reinforcement, stirrups below the unit, longitudinal reinforcement along beam edge, etc.) has not been evaluated. These issues must be addressed in each case by qualified engineer.
4.2 BEAM BOX – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel: \( R_{th} = 0.3F_V = 90kN \):
Select: \( 2 \times M12 \) threaded bars, 8.8 with nut & steel plate = 48kN x 2 = 96kN
Proper anchoring depth to avoid tearing of concrete cone must be ensured.

5.1 BEAM BOX – ANCHORING REINFORCEMENT

1) Required cross section for reinforcement:
\[
A_s = \frac{F_v}{f_{yd}} = \frac{450kN}{435MPa} = 1035mm^2
\]
3Ø16 stirrups = 201mm^2 x 6 = 1206mm^2
Capacity of selected reinforcement: 1206mm^2 x 435MPa = 524kN

Compression strut \( T_1 \):
\[ A_{s1} = A_s \]
Extra stirrups in the main beam close to the unit: 3 + 3 double stirrups Ø12 = 113mm^2 x 6 x 2 = 1356mm^2

Compression strut \( T_2 \):
\[
A_{s2} = \frac{F_v}{f_{yd}} \times 6 = \frac{450kN}{435MPa \times 6} = 172mm^2
\]
Control: shear reinforcement within distance \( a > 172mm^2 \)

2) Mandrel diameter – Bending of reinforcement - EC2, clause 8.3:
Reinforcement anchored inwards in the cross section:
\[
\phi = F_v \times \left[ \frac{1}{(s/2)} + \frac{1}{2\phi} \right] = 450000 N / 6 \times \left[ \frac{1}{(90/2)} + \frac{1}{(2\times16)} \right] = 202mm
\]
Minimum: \( 4 \times \phi = 4 \times 16 = 64mm \)
\( \Rightarrow \) Select: \( \phi = 320mm \) for one of the bars.
\( \Rightarrow \) Select: \( \phi = 80mm \) and bend around reinforcement in top of beam (minimum Ø16 in top of beam)
Reinforcement anchored in the longitudinal direction of the beam:

\[
\varnothing_2 = F_y \times \left[ \frac{1}{a_b} + \frac{1}{2\varnothing} \right] = \frac{450000 \text{N}}{6} \times \left[ \frac{1}{62.5} + \frac{1}{2 \times 16} \right] = 179 \text{mm}
\]

⇒ Select: \(\varnothing_2 = 200 \text{mm}\)

3) Anchoring of reinforcement, EC2 clause 8.4.3 and 8.4.4:

\[l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times l_{b,\text{reqd}} \geq l_{b,\text{min}}\]

\[
l_{b,\text{reqd}} = \frac{\varnothing}{4} \times \frac{\sigma_{sd}}{f_{bd}}
\]

Stress in reinforcement: \(\sigma_{sd} = \frac{450 \text{kN}}{1206 \text{mm}^2} = 373 \text{MPa}\)

\[
l_{b,\text{reqd}} = \frac{16 \times 373}{4 \times 2.79} = 535 \text{mm}
\]

\[
l_{b,\text{min}} = \max(0, 3 \times l_{b,\text{reqd}}; 10 \times \varnothing; 100 \text{mm}) = 160 \text{mm}
\]

\[l_{bd} = 1.0 \times 1.0 \times 1.0 \times 1.0 \times 1.0 \times 535 \text{mm} = 535 \text{mm}\]

⇒ Reinforcement bent in longitudinal direction: Select: \(l = 550 \text{mm}\)

⇒ Reinforcement bent in longitudinal direction: \(330 \text{mm} + 365 \text{mm} = 695 \text{mm} > 535 \text{mm}\) ⇒ OK!
Figure 8: Illustration
Note: The figure illustrates only the calculated suspension reinforcement and the extra stirrups close to the unit. The beam shall of cause have proper shear reinforcement/stirrups in every point, also in-between the illustrated stirrups. The other issues mentioned in chapter 2.1 (transverse reinforcement, stirrups below the unit, longitudinal reinforcement along beam edge, etc.) has not been evaluated. These issues must be addressed in each case by qualified engineer.
5.2 BEAM BOX – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel: $R_0=0.3 \times F_V = 135 \text{kN}$:
Select: 1xM20 threaded bars, 8.8 with nut & steel plate = 141kN
Proper anchoring depth to avoid tearing of concrete cone must be ensured.

PART 6 BSF 700

6.1 BEAM BOX – ANCHORING REINFORCEMENT

1) Required cross section for reinforcement:
   
   $A_s = \frac{F_y}{f_{yd}} = \frac{700 \text{kN}}{435 \text{MPa}} = 1609 \text{mm}^2$

   2Ø25 stirrups = 490mm$^2$ x 4 = 1960mm$^2$
   Capacity of selected reinforcement: 1960mm$^2$ x 435MPa = 852kN

   Compression strut $T_1$:
   $A_{s1} = A_s$
   Extra stirrups in the main beam close to the unit: 4+4 double stirrups Ø12 = 113mm$^2$ x 8 x 2 = 1808mm$^2$

   Compression strut $T_2$:
   
   $A_{s2} = \frac{F_y}{4} \times \frac{1}{f_{yd}} = \frac{700 \text{kN}}{435 \text{MPa} \times 4} = 402 \text{mm}^2$

   Control: shear reinforcement within distance $a > 402 \text{mm}^2$

2) Mandrel diameter – Bending of reinforcement - EC2, clause 8.3:
Reinforcement anchored inwards in the cross section:

   $\phi = F_{y} \times \left[ \frac{1/(s/2) + 1/(2\theta)}{f_{yd}} \right] = 700000 \text{N} / 4 \times \left[ \frac{1/(232/2) + 1/(2 \times 25)}{19.8} \right] = 252 \text{mm}$

   Minimum: $\phi = 7 \times 25 \text{mm} = 175 \text{mm}$
   $\Rightarrow$ Select: $\phi = 320 \text{mm}$
Reinforcement anchored in the longitudinal direction of the beam:

\[
\phi_2 = F_y \times \left[ \frac{1}{a_b} + \frac{1}{2\phi} \right] / f_{cd} = 700000N / 4 \times \left( \frac{1/91mm + 1/(2 \times 25mm)}{19.8MPa} \right) = 274mm
\]

⇒ Select: \( \phi_2 = 320mm \)

3) Anchoring of reinforcement, EC2 clause 8.4.3 and 8.4.4:

\[
l_{bd} = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_4 \times l_{b,\text{reqd}} \geq l_{b,\text{min}}
\]

\[
l_{b,\text{reqd}} = \frac{\phi}{4} \times \frac{\sigma_{sd}}{f_{bd}}
\]

Stress in reinforcement: \( \sigma_{sd} = \frac{700kN}{1960mm^2} = 357MPa \)

\[
l_{b,\text{reqd}} = \frac{25 \times 357}{4 \times 2.79} = 800mm
\]

\[
l_{b,\text{min}} = \max(0,3l_{b,\text{reqd}}; 10\phi; 100mm) = 250mm
\]

\[
l_{bd} = 1,0 \times 1,0 \times 1,0 \times 1,0 \times 800mm = 800mm
\]

⇒ Reinforcement bent in longitudinal direction: Select: \( l = 800mm \)

⇒ Reinforcement bent in longitudinal direction: \( 198mm + 278mm + 496mm = 972mm > 800mm \) ⇒ OK!

Stirrups in the anchoring zone of the bar bent inwards shall always be included, see also EC2 clause. 8.7.4

\[
\sum A_{st} = A_s = 490mm^2 \Rightarrow 4\phi = 4 \times 2 \times 78mm^2 = 624mm^2
\]
Figure 9: Illustration.
Note: The figure illustrates only the calculated suspension reinforcement and the extra stirrups close to the unit. The beam shall of cause have proper shear reinforcement/stirrups in every point. Transverse stirrups in the anchoring length of the Ø25 bar bent inwards shall always be included for this unit. The other issues mentioned in chapter 2.1 (stirrups below the unit, longitudinal reinforcement along beam edge, etc.) has not been evaluated. These issues must be addressed in each case by qualified engineer.

6.2 BEAM BOX – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel: $R_u = 0.3 \times F_v = 210\text{kN}$:

Select: 2×M20 threaded bars, 8.8 with nut & steel plate = 210kN (limited by selected steel-plate)
Proper anchoring depth to avoid tearing of concrete cone must be ensured.
<table>
<thead>
<tr>
<th>Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.06.2014</td>
<td>Changed the half round steel on the BSF700 unit. Updated Table 1.</td>
</tr>
<tr>
<td>20.08.2014</td>
<td>Changed position of the M20 threaded bars in the half round steel BSF 700 unit. Changed steel plate anchoring M20 threaded bars BSF 700 unit.</td>
</tr>
<tr>
<td>13.01.2015</td>
<td>Updated Table 4. Required thread length in blind holes.</td>
</tr>
<tr>
<td>23.01.2015</td>
<td>Specified in Section 1.1 that this Memo only give an example with respect to load bearing model, calculations and reinforcement detailing. Corrected figure 6, 7, 8 &amp; 9.</td>
</tr>
<tr>
<td>27.02.2015</td>
<td>Included a nut on the front side of the steel plate anchoring the threaded bars. (To ensure correct position of the plate when casting the concrete).</td>
</tr>
<tr>
<td>24.05.2016</td>
<td>New template.</td>
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