Reinforcement design for BCC 250

PART 1 – BASIC ASSUMPTIONS

1.1 GENERAL

In these calculations certain assumptions has been made about dimensions and qualities in the precast concrete elements that may not always be the case. Therefore the following calculations of anchorage of the units and the resulting reinforcement must be considered as an example to illustrate the calculation model.

In beams it must always be checked that the forces from the anchorage reinforcement can be transferred to the beam's main reinforcement. The recommended shear reinforcement (stirrups) includes all necessary stirrups in the beam end; i.e. the normal shear reinforcement in beam ends and an addition due to the cantilever action of the beam unit from the beam.

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 the flow of forces.

1.2 STANDARDS

The calculations are carried out according to:

Eurocode 2: Design of concrete structures. Part 1-1. General rules and rules for buildings.

Eurocode 3: Design of steel structures. Part 1-1: General rules and rules for buildings.

Eurocode 3: Design of steel structures. Part 1-8: Design of joints.

EN 10080: Steel for the reinforcement of concrete. Weldable reinforcing steel. General.

For all NPDs in the Eurocodes the recommended values are used.

These NDPs are: In EC 2: γ_c; γ_s; α_{cc}; α_{ct}; k_1; k_2 and $Ø_{m,min}$. In EC 3: γ_{M0}; γ_{M1} and γ_{M2}.

1.3 LOADS

Vertical ultimate limit state load = F_V = 250 kN

Horizontal ultimate limit state load = $F_H = 0{,}3 \times F_V$ = 75 kN

The design is carried out with a horizontal force of 30 % of the vertical force. Recommended capacity for transfer of active forces (as wind loads) may be assumed to be 20 % of smallest vertical load present at the same time.

Reinforcement design for BCC 250

1.4 QUALITIES

Concrete grade C45/55: $f_{cd} = \alpha_{cc} \cdot f_{ck}/\gamma_c = 1{,}0 \cdot 45/1{,}5 = 30{,}0$ MPa

$f_{ctd} = \alpha_{ct} \cdot f_{ctk,0,05}/\gamma_c = 1{,}0 \cdot 2{,}70/1{,}5 = 1{,}80$ MPa

$f_{bd} = 2{,}25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd} = 2{,}25 \cdot 1{,}0 \cdot 1{,}0 \cdot 1{,}80 = 4{,}05$ MPa

Reinforcement B500C: $f_{yd} = f_{yk}/\gamma_s = 500/1{,}15 = 435$ MPa

Tension in threaded bars: 8.8 quality steel: $f_{yd} = f_y/\gamma_{M2} = 640/1{,}25 = 512$ MPa

Nominal diameter (mm)	M10	M12	M16	M20	M24	M30	M33	M36
Equivalent diameter (mm)	8,6	10,4	14,1	17,7	21,2	26,7	29,7	32,6
Stress area (mm^2)	58	84	157	245	353	561	694	835

Structural steel S355:

Tension and compression:

$f_{yd} = f_y/\gamma_{M0} = 355/1{,}00 = 355 \text{ MPa} < f_u/\gamma_{M2} = 510/1{,}25 = 408$ MPa

Shear: $f_{sd} = f_y/(\gamma_{M0} \cdot \sqrt{3}) = 355/(1{,}00 \cdot \sqrt{3}) = 205$ MPa

Welds: $f_{vw.d} = \frac{f_u}{\gamma_{M2}\sqrt{3}} \times \frac{1}{\beta_w} = \frac{510}{1{,}25 \times \sqrt{3}} \times \frac{1}{0{,}9} = 262 \text{ MPa}$

Reinforcement design for BCC 250

PART 2 – ANCHORAGE OF THE UNITS

2.1 BEAM UNIT - EQUILIBRIUM

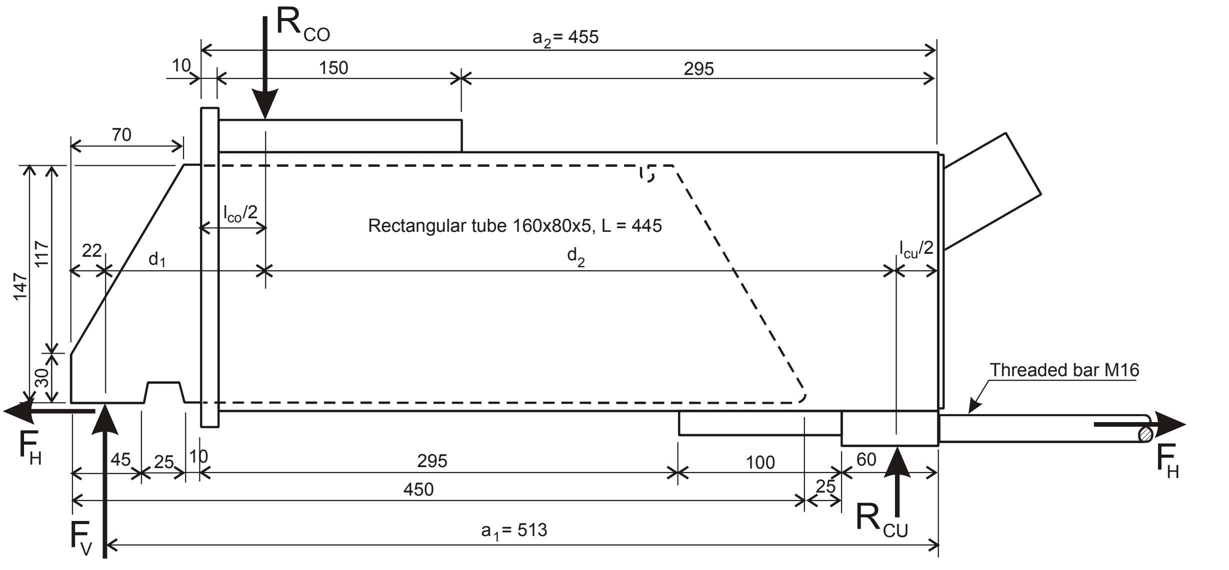

Figure 1. Designations and assumed dimensions.

Neglecting the moment created by the small vertical shift in the transfer of F_H.

$R_{CU} = F_V \times d_1/d_2$

$R_{CO} = F_V + R_{CU}$

$l_{CU} = R_{CU} /(f_{cd} \times b)$ (b is the width of the beam unit)

$l_{CO}/2$ is decided by the location of the front reinforcement. Assume 4-Ø12:

$l_{CO}/2 = 10+(8\times14+3\times8)/2 = 78$ mm

$d_1 = a_1 - a_2 + l_{CO}/2$

$d_2 = a_2 - l_{CO}/2 - l_{CU}/2$

Reinforcement design for BCC 250

Use a spread sheet. Assume d_1/d_2, calculate resulting d_1/d_2. Change assumed value until they are equal. (Spread sheet "Equilibrium-BCC250-beam-unit.exc".)

Equilibrium of BCC 250 beam unit:

			Concrete grade = C	45	/55	
			Material coefficient for concrete =	1,5		
Geometry: a_1 =	513	mm	f_{cd} =	30,0	MPa	
a_2 =	455	mm				
Width of the beam unit =	80	mm	F_V =	250	kN	
$l_{CO}/2$ =	78	mm				
			Assumed d_1 / d_2 =	0,3807731		
R_{CU} =	95	kN	d_1 =	136	mm	
R_{CO} =	345	kN	d_2 =	357	mm	
l_{CU} =	40	mm				
			Calculated d_1 /d_2 =	0,3807731		

Reinforcement design for BCC 250

2.2 BEAM UNIT – ANCHORAGE IN FRONT

2.2.1 Check of capacity

$A_{s,reqd} = R_{CO}/f_{yd,reinf} = 345/0{,}435 = 793\ mm^2$

Assumed 4-Ø12 = $2 \times 4 \times 113 = 904\ mm^2$ – ok

2.2.2 Anchorage

In order to achieve equilibrium in the joint where the reinforcement bringing R_{CO} down is anchored, the same amount of reinforcement must be supplied horizontally in order to carry a 45° compression diagonal (strut and tie model).

Select 4-Ø12 U-shaped stirrups.

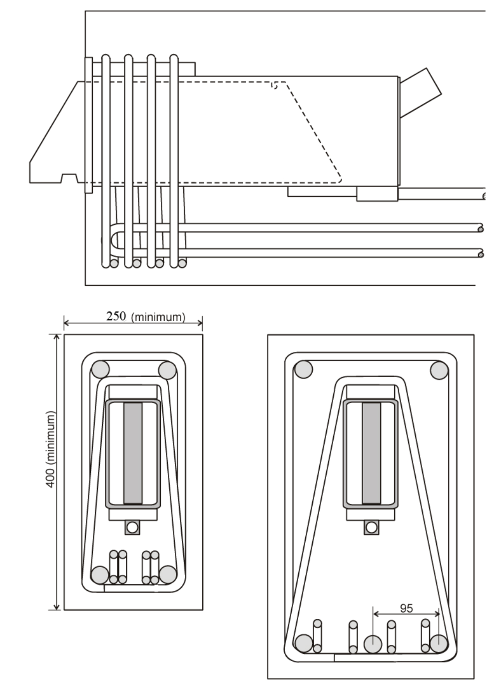

Figure 2. Anchorage of front reinforcement.

As illustrated in the left section in figure 2 it will be congested if the beam has minimum dimensions. This must be taken into account when the anchorage length of the horizontal U-shaped bars is calculated. (The main reinforcement of the beam is not shown in the side view.)

Select to check the anchorage for a situation as illustrated in the right hand section in figure 2.

According to EC2 clause 8.4.4:

$l_{bd} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \cdot \alpha_5 \cdot l_{b,reqd} \geq l_{b,min}$

$$l_{b,reqd} = \frac{Ø}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} = \frac{12}{4} \cdot \frac{345/0{,}904}{4{,}05} = 283\ mm$$

$l_{b,min} = \max(0{,}3 \cdot l_{b.reqd};\ 10 \cdot Ø;\ 100\ mm) = 120\ mm$

Straight bar: $\alpha_1 = 1{,}0$

Reinforcement design for BCC 250

Concrete cover: $c_d = \min(a/2; c_1) = \min(20/2; 50) = 10$ mm

$$\alpha_2 = 1 - 0{,}15 \cdot (c_d - 3 \cdot Ø)/Ø = 1 - 0{,}15 \cdot (10 - 3 \cdot 12)/12 > 1{,}0$$

$$\alpha_2 = 1{,}0$$

Confinement by reinforcement: Assume transverse reinforcement Ø12-c/c150 mm:

$$\alpha_3 = 1 - K \cdot \lambda = 1 - 0{,}05 \cdot \frac{113 \cdot \frac{300}{150} - 0{,}25 \cdot 113}{113} = 0{,}91$$

Confinement by welded transverse reinforcement:

$$\alpha_4 = 1{,}0$$

Confinement by transverse pressure:

$$\alpha_5 = 1{,}0$$

$l_{bd} = 1{,}0 \cdot 1{,}0 \cdot 0{,}91 \cdot 1{,}0 \cdot 1{,}0 \cdot 283 = 258$ mm

It must always be checked that the beam's main reinforcement has sufficient anchorage at the end of the horizontal part of the front anchorage. This will probably lead to greater lengths for the horizontal part of the front anchorage than calculated here.

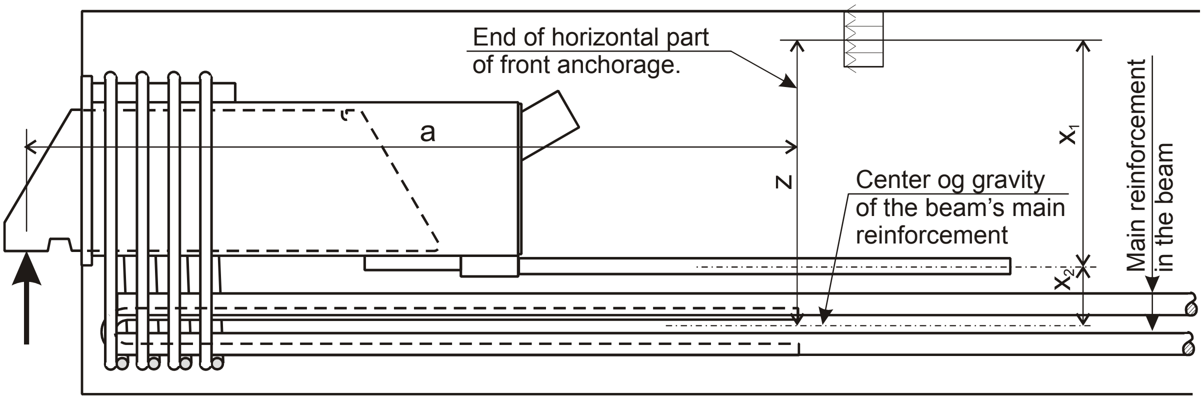

Figure 3. Anchorage of the beam's main reinfocement.

The force is approximately [$F_V \times \frac{a}{z} + \frac{F_V}{2} + F_H \frac{x_1}{z}$]. Additional force in the beam's top reinforcement is about [$F_H \cdot \frac{x_2}{z}$], but this force leads to a reduction in the compressive stresses and may be neglected. If there is a large distance between the horizontal part of the front anchorage and the beam's main reinforcement, the length of the horizontal part of the front anchorage must be increased with this distance. (This distance is approximately zero in the figure.)

2.3 BEAM UNIT – ANCHORAGE OF HORIZONTAL FORCES

2.3.1 Check of capacity

F_H = 75 kN (see clause 1.3)

$A_{s,reqd}$ = 75/0,512 = 146 mm^2 (see clause 1.4)

M16 threaded bar (157 mm^2) is assumed - ok

2.3.2 Anchorage length

$l_{bd} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \cdot \alpha_5 \cdot l_{b,reqd} \geq l_{b,min}$

No information exists on the bond characteristics of threaded bars. Assume η_1 to be 0,7.

$f_{bd} = 2{,}25 \cdot 0{,}7 \cdot 1{,}0 \cdot 1{,}80 = 2{,}84$ MPa; $l_{b,reqd} = \frac{Ø}{4} \cdot \frac{\sigma_{sd}}{f_{bd}} = \frac{16}{4} \cdot \frac{75/0{,}157}{2{,}84} = 673$ mm

$l_{b,min} = \max(0{,}3 \cdot l_{b.reqd};\ 10 \cdot Ø;\ 100\text{ mm}) = 202$ mm

Straight bar: $\alpha_1 = 1{,}0$

Concrete cover: $c_d = \min(a/2;\ c_1;\ c) = \min(50/2;\ 100;\ 100) = 25$ mm

$\alpha_2 = 1 - 0{,}15 \cdot (c_d - 3 \cdot Ø)/Ø = 1 - 0{,}15 \cdot (25\text{-}3 \cdot 16)/16 > 1{,}0$; i.e. $\alpha_2 = 1{,}0$

Confinement by reinforcement: Assume transverse reinforcement Ø12-c/c150 mm:

$$\alpha_3 = 1 - K \cdot \lambda = 1 - 0{,}05 \cdot \frac{113 \cdot \frac{300}{150} - 0{,}25 \cdot 113}{113} = 0{,}91$$

Confinement by welded transverse reinforcement: $\alpha_4 = 1{,}0$

Confinement by transverse pressure: $\alpha_5 = 1{,}0$

$l_{bd} = 1{,}0 \cdot 1{,}0 \cdot 0{,}91 \cdot 1{,}0 \cdot 1{,}0 \cdot 673 = 612$ mm

Select 620 mm

Reinforcement design for BCC 250

2.4 COLUMN UNIT – ANCHORAGE IN THE COLUMN

2.4.1 Check of capacity

$M = F_H \times (15+22/2) + F_V \times [(70/2)-35] =$

$= 250 \times (0,3 \times 26 + 0) = 1950$ kNmm

$S = 1950/245 = 7,96$ kN

$A_s = 7,96/0,512 = 16\ mm^2$

M10 at the top is ok (see table in clause 1.4)

$F_H - S = 0,3 \times 250 - 8 = 67$ kN

$A_s = 67/0,512 = 131\ mm^2$

M16 in the bottom is ok

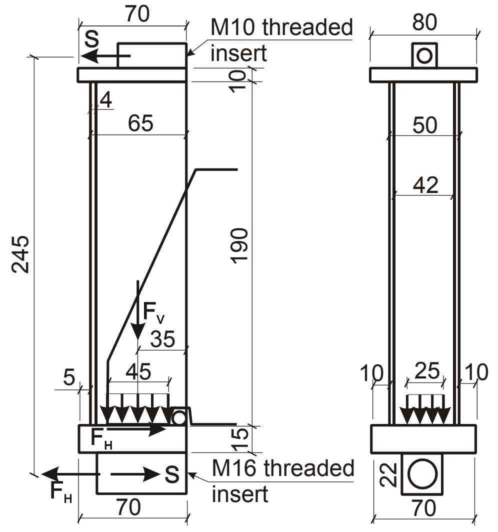

Figure 4. Assumed dimensions. Equilibrium of the column unit.

2.4.2 Anchorage of the bolts

See separate calculations: ”Design of anchorages used in the BCC units.”

See also Memo 27.

PARR 3 – REINFORCEMENT

3.1 BEAM – REINFORCEMENT IN THE REAR

$A_{s,reqd} = R_{CU}/f_{sd} = 95/0{,}435 = 218\ mm^2$,

corresponding to 218/(2×113) = 0,96; i.e. 1 – Ø 12 stirrup.

3.2 BEAM – SHEAR STIRRUPS

Use a strut-and-tie model with compressive diagonals at 45º.

The shear force within the central part of the beam unit is assumed to be R_{CO} = 345 kN.

Assume z = 300 mm and stirrup diameter Ø12.

$s = A_{sw} \cdot z \cdot f_{ywd} \cdot \cot\theta / V$

$s = 2 \times 113 \times 435 \times 300 \times \cot 45^o / 345 \times 10^3 = 85$ mm

Select Ø12 c/c 80 mm. This reinforcement should be brought approximately 200 mm past the end of the beam unit in order to absorb any splitting effects from the anchorage of the threaded bar.

3.3 BEAM – CHECK OF SHEAR COMPRESSION

Assume beam width of 300 mm and beam depth of 450 mm. (See also clause 2.2.) This means that $z_{min} \approx$ 450–50–100 = 300 mm with one layer of reinforcement in the top of the beam and three layers in the bottom.

The shear reinforcement is calculated based on 45º compressive field. The check of shear compression will be carried out under the same assumption:

$V_{Rd,max} = \alpha_{cw} \cdot b_w \cdot z \cdot \upsilon_1 \cdot f_{cd} / (\cot\theta + \tan\theta)$

$V_{Rd,max} = \{1{,}0 \cdot (300-80) \cdot 300 \cdot 0{,}6 \cdot [1-(45/250)] \cdot 30{,}0/(\cot 45^o + \tan 45^o)\} \cdot 10^{-3}$

V_{ccd} = 974 MPa > 345 MPa - OK

3.4 COLUMN – SPLITTING STRESS

Splitting stress under the column unit according to Leonhardt ≈ $0{,}2 \times F_V = 0{,}2 \times 250 = 50$ kN

$A_S = 50/0{,}435 = 115$ mm

1-Ø10 stirrup ($2 \times 78{,}5\ mm^2$) is sufficient.

3.5 CONCLUSION – REINFORCEMENT IN THE BEAM

For ease of maintaining the oversight the beam's main reinforcement is not show in the side view. Between the shown stirrups in each end of the beam a normal calculation of the shear reinforcement must be carried out. The main reinforcement in the beam must of course also be calculated.

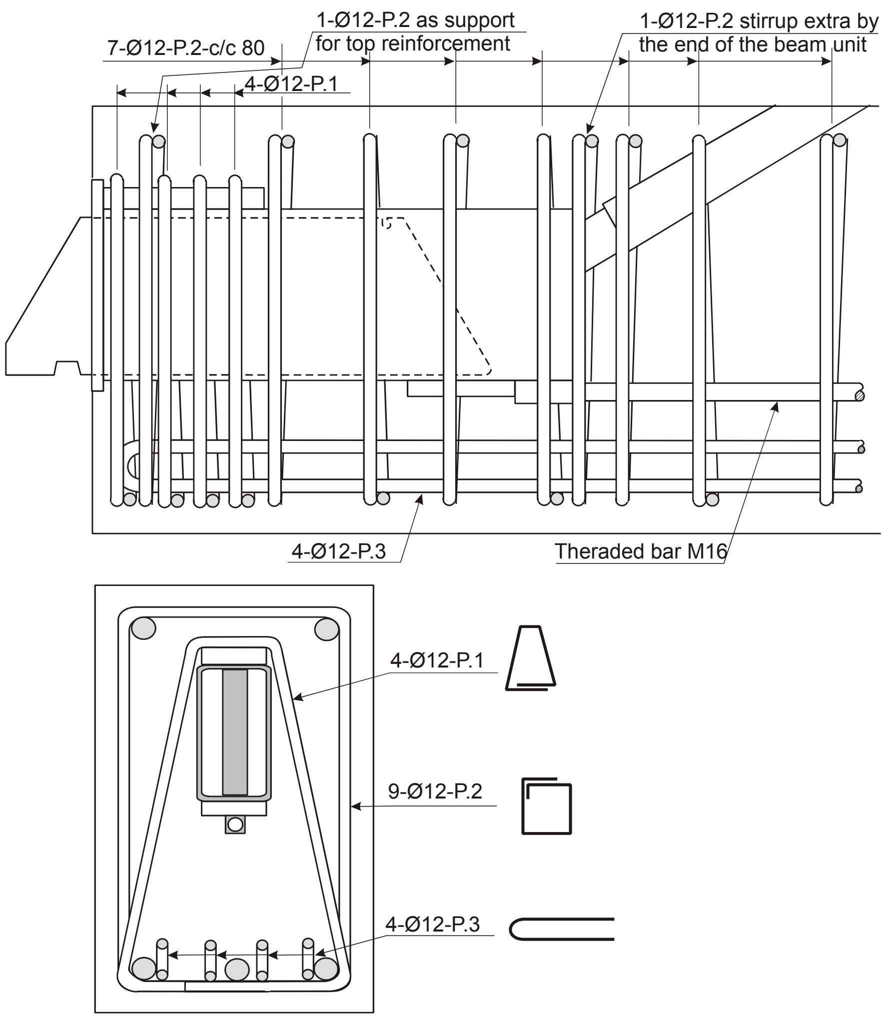

Figure 5. Reinforcement in the beam end.

At the end of the horizontal part of the front anchorage (P.3) it must be checked that the beam's main reinforcement has sufficient anchorage. See clause 2.2.2.