MEMO 521

MEMO 521 BSF UNITS DESIGN OF REINFORCEMENT DESIGN	Dato: 17.04.2013 Siste rev.: 24.05.2016 Dok. nr.: K4-10/521E	Sign.: sss Sign.: sss Control: ps

BSF UNITS - DESIGN OF REINFORCEMENT

CONTENT

PART 1 - BASIC ASSUMPTIONS

1.1 GENERAL

In these calculations, certain assumptions have 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.**

The capacity of the steel part of the beam unit (i.e. the knife) is independent of the concrete quality in the beam as long as the anchoring reinforcement bars are located within the prescribed positions for the different units. Thus, use of weaker or stronger concrete in the beam will only affect aspects related to the beam itself. (I.e the required cross section of the beam, amount of shear reinforcement in the beam end, required anchoring lengths etc.)

This is somewhat different for the steel parts of the column unit. The dimensions of the different steel parts in the column unit are designed with the assumption of concrete quality C35/45 with strengths according to section 1.3. Thus, use of weaker concrete (less f_{cd}) will imply reduced capacity for vertical and horizontal force transfer into the column due to possible concrete failure. Use of stronger concrete (higher f_{cd}) in the column will not increase the capacity as this is limited by the steel components.

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 BSF beam unit.

The information found here and in other 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 structural behaviour of concrete and steel structures.

1.2 STANDARDS

The calculations are in accordance with:

- 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.
- CEN/TS 1992-4-2:2009 Design of fastenings for use in concrete. Headed Fasteners.

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

Parameter	γ_c	γ_s	α_{cc}	α_{ct}
Value	**1,5**	**1,15**	**0,85**	**0,85**

Table 1: NDP-s in EC2.

Parameter	γ_{M0}	γ_{M1}	γ_{M2}
Value	**1,1**	**1,1**	**1,25**

Table 2: NDP-s in EC3.

1.3 QUALITIES

Concrete C35/45: f_{ck} = 35,0 MPa EC2, Table 3.1

$f_{cd} = \alpha_{cc} \times f_{ck}/\gamma_c$ = 0,85×35/1,5 = 19,8 MPa EC2, Clause 3.1.6

$f_{ctd} = \alpha_{ct} \times f_{ctk,0,05}/\gamma_c$ = 0,85×2,2/1,5 = 1,24 MPa EC2, Clause 3.1.6

$f_{bd} = 2{,}25 \times \eta_1 \times \eta_2 \times f_{ctd}$ = 2,25×1,0×1,0×1,24 = 2,79 MPa EC2, Clause 8.4.2

Reinforcement 500C (EN 1992-1-1, Annex C): $f_{yd} = f_{yk}/\gamma_s$ = 500/1,15 = 435 MPa EC2, Clause 3.2.7

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 steels in front and back of the unit.*

Steel Sxxx (EN 10025-2):

S355: Tension: $f_{yd} = f_y/\gamma_{M0}$ = 355/1,1 = 322 MPa

Compression: $f_{yd} = f_y/\gamma_{M0}$ = 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: $$f_{w,d} = \frac{f_u}{\gamma_{M2}\sqrt{3}} \times \frac{1}{\beta_w} = \frac{510}{1{,}25 \times \sqrt{3}} \times \frac{1}{0{,}9} = 262 MPa$$

S275: Tension: $f_{yd} = f_y/\ \gamma_{M0} = 275/1{,}1 = 250$ MPa

Compression: $f_{yd} = f_y/\ \gamma_{M0} = 275/1{,}1 = 250$ MPa

Shear: $f_{sd} = f_y/(\gamma_{M0}\times\sqrt{3}) = 275/(1{,}1\times\sqrt{3}) = 144$ MPa

Weld S275: $$f_{w,d} = \frac{f_u}{\gamma_{M2}\sqrt{3}} \times \frac{1}{\beta_w} = \frac{430}{1{,}25 \times \sqrt{3}} \times \frac{1}{0{,}85} = 233 MPa$$

Threaded bars/nut:

8.8 quality steel: $f_{yd} = 0{,}9\times f_u/\ \gamma_{M2} = 0{,}9\times 800/1{,}25 = 576$ MPa

1.4 DIMENSIONS AND CROSS-SECTION PARAMETERS

UNIT	KNIFE				POSITION	HALF ROUND STEEL			HORIZONTAL ANCHORING [1)]
	L [mm]	H [mm]	t [mm]	Steel grade		D [mm]	L [mm]	Steel grade	
BSF225	510	195	20	S355	FRONT (TOP)	Ø76	100	S355	2×M12, 8.8+ nut, L=650mm & st.pl.50×50×8, S355
					BACK (BOTTOM)	Ø76	100	S275	1×M16, 8.8+nut, L=350mm & st.pl.70×70×10,S355
BSF300	510	235	20	S355	FRONT (TOP)	Ø76	100	S355	2×M12, 8.8+nut, L=650mm & st.pl.50×50×8, S355
					BACK (BOTTOM)	Ø76	100	S275	1×M16, 8.8+nut, L=350mm & st.pl.70×70×10,S355
BSF450	645	250	30	S355	FRONT (TOP)	Ø76	140	S355	2×M12, 8.8+nut, L=750mm & st.pl.50×50×8, S355
					BACK (BOTTOM)	Ø76	100	S275	1×M16, 8.8+nut, L=350mm & st.pl.70×70×10,S355
BSF700	645	280	40	S355	FRONT (TOP)	Ø175	140	S355	2×M16, 8.8+nut, L=750mm & st.pl.70×70×10, S355
					BACK (BOTTOM)	Ø76	100	S275	1×M20, 8.8+nut, L=350mm & st.pl.90×90×12,S355

Table 3: Dimensions - beam unit. [1)] See Table 5.

UNIT	BOTTOM PLATE				VERTICAL REINFORCMENT BAR	HORIZONTAL ANCHORING[1)]
	Length [mm]	Width [mm]	Thickness [mm]	Steel grade		
BSF225	110	100	20	S355	1×ø20 L=600mm	2×M12, 8.8 +nut & st.pl. 50×50×8, S355
BSF300	110	100	20	S355	1×ø20 L=600mm	2×M12, 8.8 +nut & st.pl. 50×50×8, S355
BSF450	125	140	25	S355	1×ø25 L=600mm	2×M16, 8.8 +nut & st.pl. 70×70×10, S355
BSF700	150	150	40	S355	2×ø25 L=790mm	2×M20,8.8 +nut & st.pl. 90×90×12, S355

Table 4: Dimensions - column unit. [1)] See Table 5.

NOMINAL DIAMETER	M12	M16	M20
Equivalent diameter: $Ø_{eq}$ [mm]	10,4	14,1	17,7
Stress area: A_s [mm^2]	84	157	245
Tensile capacity (8.8): $F_{cap}= f_{yd}×A_s$ [kN]	48	90	141
Width across flats: NV [mm]	19	24	30
Required dim. of square steel plate anchoring F_{cap}:[1)] $b_{req}≥[F_{cap}/f_{cd}+\pi×Ø^2_{nom}/4]^{0.5}$ [mm] Select b×b	≈50,4 Select 50×50	69 Select 70×70	86 Select 90×90
Nett area for compression anchorage: $A_{net}=A_{steel\ plate}-\pi×Ø^2_{nom}/4$ [mm^2]	2387	4699	7786
Concrete stress: $\sigma_c=F_{cap}/A_{net}$ [MPa]	20,1	19,1	18,1
Required thickness of steel plate, S355: [1)] $a=(2^{0.5}×b-NV)/2$ -> $t_1≥a×(\sigma_c/f_{yd})^{0,5}$[mm] $c=b/2-NV/2$ -> $t_2≥ 3^{0,5}×c×(\sigma_c/f_{yd})^{0,5}$[mm] $t>[t_1, t_2]$	a=25,9 c=15,5 | t_1=6,5 t_2=6,7 Select t=8mm	a=37,5 c=23 | t_1=9,1 t_2=9,7 Select t=10mm	a=48,6 c=30 | t_1=11,5 t_2=12,3 Select t=12mm
Standard height of nut: (H) [mm]	10,0	13,0	16,0
Required thread length in blind holes: S275	18mm	24mm	30mm
Required thread length in blind holes: S355	18mm	24mm	30mm
Dimension of corresponding threaded insert [mm]	50×18×18	60×22×22	70×30×30

Table 5: Dimensions - threaded bars, inserts and anchoring steel plates.
(The listed dimensions are based on the concrete quality and parameters given in above Section 1.2 and Section 1.3.)

1.5 LOADS

Vertical ultimate limit state load: F_V= According to Table 6.
Horizontal ultimate limit state load - in axial direction: F_H=0kN (see notes below)
Horizontal ultimate limit state load - in transverse direction: F_T=0kN

***Note on loads:**

- The BSF unit 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 by stiff columns. 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 unfavourable load combination:

  Vertical force 1,0F_v + 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.

- The BSF knife will normally give an eccentric load on the supporting column. Thus, a small pair of horizontal forces will occur at top and bottom of the column, balancing the eccentricity. The amplitude of these horizontal forces will be proportional to the occurring vertical force. For normal situations, the horizontal force will be less than: $F_{V,occuring} \times 0,1$. Thus, normally this force can be carried through the BSF connection, since the portion is less than the minimum friction factor. However, this assumption must be controlled in each case.

- Horizontal anchoring of the steel parts assumes minimum concrete grade C35/45 in column and beam.

UNIT	VERTICAL ULTIMATE LIMIT STATE LOAD F_v [kN]	DESIGN LOAD BEAM AND COLUMN UNIT		HORIZONTAL ANCHORING IN BEAM	
		VERT. $1{,}0F_v$ [kN]	HOR. $0{,}3F_v$ [kN]	TOP OF UNIT $H=0{,}2F_v$	BOTTOM OF UNIT $H=0{,}2F_v$
BSF225	225	225	67,5	45	45
BSF300	300	300	90	60	60
BSF450	450	450	135	90	90
BSF700	700	700	210	140	140

Table 6: Design loads.

1.6 TOLERANCES

The design nominal gap between column and beam is 20mm, with a tolerance of ±10mm.The tolerances are handled by 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 column will always be the same.

The tolerance on location of the reinforcement in front and back is ±5mm.

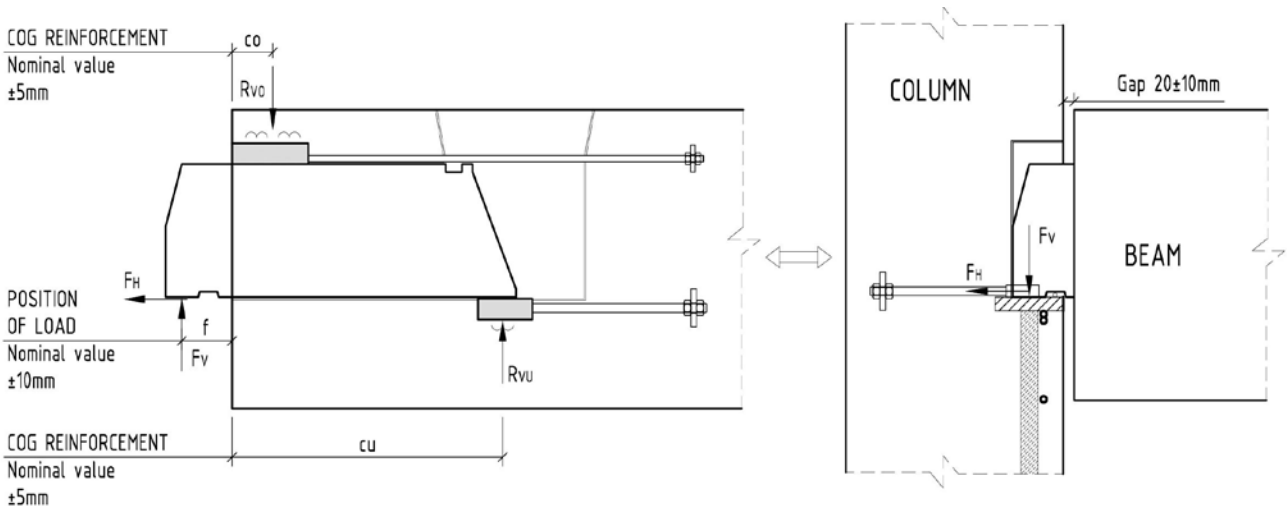


Figure 1: Tolerances.

PART 2 PRINCIPAL DESIGN OF REINFORCEMENT FOR BSF UNITS

2.1 GENERAL

The design of the reinforcement is carried out assuming the maximum cantilevering of the knife in combination with the most unfavourable location of the front and back reinforcement.

2.2 BEAM UNIT - EQUILIBRIUM

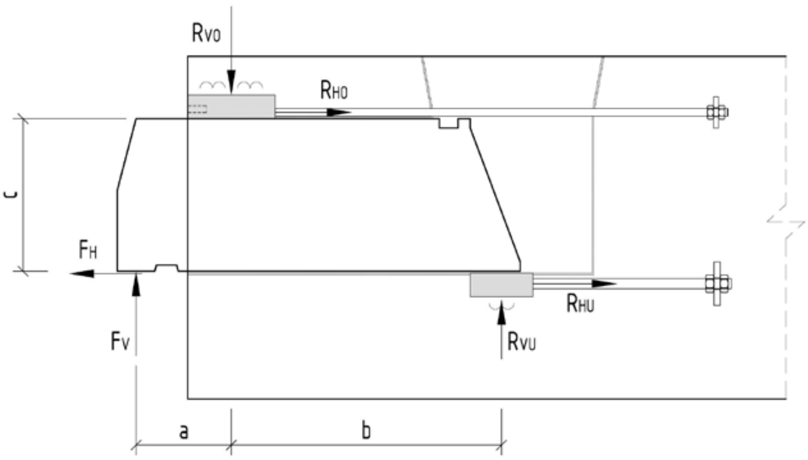


Figure 2: Equilibrium.

When evaluating the required amount of vertical suspension reinforcement in front and back of the unit, the horizontal reaction force R_{HU} is assumed $0{,}1F_V$, and R_{HO} is assumed $0{,}2F_V$. Unfavourable tolerances on location of reinforcement and loading are included in the parameters a, and b. The equilibrium equations become:

$$R_{VO} = F_V \times \frac{a+b}{b} + R_{HO} \times \frac{c}{b} = F_V \times \frac{a+b}{b} + 0{,}2F_V \times \frac{c}{b}$$

$$R_{VU} = R_{VO} - F_V$$

2.3 BEAM UNIT – ANCHORING REINFORCEMENT

<u>1) Vertical suspension reinforcement in front:</u>

The required amount of reinforcement in the front of the unit becomes:

$$A_s = \frac{R_{VO}}{f_{yd}}$$

2) Vertical suspension reinforcement at back:

The required amount of reinforcement at the back of the unit becomes:

$$A_s = \frac{R_{VU}}{f_{yd}}$$

Bending of anchoring reinforcement - EC2, clause 6.5.4/6.5.2 and fib Bulletin 52 "Structural concrete-Textbook on behaviour, design and performance", vol.2, section 3.2.3:

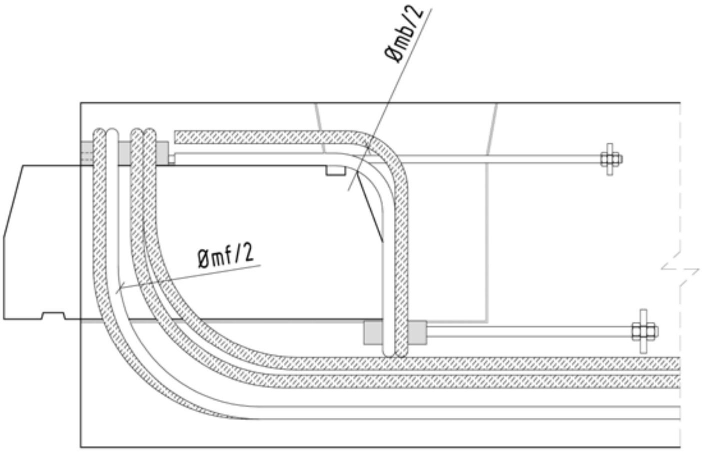


Figure 3: Bending of reinforcement.

Allowable concrete stress in node:

$$f_{cd2} = 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd}$$

Actual concrete stress in node:

$$\sigma_c = \frac{R}{b_{eff} \times Ø_m \times \sin\theta \times \cos\theta}$$

b_{eff}= effective beam width. If the compression strut crosses the unit, the width of the unit should be extracted.

$Ø_m$= Mandrel diameter of reinforcement

θ=assume concrete strut in 45degrees. ⇒ sinθ×cosθ=0,5

R=Force in reinforcement.

Solving for $Ø_m$, inserting $\sigma_c=f_{cd2}$ and $\sin\theta\times\cos\theta=0{,}5$:

$$Ø_m = \frac{R}{b_{eff}\times f_{cd2}\times\sin\theta\times\cos\theta} = \frac{R}{b_{eff}\times 0{,}6\times(1-\frac{f_{ck}}{250})\times f_{cd}\times 0{,}5}$$

Minimum mandrel diameter - bending of front reinforcement:

$$Ø_{mf} = \frac{R_{VO}}{b_{eff}\times 0{,}6\times(1-\frac{f_{ck}}{250})\times f_{cd}\times 0{,}5}$$

Minimum mandrel diameter - bending of reinforcement at back:

$$Ø_{mb} = \frac{R_{VU}}{b_{eff}\times 0{,}6\times(1-\frac{f_{ck}}{250})\times f_{cd}\times 0{,}5}$$

⇒ Select appropriate mandrel diameter. The minimum mandrel diameter shall comply with the requirements of EN 1992-1-1, 8.3.

From the strut and tie model in Figure 6 it is seen the force is reduced towards the bend of the front suspension stirrups for high beams, however the full value of R_{VO} will be used when evaluating the minimum mandrel diameter.

3) Anchoring of stirrups in front - EC2, clause 8.4.3 and 8.4.4:

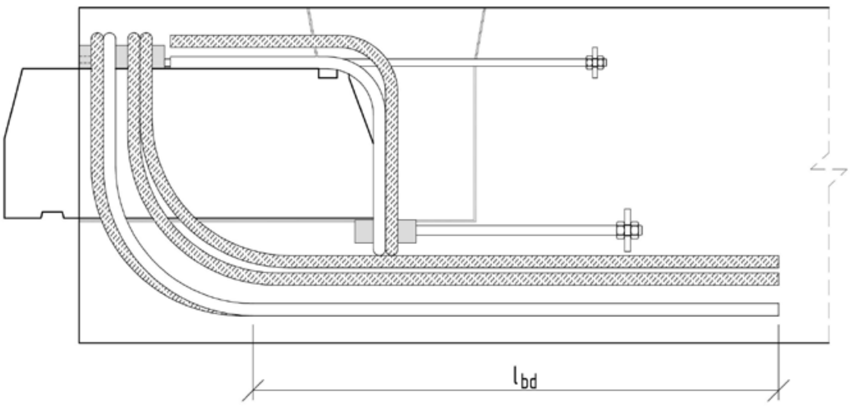


Figure 4: Anchoring of reinforcement.

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

$$l_{b,reqd} = \frac{Ø}{4}\times\frac{\sigma_{sd}}{f_{bd}}$$

Stress in stirrup: $\sigma_{sd} = \frac{R_{VO}}{A_s}$

A_s= Total area of selected reinforcement bars.

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

Table 8.2: Straight bar:

$α_1 = 1,0$

Table 8.2: Concrete cover:

$α_2 = 1 - 0,15 \times (c_d - 3 \times Ø)/Ø$

Neglecting any positive effect of concrete cover, selecting $α_2=1,0$

Table 8.2: Confinement by reinforcement:

$α_3 = 1 - K \times λ$

Neglecting any positive effect of transverse reinforcement, selecting $α_3 = 1,0$

Table 8.2: Confinement by welded transverse reinforcement:

$α_4 = 1,0$

Not relevant.

Table 8.2: Confinement by transverse pressure:

$α_5 = 1,0$

Not relevant.

$α_2 \times α_3 \times α_5 > 0,7$

4) Lap of stirrups - EC2, clause 8.7.3:

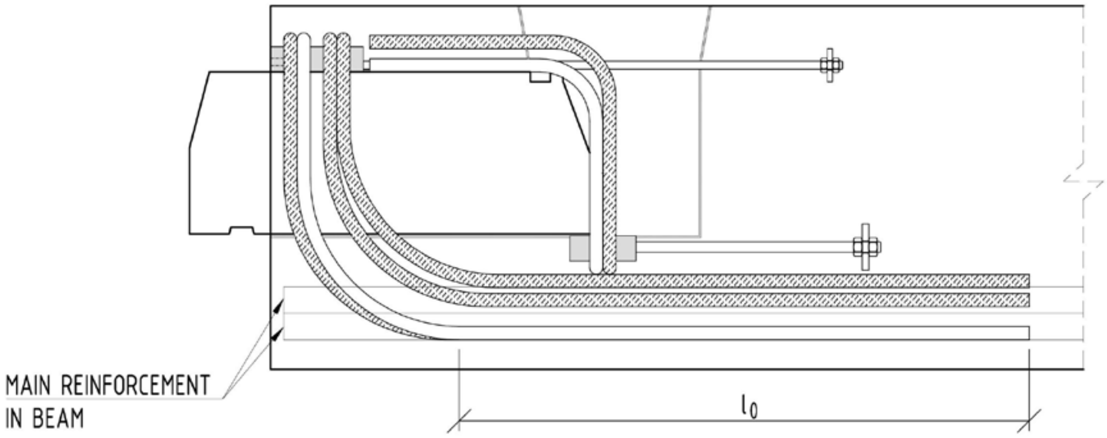


Figure 5: Lap of reinforcement.

$l_0 = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_5 \times \alpha_6 \times l_{b,reqd} \geq l_{0,min}$

Required lap length:

$l_{b,reqd}$ = as calculated in clause 3.

$l_{0,min} = \max(0{,}3 \times \alpha_6 \times l_{b,reqd};\ 15 \times \emptyset;\ 200\text{mm})$

Table 8.2: α_1, α_2, α_3 and α_5=1,0 as calculated in clause 3.

Table 8.3: α_6=1.5 (All reinforcement is lapped)

$\Rightarrow l_0 = 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}5 \times l_{b,reqd}$

5) Anchoring of main reinforcement:

It must be ensured the horizontal part of the front reinforcement is continued until the main reinforcement is sufficient anchored to carry the load.

2.4 BEAM UNIT - HORIZONTAL ANCHORING

The beam unit is anchored for a total horizontal load of F_H=0,3F_V. The knife will be in contact with both the half round steel in front and back. Due to the geometry of the knife, the reaction force at back of the knife is approximately half of the vertical load on the unit. Assuming the minimum friction factor 0,2 at back of the knife, a horizontal force with magnitude 0,1F_V can always be transferred at back of the knife. Thus, the remaining horizontal force 0,2F_V must be transferred in front of the knife towards the half round steel at top. It's chosen to anchor both of the half round steels for a horizontal force F_H=0,2F_V.
The required dimension of threaded bars, steel plate and machined thread lengths in the half round steel is found from Table 5.

2.5 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

2.5.1 STRUT AND TIE MODEL

The load bearing mechanism in the end of the beam may be described with strut and tie models. Figure 6 illustrates the models for the internal height (z) as various multiples of the internal distance b. As indicated, a local truss (blue) carrying the bending moment from the cantilevering will have one or several levels depending on the height of the beam.

Low beams:
For low beams the entire reaction force R_{VU} will be carried/lifted by the prescribed special reinforcement at back of the unit, and the required reinforcement in the first length (b) of the beam end will consist of the special front and back suspension reinforcement for the unit, together with the beam shear stirrups for the shear force R_{VO}.

Higher beams:
For higher beams, the illustration indicates that some of the reaction force R_{VU} will bypass the prescribed special suspension reinforcement and spread into the underlying concrete with compression diagonals towards the end of the beam. The model indicates that the vertical part of the compression force will hang onto the front suspension reinforcement and decrease the tension in the front suspension reinforcement towards the bottom of the beam. For design purpose it is recommended to not take advantage of these reductions, neither when selecting minimum mandrel diameter and anchoring length of the front reinforcement, nor when calculating the required amount of suspension reinforcement at back of the unit. The horizontal part of the compression diagonals must be anchored with horizontal reinforcement inwards from the beam end. For design purpose, the horizontal force may be thought of as smeared, giving horizontal force intensity towards the vertical end the beam:

For the case of z=2b, the horizontal force per unit height of the beam becomes:

$1/2(a/b)\times F_v/(z/2)$. This corresponds to: $(a/b)\times F_v/z= R_{VU}/z$.

For the case of z=3b, the horizontal force per unit height of the beam becomes:

$1/3(a/b)\times F_v/(z/3)$. This corresponds to: $(a/b)\times F_v/z= R_{VU}/z$.

The above evaluation illustrates that the force intensity towards the end of the beam always becomes: R_{VU}/z. Thus, the intensity is depending on the beam height. Horizontal bars are recommended included when the internal height (z) is above b+ $Ø_{mandrel}/2$, see Figure 7.

As indicated, the vertical part of the compression diagonals towards the end of the beam will hang onto the front suspension reinforcement. This internal effect will however not reduce the shear force in the beam, as vertical equilibrium in every cross section within the first length b of the beam will require a shear force equal to the force R_{VO}. Thus, integrity for the occurring forces in higher beams is ensured by designing the shear reinforcement in the beam within the first length (b) for the force R_{VO}, and including the above described horizontal anchoring reinforcement from the beam end. It is important these horizontal bars are proper anchored inwards from the end of the beam unit. No additional stirrups at back of the unit to “catch” the vertical force bypassing the special reinforcement will be required, as the strut and tie model shows that this force is spread towards the end of the beam.

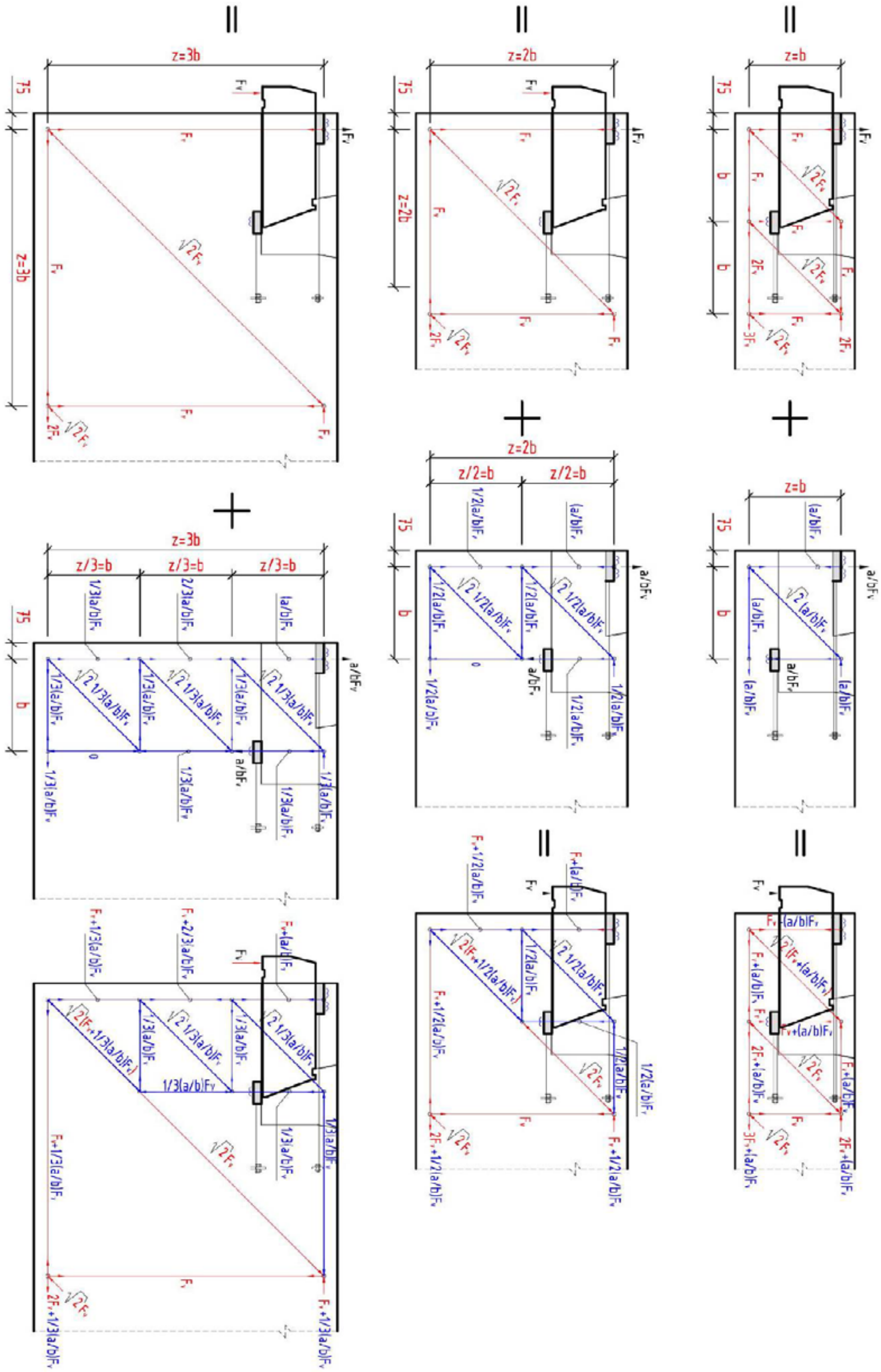


Figure 6: Strut and tie model in beam end. (Should be printed in colour)

2.5.2 SHEAR STIRRUPS IN BEAM END

The shear force within the central part of the beam unit will equal the force R_{VO}

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} = \frac{R_{VO}}{z \times f_{yd}}$$

The shear reinforcement according to above requirement should be brought approximately 200mm past the end of the beam unit in order to absorb any splitting effects from the threaded bars anchoring the horizontal force.

(Note: The anchoring reinforcement shall be anchored as deep as possible in the cross-section. If the deviation between the z-value calculated to the centre of the main reinforcement and the z-value calculated to the centre of the horizontal part of the anchoring stirrups exceeds 5%, the less of the to values shall be used in the above evaluation of shear reinforcement in beam end. If the deviation between the two values is significant, the flow of forces must be evaluated especially.

2.5.3 SHEAR COMPRESSION IN BEAM END

Shear compression is evaluated according to :

EC2, clause 6.2.3

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

$b_w = b_{beam} - b_{unit}$

2.5.4 HORIZONTAL BARS IN BEAM END

According to the strut and tie model:

$$\frac{A_s}{s} = \frac{R_{VU}}{z \times f_{yd}}$$

Recommended included when $z > b + Ø_{mandrel}/2$, see Figure 7

where: $Ø_{mandrel}$ = mandrel diameter of front stirrups

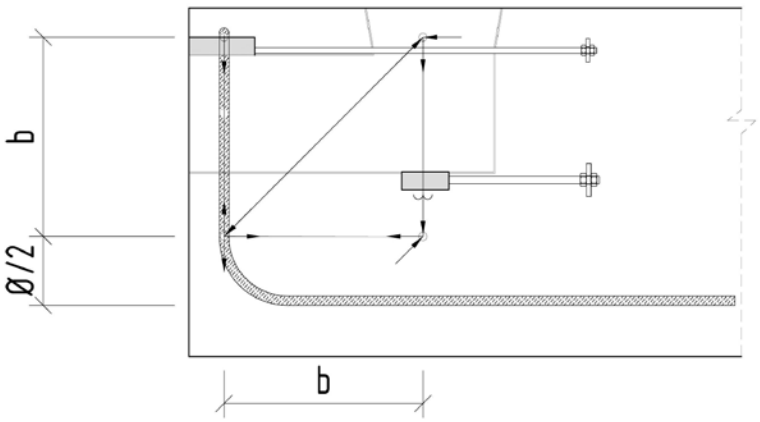
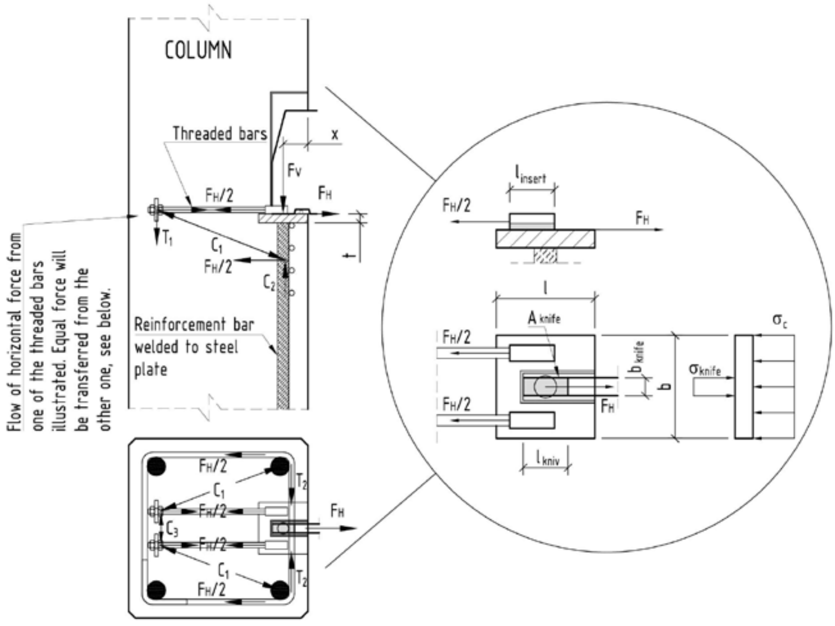


Figure 7: Illustration.

Assuming: z=0,9d, and d=h-2xconcrete cover gives the following expression on beam height:

$h > (b + Ø_{mandrel}/2)/0{,}9 + 2 \times \text{concrete cover}$

2.6 COLUMN UNIT



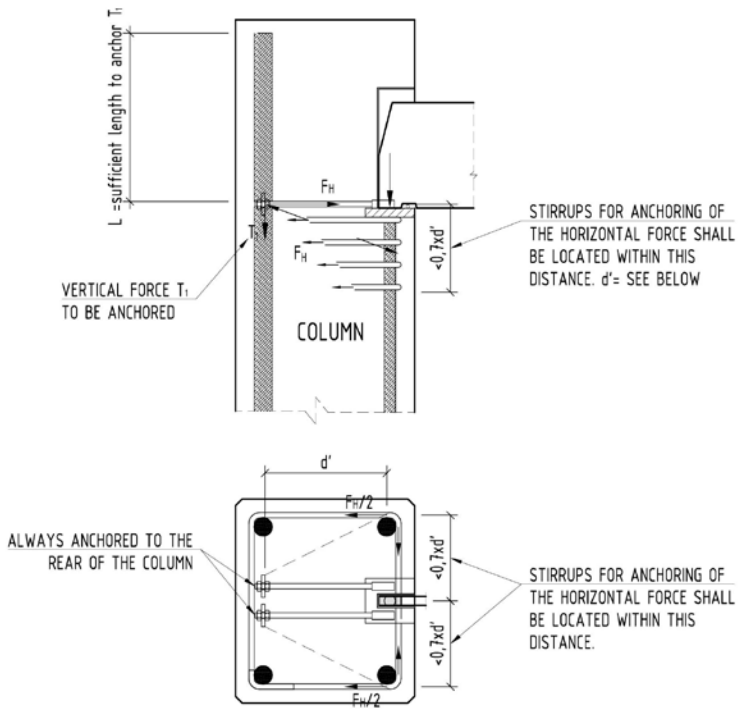


Figure 8: Principal sketch of force transfer in column.

1) Transfer of vertical load F_V:

A uniform stress distribution in the contact area between knife and steel plate is assumed, see Figure 8. A part of the force is transferred directly into the reinforcement bar welded to the steel plate. The remaining force is carried by uniform concrete stress in the contact area between steel plate and concrete. The following formulas are applied:

I: Stress from knife.

$$\sigma_{knife} = \frac{F_v}{A_{knife}}$$

II: Force going directly into reinforcement bar (diameter reinforcement=Ø).

The anchored force will be the minimum of:

a) $$F_{Øa} = A_Ø \times \sigma_{knife} = \frac{\pi \times Ø^2}{4} \times \sigma_{knife}$$

b) $$F_{Øb} = 2 \times \pi \times Ø / 2 \times f_{bd} \times L_{bar}$$

III: Concrete stress:

$$\sigma_c = \frac{F_v - F_Ø}{(A_s - A_Ø)} < f_{cd}$$

2) Transfer of horizontal load $F_H=0{,}3F_V$:

The horizontal force is transferred from the horizontal steel plate via the threaded inserts to the threaded bars. The threaded bars are anchored with a steel plate and nut. The anchoring is recommended to the rear of the column. The horizontal force is further assumed transferred via a strut-and-tie model into the column stirrups as illustrated in Figure 8, part 1. The column reinforcement shall be consistent with the selected model. This is in accordance with clause 5.3.1 in CEN/TS 1992-4-2. It's recommended to place the reinforcement for horizontal force as close to the unit as possible to reduce the angles in the strut and tie model. However, clause 6.2.2 gives specific requirements to location of the reinforcement, see also Figure 8, part 2. Only reinforcement bars with a distance ≤0,7d' from the threaded bars should be assumed effective.

Calculating the maximum tension forces in the strut & tie model (reinforcement at maximum distance 0,7d'):

$$T_1 = F_H / 2 \times 0{,}7$$

$$\Rightarrow T_1 = F_H / 2 \times 0{,}7 = 0{,}35 F_H$$

⇒ The summarized vertical tension force from the two nodes equals $2 \times 0{,}35F_H = 0{,}7F_H$.
Note: This force has to be sufficient anchored downwards from the position of the threaded bars. Normally this will be safeguarded by compression forces in the column, or by sufficient anchoring of the main reinforcement from the unit and upwards to the top of the column. Special care must be taken if the unit is located at the very top of the column.

$$T_2 = F_H / 2 \times 0{,}7$$

$$\Rightarrow T_2 = F_H / 2 \times 0{,}7 = 0{,}35 F_H$$

$\Rightarrow$ T_2 to be included in addition to splitting stress when designing the stirrups below the unit.

3) Splitting stress - EC2, clause 6.5.3 (3):

Tensile force: $T = \frac{1}{4} \times \frac{b-a}{b} \times F_V$

$\Rightarrow$ Conservative simplification: T=0,25×Fv

To be distributed according to EC2.

4) Stirrups in column directly under the column unit:

Required reinforcement due to splitting stress (3) and horizontal force (2). Conservative simplification:

$$A_s = \frac{T}{f_{yd}} + \frac{T_2}{f_{yd}} = \frac{0{,}25 \times F_v}{f_{yd}} + \frac{0{,}35 \times F_H}{f_{yd}} = \frac{0{,}25 \times F_v}{f_{yd}} + \frac{0{,}35 \times 0{,}3 \times F_H}{f_{yd}} \approx \frac{0{,}4 \times F_V}{f_{yd}}$$

Required amount of stirrups: $n = \frac{A_s}{\pi \times Ø^2_{stirrup} / 4}$

5) Principal reinforcement in column:

Figure 9 illustrates and summarizes the principal reinforcement in the column locally around the unit. The reinforcement in Zone 1 shall correspond to the reinforcement calculated in above clause 4.

It is further recommended to include extra centre stirrups along the length of the unit. These stirrups shall be anchored around the reinforcement bar(s) welded to the steel plate, and it is recommended to use the same spacing and dimension for these stirrups as for the standard stirrups. In case of a single unit, an extra longitudinal bar has to be introduced in order to anchor the centre stirrups at the rear side of the column.

In case of double units, the threaded bars are screwed into the threaded inserts in both units, making a horizontal connection right through the column.

Figure 9 illustrates the column with four main reinforcement bars, one in each corner of the stirrups. This is only an illustration. The knife(s) will give eccentric load(s) on the column and the required amount of main reinforcement shall be evaluated in each case, based on the actual occurring axial force and bending moment(s) from the eccentricity (-ies).

It's an assumption the recess for the knife in the column is always filled with grout. Thus, the capacity of the column can be evaluated without reduction in cross-section due to the column unit.

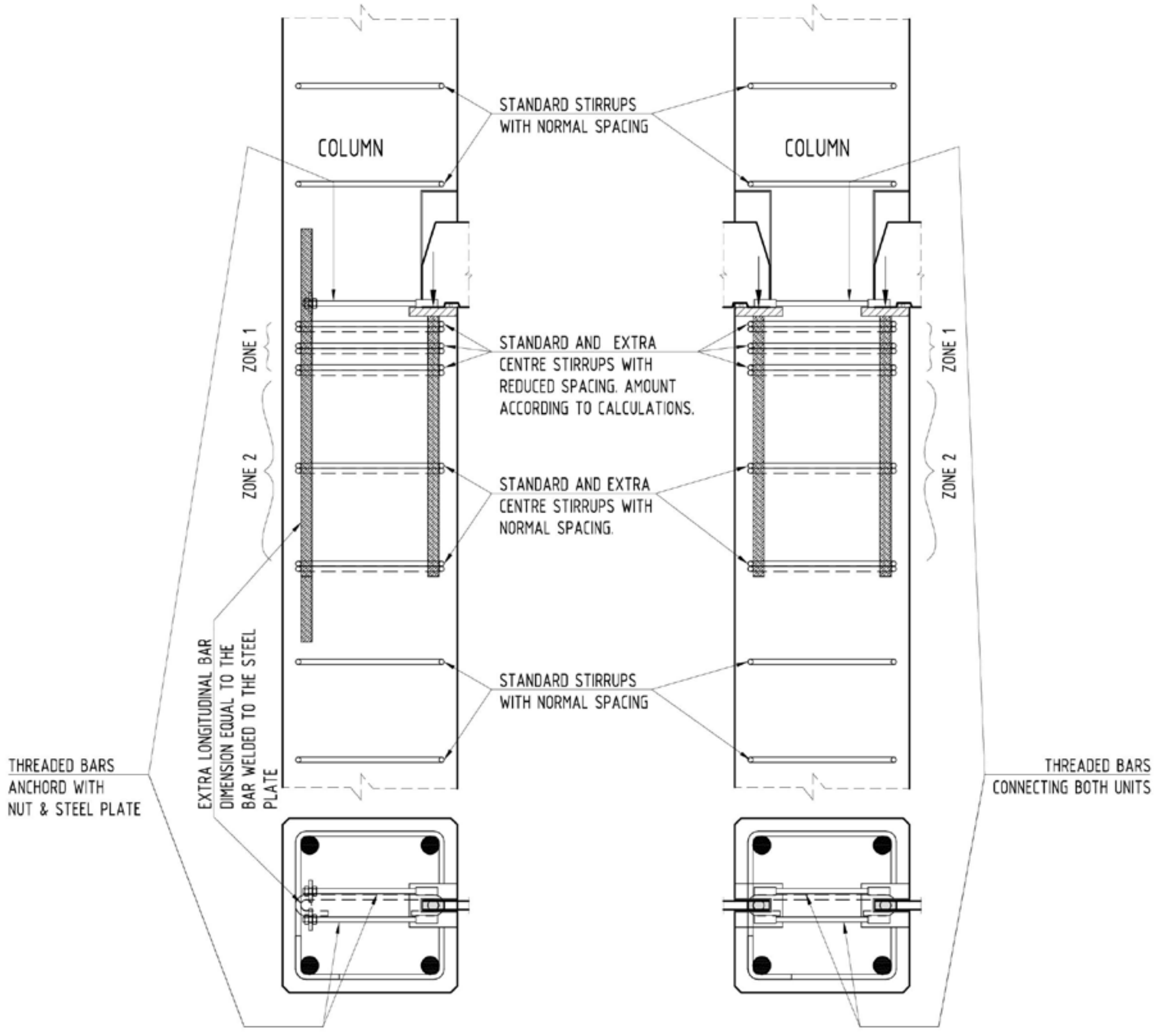


Figure 9: Principal reinforcement in column.

PART 3 - BSF 225

3.1 BEAM UNIT - EQUILIBRIUM

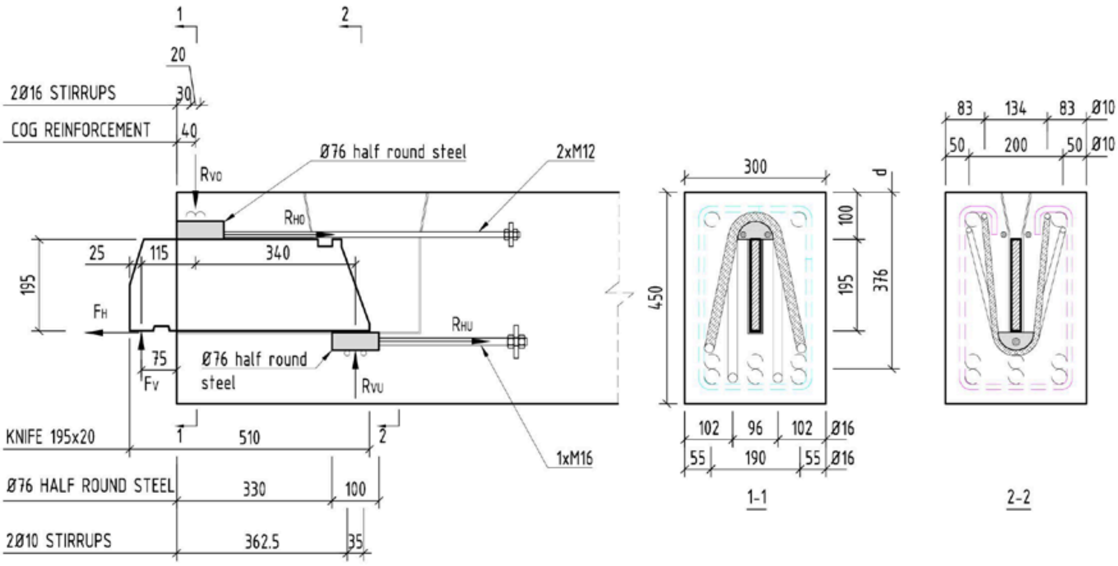


Figure 10: BSF 225 Beam unit. Situation I-nominal values on cantilever and location of anchoring reinforcement.

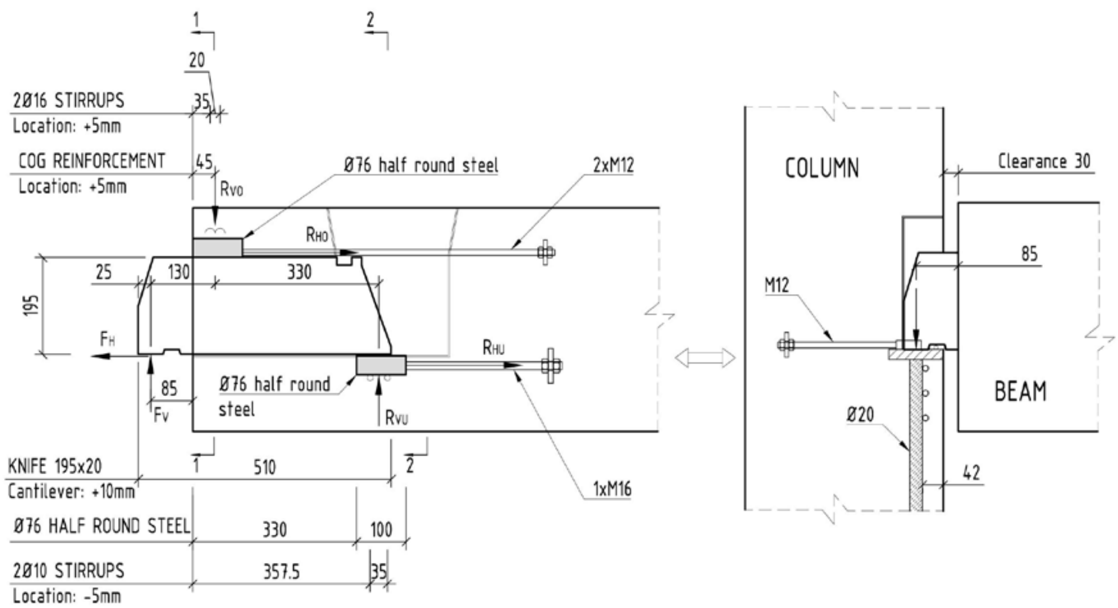


Figure 11: BSF 225 Beam unit. Situation II-unfavourable tolerances on cantilever and location of anchoring reinforcement.

Forces situation I:

Equilibrium:

$$R_{VO} = F_V \times \frac{115mm + 340mm}{340mm} + R_{HO} \times \frac{195mm}{340mm}$$

$$= 225kN \times \frac{115mm + 340mm}{340mm} + 0{,}2 \times 225kN \times \frac{195mm}{340mm} \approx 327kN$$

$$R_{VU} = R_{VO} - 225kN = 327kN - 225kN = 102kN$$

Forces situation II:

Equilibrium:

$$R_{VO} = F_V \times \frac{130mm + 330mm}{330mm} + R_{HO} \times \frac{195mm}{330mm}$$

$$= 225kN \times \frac{130mm + 330mm}{330mm} + 0{,}2 \times 225kN \times \frac{195mm}{330mm} = 340{,}2kN$$

$$R_{VU} = R_{VO} - 225kN = 340{,}2kN - 225kN = 115{,}2kN$$

3.2 BEAM UNIT – ANCHORING REINFORCEMENT

<u>**1) Vertical suspension reinforcement in front -Situation II is assumed:**</u>

Reinforcement:

$$A_s = \frac{R_{VO}}{f_{yd}} = \frac{340{,}2kN}{435MPa} = 782mm^2$$

2Ø16Stirrups= 201mm^{2}x4=804mm^2

Capacity of selected reinforcement: 804mm^2×435MPa=349kN

Minimum mandrel diameter:

$$Ø_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{340200}{270 \times 0{,}6 \times (1 - \frac{35}{250}) \times 19{,}8MPa \times 0{,}5} = 247 \text{ mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=300mm-30mm=270mm

$Ø_{mf}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=250mm

2) Vertical suspension reinforcement at back -Situation II is assumed:

Reinforcement:

$$A_s = \frac{R_{VU}}{f_{yd}} = \frac{115{,}2kN}{435MPa} = 265mm^2$$

2Ø10stirrup= 78mm^{2}x4=312mm^2

Capacity of selected reinforcement: 312mm^2×435MPa=135kN

Minimum mandrel diameter:

$$\varnothing_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0{,}6 \times (1-\frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{115200}{270 \times 0{,}6 \times (1-\frac{35}{250}) \times 19{,}8MPa \times 0{,}5} = 84\,\text{mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=300mm-30mm=270mm

$Ø_{mb}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=100mm

3) Anchoring of stirrups in front, EC2 clause 8.4.3 and 8.4.4:

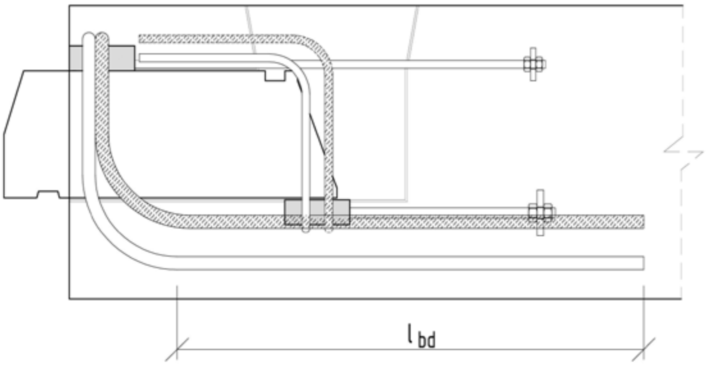


Figure 12: Anchoring of reinforcement.

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

$$l_{b,reqd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}}$$

Stress in stirrup: $\sigma_{sd} = \frac{340{,}2kN}{804mm^2} = 423MPa$

$$l_{b,reqd} = \frac{16}{4} \times \frac{423}{2{,}79} = 606\text{mm}$$

$l_{b,min}$ = max(0,3×$l_{b,reqd}$; 10×Ø; 100mm)=182mm

Table 8.2: Straight bar:

α_1= 1,0

Table 8.2: Concrete cover:

$\alpha_2 = 1{-}0{,}15\times(c_d{-}3\times\varnothing)/\varnothing$

Neglecting any positive effect of concrete cover, selecting α_2=1,0

Table 8.2: Confinement by reinforcement:

$\alpha_3 = 1{-}K\times\lambda$

Neglecting any positive effect of transverse reinforcement, selecting α_3 =1,0

Table 8.2: Confinement by welded transverse reinforcement:

α_4 = 1,0

Not relevant.

Table 8.2: Confinement by transverse pressure:

α_5 =1,0

Not relevant.

$\alpha_2\times\alpha_3\times\alpha_5$=1,0×1,0×1,0=1,0 > 0,7 – OK

l_{bd} = 1,0×1,0×1,0×1,0×1,0×606mm=606mm

4) Lap of stirrups, EC2 clause 8.7.3:

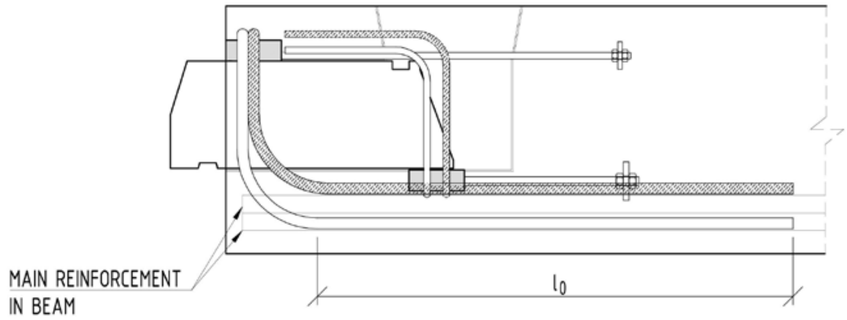


Figure 13: Lap of reinforcement.

$l_0 = \alpha_1\times\alpha_2\times\alpha_3\times\alpha_5\times\alpha_6\times l_{b,reqd} \geq l_{0,min}$

Required lap length:

$l_{b,reqd}$ = 606mm, see evaluation in clause 3.

$l_{0,min} = \max(0{,}3\times\alpha_6\times l_{b,reqd};\ 15\times\varnothing;\ 200mm)$

Table 8.2: α_1, α_2, α_3 and α_5=1,0 as calculated in clause 3.

Table 8.3: α_6=1.5 (All reinforcement is lapped)

$\Rightarrow l_0$ = 1,0×1,0×1,0×1,0×1,5×606mm=909mm

$\Rightarrow$Select: l_0=950mm

5) Anchoring of main reinforcement:

It must be ensured the horizontal part of the front reinforcement is continued until the main reinforcement is sufficient anchored to carry the load.

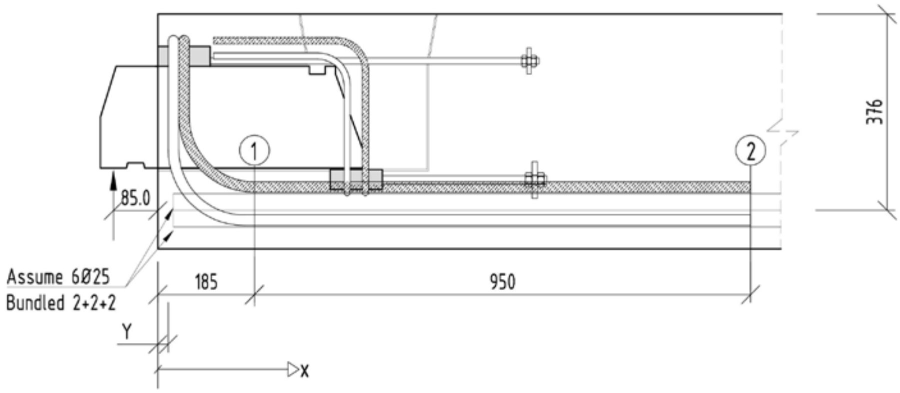


Figure 14: Anchoring.

Example, assuming:

- Main reinforcement at bottom: 6Ø25, bundled 2+2+2.
- Horizontal part of the front anchoring bars is 950mm (≈ equals the minimum calculated lap length). I.e. the bars end at x=185+950=1135mm.
- Y=30mm

Section 1 (at x=185mm):

Equivalent diameter of 2Ø25 bundled:

$$Ø_n = Ø \times \sqrt{2} = 25 \times \sqrt{2} = 35mm$$

Anchoring length of a bundle:

$$L_n = \frac{\pi \times 12{,}5^2 \times 435MPa \times 2}{\pi \times Ø_n \times f_{bd}} = \frac{\pi \times 12{,}5^2 \times 435MPa \times 2}{\pi \times 35 \times 2{,}79MPa} = \frac{427kN}{0{,}3067kN/mm} = 1392mm$$

Force anchored in Ø25:

$F_{Ø25}=f_{bd}\times Ø_n \times\pi\times(185-Y)\times3=2{,}79\times35\times\pi\times(185-30)\times3=142kN$

Force anchored in Ø16:

$F_{Ø16}=340{,}2kN$

Total anchored force:

$F=F_{Ø25}+F_{Ø16}=142kN+340{,}2kN=482{,}2kN$

Tension in reinforcement at x=185mm: (clause 6.2.3(7))

$S(x)=M(x)/z+0{,}5V_{Ed}\times (\cot(\theta)-\cot(\alpha))$

$=M(x)/z+0{,}5\times V_{Ed}\times (\cot(45)-\cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0{,}5\times V_{Ed}\times (1-0)$

$= M(x)/z+0{,}5\times V_{Ed}$

Bending moment at x=185:

$M\ (x=185)=225kN\times(185+85)mm=60{,}8kNm$

Assume: $z=0{,}9d=0{,}9\times376mm=338mm$ (approximately)

$S\ (x=185)=60{,}8kNm/0{,}338m+340{,}2kN/2=350kN$

⇒ The anchoring at x=185mm is sufficient in this case.

<u>Section2 (at x=1135mm):</u>

Force anchored in Ø25:

$F_{Ø25}=f_{bd}\times Ø_n\times\pi\times(1135-Y)\times3=2{,}79\times35\times\pi\times(1135-30)\times3=1017kN$

Force anchored in Ø16:

$F_{Ø16}=0kN$

Total anchored force:

$F=F_{Ø25}+F_{Ø16}=1017kN+0kN=1017kN$

Tension in reinforcement at x=1135mm: (clause 6.2.3(7))

$S(x)=M(x)/z+0{,}5V_{Ed}\times(\cot(\theta)-\cot(\alpha))$

$=M(x)/z+0{,}5\times V_{Ed}\times(\cot(45)-\cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0{,}5\times V_{Ed}\times(1-0)$

$= M(x)/z+0{,}5\times V_{Ed}$

Moment at x=1135:

$M\ (x=1135)=225kN\times(1135+85)mm=274{,}5kNm$

Assume: $z=0{,}9d=0{,}9\times376mm=338mm$ (approximately)

$S\ (x=1135)=274{,}5kNm/0{,}338m+225kN/2=925kN$

⇒ The anchoring at x=1135mm is sufficient in this case.

Note: No reduction in the bending moment due to distributed load on top of the beam is accounted for in this example. Normally this will be the case, thus the cross section forces in section 2 will normally be less than calculated here.

3.3 BEAM UNIT – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel in top R_{HO}=0,2xF_V=45kN:

Select: 2×M12 threaded bars 8.8 with nut & steel plate = 48kN×2=96kN

Machined thread length in half round steel according to Table 5

Horizontal anchoring of half round steel at bottom R_{HU}=0,2xF_V=45kN:

Select: 1×M16 threaded bar 8.8 with nut & steel plate = 90kN

Machined thread length in half round steel according to Table 5.

3.4 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

3.4.1 SHEAR STIRRUPS IN BEAM END

Use a strut-and-tie model with compression diagonal at 45°. The shear force within the central part of the beam unit is assumed to be R_{VO}=340,2kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{340{,}2 \times 10^3\, N}{0{,}9 \times 0{,}376m \times 435MPa} = 2311mm^2 \,/\, m$$

Assume height of beam h=450mm

Assume d=376mm

Assume z=0,9d

Assume stirrup diameter Ø10.

⇒ Ø10c60 (2617mm^2/m)

⇒Select Ø10 c/c60. This reinforcement should be brought approximately 200mm past the end of the beam unit in order to absorb any splitting effects from the threaded bars anchoring the horizontal force.

3.4.2 SHEAR COMPRESSION IN BEAM END

Shear compression: EC2, clause 6.2.3

$V_{Rd,max}$ = α_{cw}×b_w×z×υ_1×f_{cd}/(cot θ + tan θ)

b_w=b_{beam}-b_{unit}

Assume with of beam: b_{beam}=300mm

⇒ b_w =300mm-30mm=270mm

Assume height of beam h=450mm

Assume d=376mm

Assume z=0,9d

$V_{Rd,max} = \{1{,}0\times270\times0{,}9\times376\times0{,}6\times[1-(35/250)]\times19{,}8/(1+1)\}\times10^{-3}$

$V_{Rd,max}$ = 466 kN (>$V_{Rd}\Rightarrow$ OK)

3.4.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model:

$$\frac{A_s}{s}=\frac{R_{VU}}{z\times f_{yd}}$$

Included if: h>(b+$Ø_{mandrel}$/2)/0,9 +2xconcrete cover=(320mm+250mm/2)/0,9+2×30=554mm

$\Rightarrow$ Simplified: Included if h>550mm

Example: if z=700mm:

$$\frac{A_s}{s}=\frac{115200N}{0{,}7m\times435MPa}=378mm^2/m$$

Select u-bars: Ø12 c/c200=π×6^2×2/0,2m=1130mm^2/m. Distributed vertically below the unit.

Simplified: Horizontal length of bar: L=b+40Ø=320mm+40×12mm=800mm

3.4.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

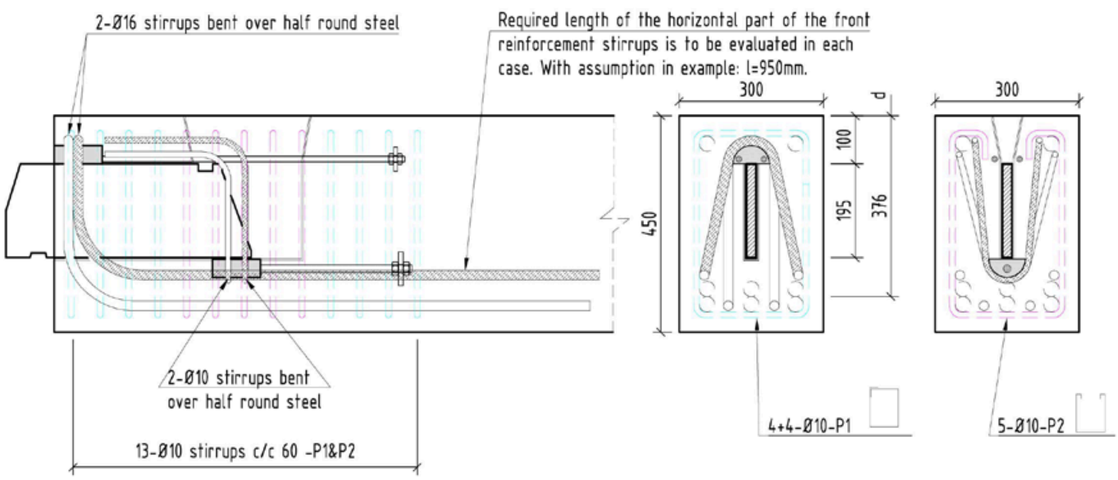


Figure 15: Reinforcement in beam end.

3.5 COLUMN UNIT

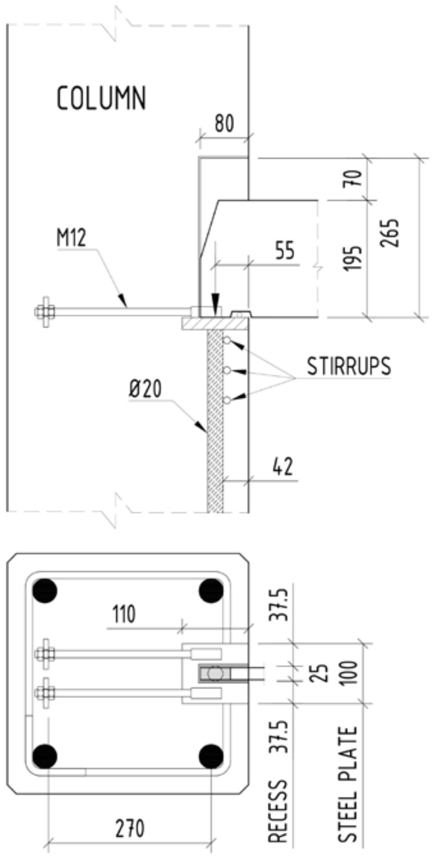


Figure 16: BSF225 column unit. (Centre stirrups are not illustrated.)

3.5.1 TRANSFER OF VERTICAL LOAD F_V

I: Stress from knife:

$$\sigma_{knife} = \frac{225000N}{20mm \times 50mm} = 225MPa$$

II: Force going directly into Ø20 reinforcement bar:

The anchored force will be the minimum of:

a) $$F_{\varnothing 20} = \pi \times \frac{20^2}{4} \times 225MPa \approx 71kN$$

b) $$F_{\varnothing 20} = Circumference \times f_{bd} \times L_{bar}$$
$$= \pi \times 20mm \times 2{,}79MPa \times 600mm \approx 105kN$$

III: Concrete stress:

$$\sigma = \frac{225kN - 71kN}{(11000 - 314)mm^2} = 14{,}4MPa$$

3.5.2 TRANSFER OF HORIZONTAL LOAD F_H

Horizontal load H=0,3×Fv=0,3×225kN=67,5kN

I: Threaded bars/inserts:

2xM12 8.8 inserts/threaded bars with nut & steel plate: 2x48kN=96kN⇒OK
Anchored to the rear of the column.

3.5.3 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Required reinforcement:

$$A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 225000N}{435MPa} = 207mm^2$$

Required amount of ø10 stirrups:

$$n = \frac{207mm^2}{78mm^2} = 2{,}6 \Rightarrow 3$$

⇒ Three stirrups Ø10 in Zone 1 are sufficient. See Section 2.6 and Figure 9 for principal and recommended reinforcement layout.

Example column 400x400:

Considering c/c 50mm will fit with both the strut & tie model and the split forces, and thus be adequate spacing for the stirrups in zone 1.
-> Height of zone 1= 100mm.

Control of location of reinforcement for horizontal force alone: 0,7d'=0,7x270mm=189mm

Sideways: All stirrups will be within this distance -> ok.
Below unit: All stirrups will be within this distance -> ok.

⇒ Select 3ø10stirrups c/c 50. Select to use c/c 50 also for center stirrups.

PART 4 - BSF 300

4.1 BEAM UNIT - EQUILIBRIUM

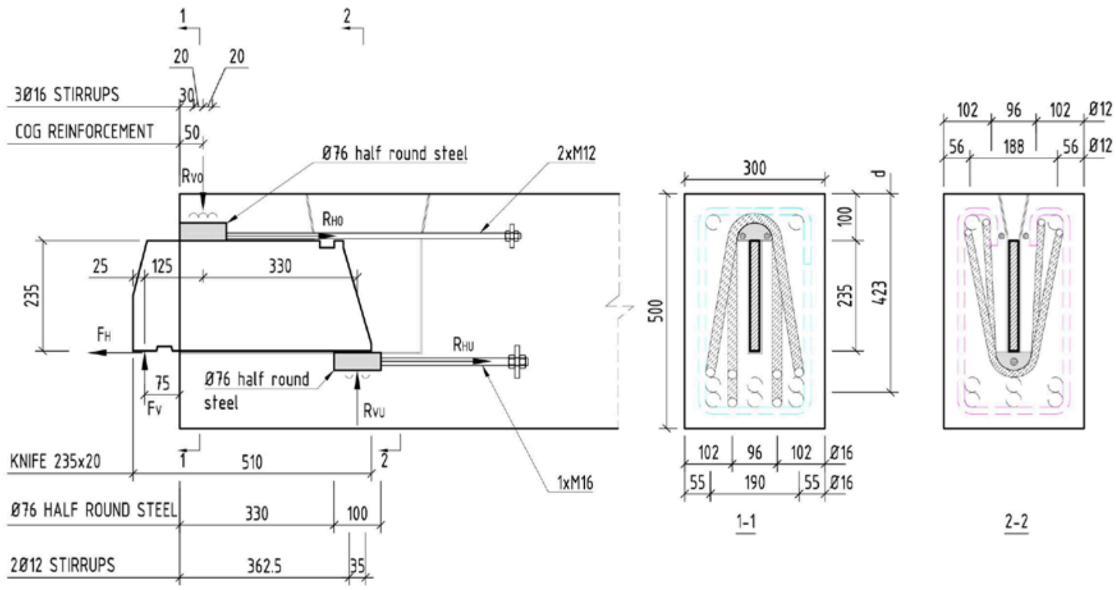


Figure 17: BSF 300 Beam unit. Situation I-nominal values on cantilever and location of anchoring reinforcement.

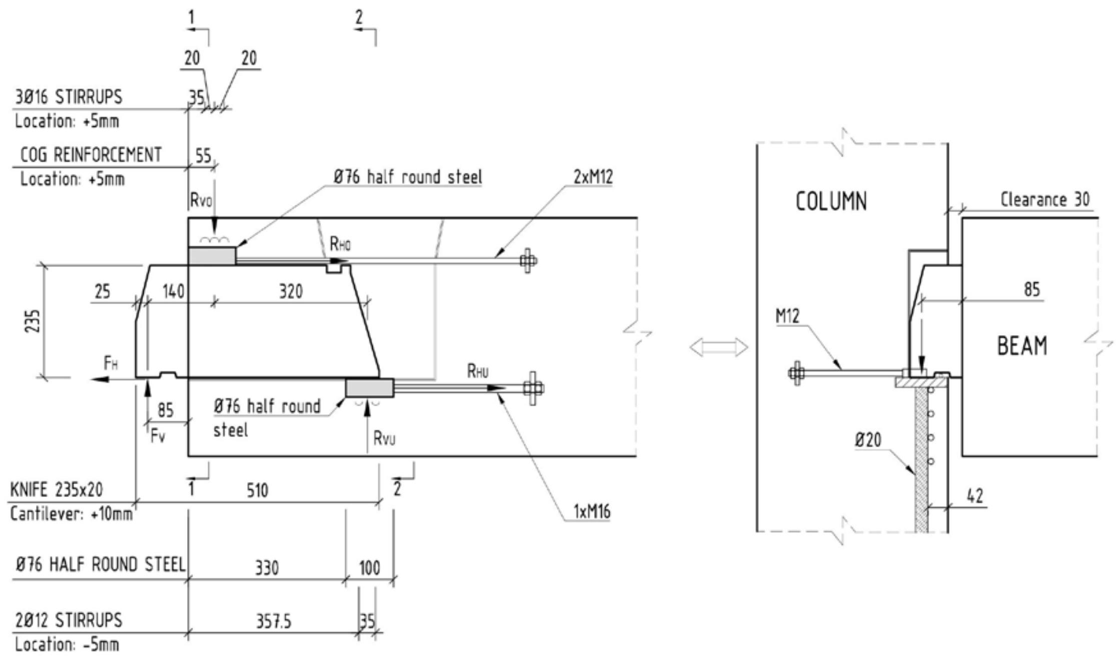


Figure 18: BSF 300 Beam unit. Situation II-unfavourable tolerances on cantilever and location of anchoring reinforcement.

Forces situation I:

Equilibrium:

$$R_{VO} = F_V \times \frac{125mm + 330mm}{330mm} + R_{HO} \times \frac{235mm}{330mm}$$

$$= 300kN \times \frac{125mm + 330mm}{330mm} + 0,2 \times 300kN \times \frac{235mm}{330mm} = 456,4kN$$

$$R_{VU} = R_{VO} - 300kN = 456,4kN - 300kN = 156,4kN$$

Forces situation II:

Equilibrium:

$$R_{VO} = F_V \times \frac{140mm + 320mm}{320mm} + R_{HO} \times \frac{235mm}{320mm}$$

$$= 300kN \times \frac{140mm + 320mm}{320mm} + 0,2 \times 300kN \times \frac{235mm}{320mm} = 475,3kN$$

$$R_{VU} = R_{VO} - 300kN = 475,3kN - 300kN = 175,3kN$$

4.2 BEAM UNIT – ANCHORING REINFORCEMENT

<u>1) Vertical suspension reinforcement in front -Situation II is assumed:</u>

Reinforcement:

$$A_s = \frac{R_{VO}}{f_{yd}} = \frac{475,3kN}{435MPa} = 1093mm^2$$

3Ø16Stirrups= 201mm^{2}x6=1206mm^2

Capacity of selected reinforcement: 1206mm^2×435MPa=524kN

Minimum mandrel diameter:

$$Ø_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{475300}{270 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 345\,\text{mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=300mm-30mm=270mm

$Ø_{mf}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=350mm

2) Vertical suspension reinforcement at back -Situation II is assumed:

Reinforcement:

$$A_s = \frac{R_{VU}}{f_{yd}} = \frac{175{,}3kN}{435MPa} = 403mm^2$$

2Ø12stirrup= 113mm^{2}x4=452mm^2

Capacity of selected reinforcement: 452mm^2×435MPa=196kN

Minimum mandrel diameter:

$$\varnothing_{mb,\min} = \frac{R_{VU}}{b_{eff}\times 0{,}6\times(1-\frac{f_{ck}}{250})\times f_{cd}\times 0{,}5} = \frac{175300}{270\times 0{,}6\times(1-\frac{35}{250})\times 19{,}8MPa\times 0{,}5} = 127\text{ mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=300mm-30mm=270mm

$\varnothing_{mb}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=160mm

3) Anchoring of stirrups in front, EC2 clause 8.4.3 and 8.4.4:

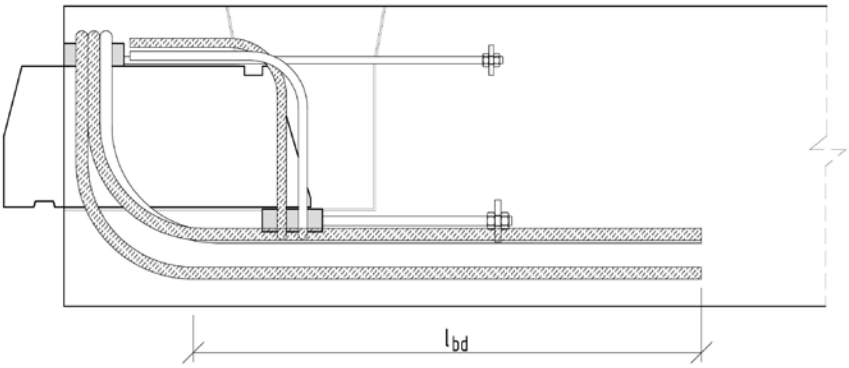


Figure 19: Anchoring of reinforcement.

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

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

Stress in stirrup: $\sigma_{sd} = \frac{475{,}3kN}{1206mm^2} = 394MPa$

$$l_{b,reqd} = \frac{16}{4} \times \frac{394}{2{,}79} = 565\text{mm}$$

$l_{b,min}$ = max(0,3×$l_{b,reqd}$; 10×Ø; 100mm)=170mm

Table 8.2: Straight bar:

α_1= 1,0

Table 8.2: Concrete cover:

$\alpha_2 = 1-0,15\times(c_d-3\times\varnothing)/\varnothing$

Neglecting any positive effect of concrete cover, selecting α_2=1,0

Table 8.2: Confinement by reinforcement:

$\alpha_3 = 1-K\times\lambda$

Neglecting any positive effect of transverse reinforcement, selecting α_3 =1,0

Table 8.2: Confinement by welded transverse reinforcement:

α_4 = 1,0

Not relevant.

Table 8.2: Confinement by transverse pressure:

α_5 =1,0

Not relevant.

$\alpha_2\times\alpha_3\times\alpha_5$=1,0×1,0×1,0=1,0 > 0,7 – OK

l_{bd} = 1,0×1,0×1,0×1,0×1,0×565mm=565mm

4) Lap of stirrups, EC2 clause 8.7.3:

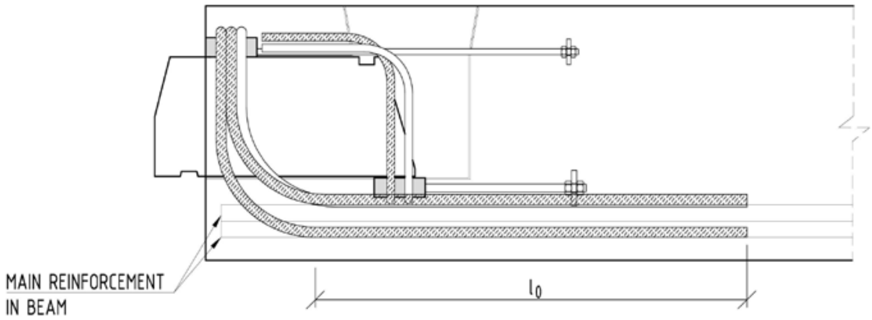


Figure 20: Lap of reinforcement.

$l_0= \alpha_1\times\alpha_2\times\alpha_3\times\alpha_5\times\alpha_6\times l_{b,reqd} \geq l_{0,min}$

Required lap length:

$l_{b,reqd}$ = 565mm, see evaluation in clause 3.

$l_{0,min} = \max(0,3\times\alpha_6\times l_{b,reqd}; 15\times\varnothing; 200mm)$

Table 8.2: α_1, α_2, α_3 and α_5=1,0 as calculated in clause 3.

Table 8.3: α_6=1.5 (All reinforcement is lapped)

$\Rightarrow l_0$ = 1,0×1,0×1,0×1,0×1,5×565mm=848mm

$\Rightarrow$Select: l_0=900mm

5) Anchoring of main reinforcement:

It must be ensured the horizontal part of the front reinforcement is continued until the main reinforcement is sufficient anchored to carry the load.

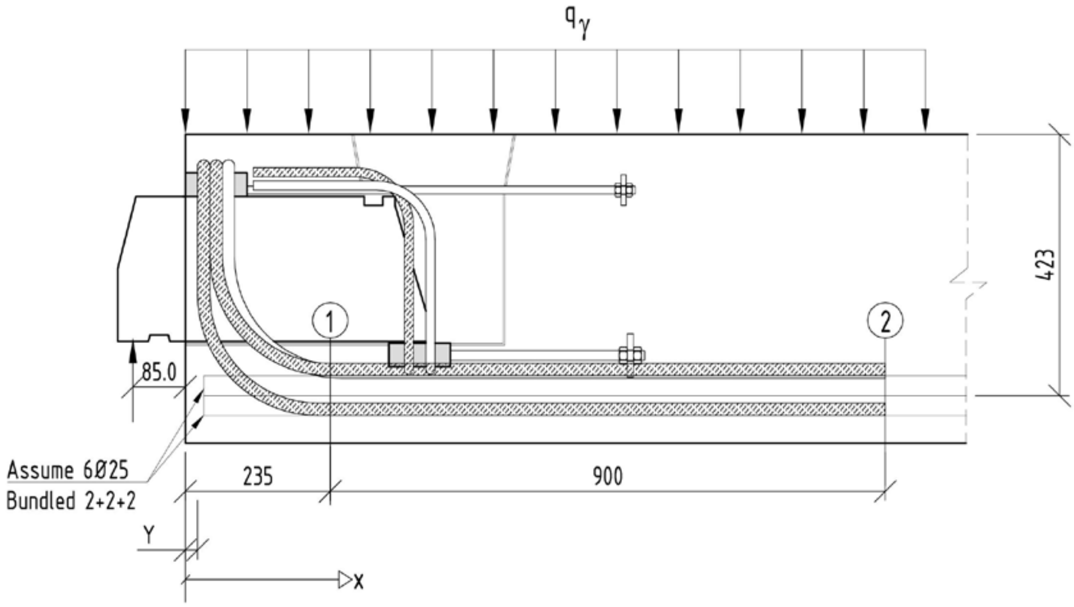


Figure 21: Anchoring.

Example, assuming:

- Main reinforcement at bottom: 6Ø25, bundled 2+2+2.
- Horizontal part of the front anchoring bars is 900mm (≈ equals the minimum calculated lap length). I.e. the bars end at x=235+900=1135mm.
- Y=30mm
- Transverse load (included safety factors) q_γ=50kN/m

Equivalent diameter of 2Ø25 bundled:

$$Ø_n = Ø \times \sqrt{2} = 25 \times \sqrt{2} = 35mm$$

Anchoring length of a bundle:

$$L_n = \frac{\pi \times 12{,}5^2 \times 435MPa \times 2}{\pi \times Ø_n \times f_{bd}} = \frac{\pi \times 12{,}5^2 \times 435MPa \times 2}{\pi \times 35 \times 2{,}79MPa} = \frac{427kN}{0{,}3067kN/mm} = 1392mm$$

Section 1 (at x=235mm):

Force anchored in Ø25:

$F_{Ø25}=f_{bd}\times Ø_n\times\pi\times(235-Y)\times3=2{,}79\times35\times\pi\times(235-30)\times3=188kN$

Force anchored in Ø16:

$F_{Ø16}$=475,3kN

Total anchored force:

$F=F_{Ø25}+F_{Ø16}$=188kN+475,3kN=663,3kN

Tension in reinforcement at x=235mm: (clause 6.2.3(7))
Neglecting reduction due to transverse load in this point.

$S(x)=M(x)/z+0,5V_{Ed}\times(\cot(\theta)-\cot(\alpha))$

$=M(x)/z+0,5\times V_{Ed}\times(\cot(45)-\cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0,5\times V_{Ed}\times(1-0)$

$= M(x)/z+0,5\times V_{Ed}$

Bending moment at x=235:

$M(x=235)=300kN\times(235+85)mm=96kNm$

Assume: $z=0,9d=0,9\times423mm=381mm$ (approximately)

$S(x=235)=96kNm/0,381m+475,3kN/2=490kN$

⇒ The anchoring at x=235mm is sufficient in this case.

<u>Section 2 (at x=1135mm):</u>

Force anchored in Ø25:

$F_{Ø25}=f_{bd}\times Ø_n\times\pi\times(1135-Y)\times3=2,79\times35\times\pi\times(1135-30)\times3=1017kN$

Force anchored in Ø16:

$F_{Ø16}=0kN$

Total anchored force:

$F=F_{Ø25}+F_{Ø16}=1017kN+0kN=1017kN$

Cross section forces:

$V(x=1135)=300kN-50kN/m\times1,135m=243kN$

$M(x=1135)=300kN\times(1,135+0,085)m - 50kN/m\times1,135^2/2=334kNm$

Tension in reinforcement at x=1135mm: (clause 6.2.3(7))

$S(x)=M(x)/z+0,5V_{Ed}\times(\cot(\theta)-\cot(\alpha))$

$=M(x)/z+0,5\times V_{Ed}\times(\cot(45)-\cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0,5\times V_{Ed}\times(1-0)$

$= M(x)/z+0,5\times V_{Ed}$

Assume: $z=0,9d=0,9\times423mm=381mm$ (approximately)

$S(x=1135)=334kNm/0,381m+243kN/2=998kN$

⇒ The anchoring at x=1135mm is sufficient in this case.

4.3 BEAM UNIT – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel in top R_{HO}=0,2xF_V=60kN:

Select: 2×M12 threaded bars 8.8 with nut & steel plate = 48kN×2=96kN

Machined thread length in half round steel according to Table 5.

Horizontal anchoring of half round steel at bottom R_{HU}=0,2xF_V=60kN:

Select: 1×M16 threaded bar 8.8 with nut & steel plate = 90kN

Machined thread length in half round steel according to Table 5.

4.4 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

4.4.1 SHEAR STIRRUPS IN BEAM END

Use a strut-and-tie model with compression diagonal at 45°. The shear force within the central part of the beam unit is assumed to be R_{VO}=475,3kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{475{,}3 \times 10^3\,N}{0{,}9 \times 0{,}423m \times 435MPa} = 2870mm^2 / m$$

Assume height of beam h=500mm

Assume d=423mm

Assume z=0,9d

Assume stirrup diameter Ø12.

⇒ Ø12c75 (3016mm^2/m)

⇒Select Ø12 c/c75. This reinforcement should be brought approximately 200mm past the end of the beam unit in order to absorb any splitting effects from the threaded bars anchoring the horizontal force.

4.4.2 SHEAR COMPRESSION IN BEAM END

Shear compression: EC2, clause 6.2.3

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

$b_w = b_{beam} - b_{unit}$

Assume with of beam: b_{beam}=300mm

⇒ b_w =300mm-30mm=270mm

Assume height of beam h=500mm

Assume d=423mm

Assume z=0,9d

$V_{Rd,max} = \{1{,}0\times270\times0{,}9\times423\times0{,}6\times[1-(35/250)]\times19{,}8/(1+1)\}\times10^{-3}$

$V_{Rd,max}$ = 525 kN (>$V_{Rd} \Rightarrow$ OK)

4.4.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model:

$$\frac{A_s}{s} = \frac{R_{VU}}{z \times f_{yd}}$$

Included if: h>(b+$Ø_{mandrel}$/2)/0,9 +2xconcrete cover=(320mm+350mm/2)/0,9+2×30=610mm

$\Rightarrow$ Simplified: Included if h>600mm

Example: if z=700mm:

$$\frac{A_s}{s} = \frac{175300N}{0{,}7m \times 435MPa} = 576mm^2 / m$$

Select u-bars: Ø12 c/c200=π×6^2×2/0,2m=1130mm^2/m. Distributed vertically below the unit.

Simplified: Horizontal length of bar: L=b+40Ø=320mm+40×12mm=800mm

4.4.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

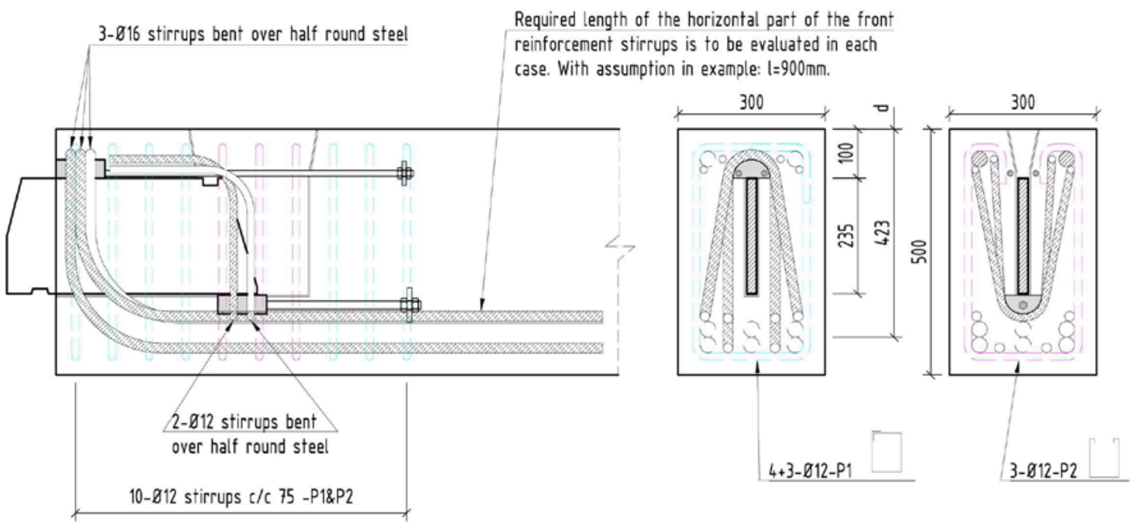


Figure 22: Reinforcement.

4.5 COLUMN UNIT

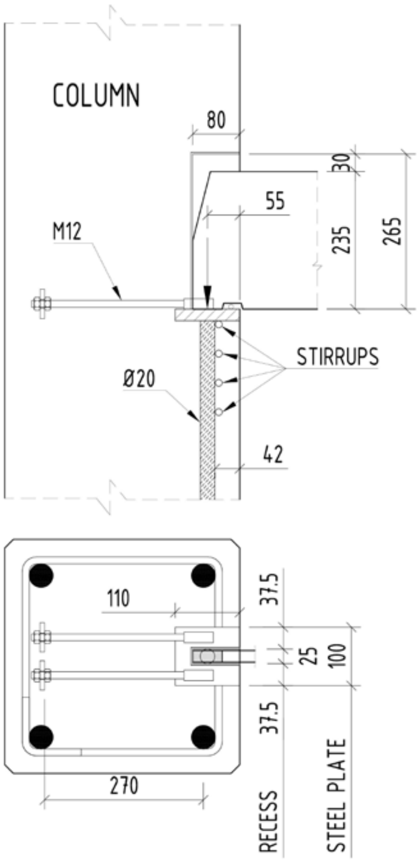


Figure 23: BSF300 column unit. (Centre stirrups are not illustrated.)

4.4.5 TRANSFER OF VERTICAL LOAD F_V

I: Stress from knife:

$$\sigma_{knife} = \frac{300000N}{20mm \times 50mm} = 300MPa$$

II: Force going directly into Ø20 reinforcement bar:

The anchored force will be the minimum of:

a) $$F_{\text{Ø}20} = \pi \times \frac{20^2}{4} \times 300MPa \approx 94kN$$

b) $$F_{\text{Ø}20} = Circumference \times f_{bd} \times L_{bar}$$
$$= \pi \times 20mm \times 2{,}79MPa \times 600mm \approx 105kN$$

III: Concrete stress:

$$\sigma = \frac{300kN - 94kN}{(11000 - 314)mm^2} = 19,3MPa$$

4.4.6 TRANSFER OF HORIZONTAL LOAD F_H

Horizontal load H=0,3×Fv=0,3×300kN=90kN

I: Threaded bars/inserts:

2xM12 8.8 inserts/threaded bars with nut & steel plate: 2x48kN=96kN⇒OK
Anchored to the rear of the column.

4.4.7 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Required reinforcement:

$$A_s = \frac{0,4 \times F_V}{f_{yd}} = \frac{0,4 \times 300000N}{435MPa} = 276mm^2$$

Required amount of ø10 stirrups:

$$n = \frac{276mm^2}{78mm^2} = 3,5 \Rightarrow 4$$

⇒ Four stirrups in Zone 1 are sufficient. See Section 2.6 and Figure 9 for principal and recommended reinforcement layout.

Example column 400x400:

Considering c/c 50mm will fit with both the strut & tie model and the split forces, and thus be adequate spacing for the stirrups in zone 1.
-> Height of zone 1= 150mm.

Control of location of reinforcement for horizontal force alone: 0,7d'=0,7x270mm=189mm
Sideways: All stirrups will be within this distance -> ok.
Below unit: All stirrups will be within this distance -> ok.

⇒ Select 4ø10stirrups c/c 50. Select to use c/c 50 also for center stirrups.

PART 5 - BSF 450

5.1 BEAM UNIT - EQUILIBRIUM

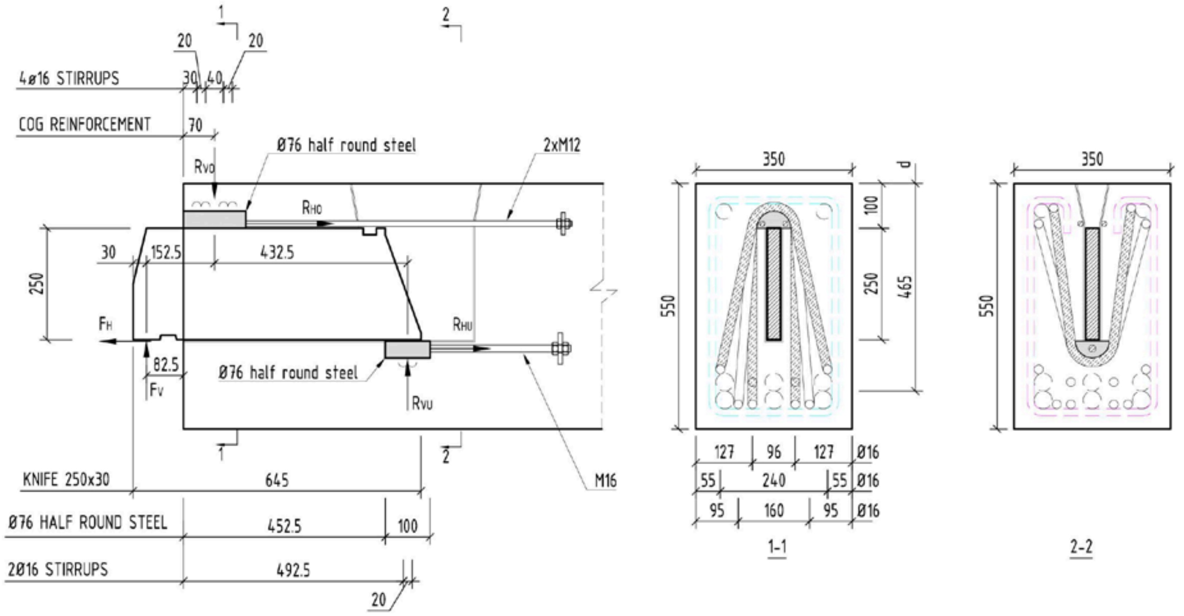


Figure 24: BSF 450 Beam unit. Situation I-nominal values on cantilever and location of anchoring reinforcement.

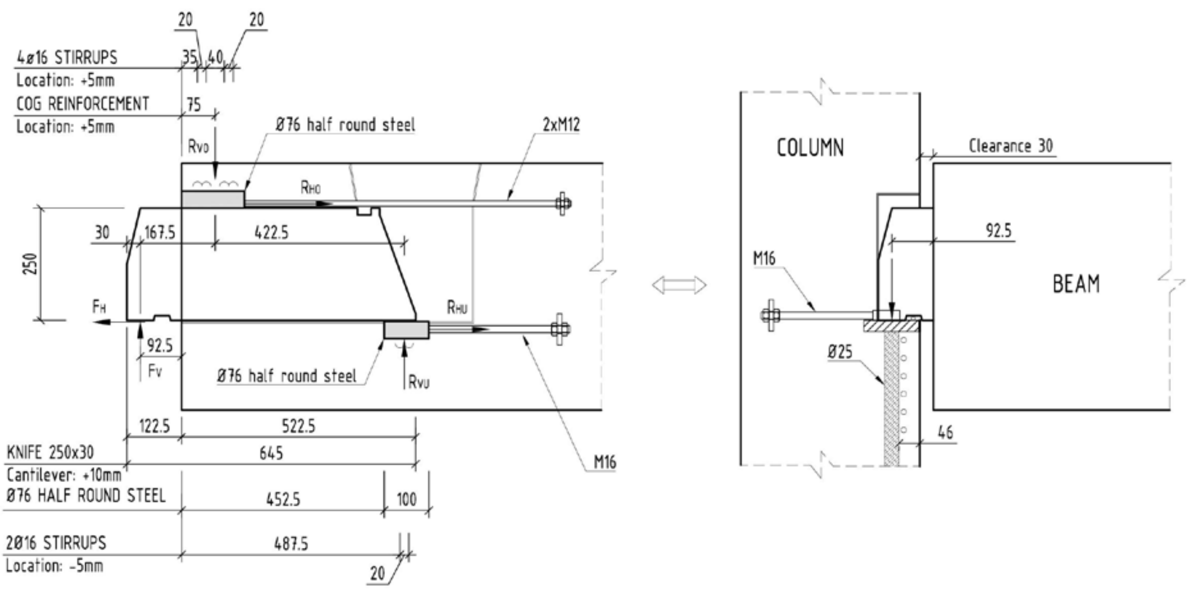


Figure 25: BSF 450 Beam unit. Situation II-unfavourable tolerances on cantilever and location of anchoring reinforcement.

Forces situation I:

Equilibrium:

$$R_{VO} = F_V \times \frac{152{,}5mm + 432{,}5mm}{432{,}5mm} + R_{HO} \times \frac{250mm}{432{,}5mm}$$

$$= 450kN \times \frac{152{,}5mm + 432{,}5mm}{432{,}5mm} + 0{,}2 \times 450kN \times \frac{250mm}{432{,}5mm} = 660{,}7kN$$

$$R_{VU} = R_{VO} - 450kN = 660{,}7kN - 450kN = 210{,}7kN$$

Forces situation II:

Equilibrium:

$$R_{VO} = F_V \times \frac{167{,}5mm + 422{,}5mm}{422{,}5mm} + R_{HO} \times \frac{250mm}{422{,}5mm}$$

$$= 450kN \times \frac{167{,}5mm + 422{,}5mm}{422{,}5mm} + 0{,}2 \times 450kN \times \frac{250mm}{422{,}5mm} = 681{,}7kN$$

$$R_{VU} = R_{VO} - 450kN = 681{,}7kN - 450kN = 231{,}7kN$$

5.2 BEAM UNIT – ANCHORING REINFORCEMENT

1) Vertical suspension reinforcement in front -Situation II is assumed:

Reinforcement:

$$A_s = \frac{R_{VO}}{f_{yd}} = \frac{681{,}7kN}{435MPa} = 1567mm^2$$

4Ø16Stirrups= 201mm^{2}x8=1608mm^2

Capacity of selected reinforcement: 4Ø16Stirrups=1608mm^2×435MPa=699kN

Minimum mandrel diameter:

$$Ø_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{681700}{310 \times 0{,}6 \times (1 - \frac{35}{250}) \times 19{,}8MPa \times 0{,}5} = 430\,\text{mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=350mm-40mm=310mm

$Ø_{mf}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

⇒ Select: Ø=450mm

2) Vertical suspension reinforcement at back -Situation II is assumed:

Reinforcement:

$$A_s = \frac{R_{VU}}{f_{yd}} = \frac{231{,}7kN}{435MPa} = 533mm^2$$

2Ø16Stirrups= 201mm^{2}x4=804mm^2

Capacity of selected reinforcement: 2Ø16Strirrups=804mm^2×435MPa=350kN

Minimum mandrel diameter:

$$Ø_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{231700}{310 \times 0{,}6 \times (1 - \frac{35}{250}) \times 19{,}8MPa \times 0{,}5} = 146\,\text{mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=350mm-40mm=310mm

$Ø_{mb}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=150mm

3) Anchoring of stirrups in front, EC2 clause 8.4.3 and 8.4.4:

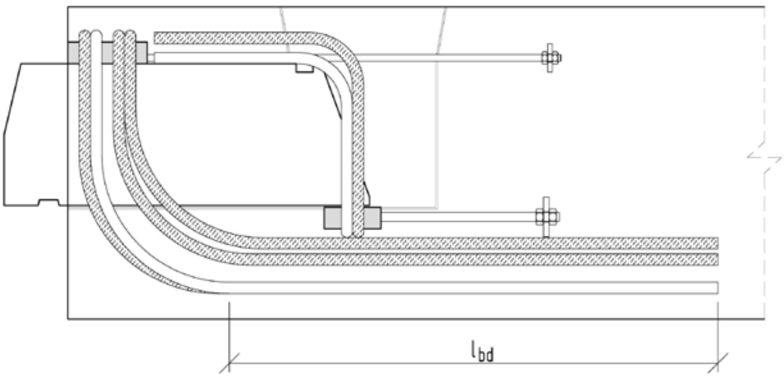


Figure 26: Anchoring of reinforcement.

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

$$l_{b,reqd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}}$$

Stress in stirrup: $\sigma_{sd} = \frac{681{,}7kN}{1608mm^2} = 424MPa$

$$l_{b,reqd} = \frac{16}{4} \times \frac{424}{2{,}79} = 608\text{mm}$$

$l_{b,min}$ = max(0,3×$l_{b,reqd}$; 10×Ø; 100mm)=182mm

Table 8.2: Straight bar:

α_1= 1,0

Table 8.2: Concrete cover:

α_2 = 1−0,15×(c_d−3×Ø)/Ø

Neglecting any positive effect of concrete cover, selecting α_2=1,0

Table 8.2: Confinement by reinforcement:

α_3 = 1−K×λ

Neglecting any positive effect of transverse reinforcement, selecting α_3 =1,0

Table 8.2: Confinement by welded transverse reinforcement:

α_4 = 1,0

Not relevant.

Table 8.2: Confinement by transverse pressure:

α_5 =1,0

Not relevant.

α_2×α_3×α_5=1,0×1,0×1,0=1,0 > 0,7 – OK

l_{bd} = 1,0×1,0×1,0×1,0×1,0×608mm=608mm

4) Lap of stirrups, EC2 clause 8.7.3:

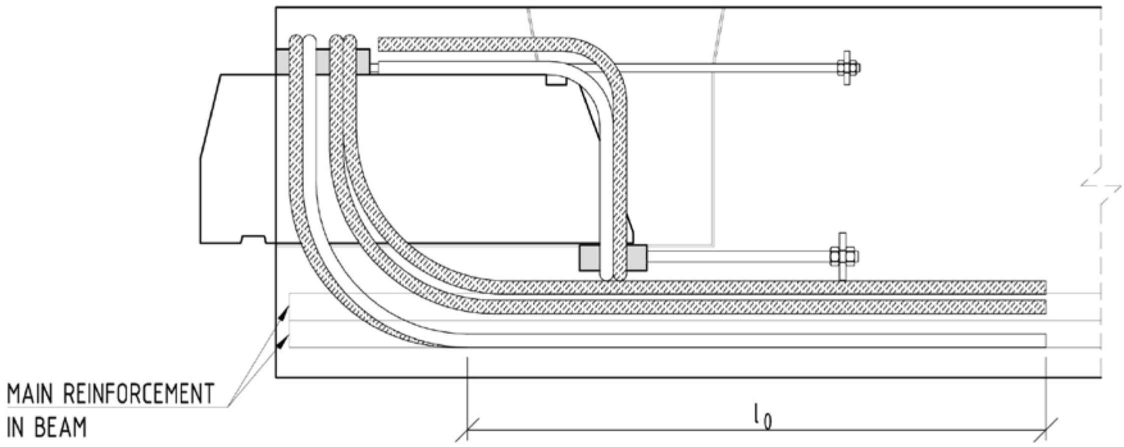


Figure 27: Lap of reinforcement.

l_0= α_1×α_2×α_3×α_5×α_6×$l_{b,reqd}$ ≥ $l_{0,min}$

Required lap length:

$l_{b,reqd}$ = 608mm, see evaluation in clause 3

$l_{0,min}$ = max(0,3×α_6×$l_{b,reqd}$; 15×Ø; 200mm)

Table 8.2: α_1, α_2, α_3 and α_5=1,0 as calculated in clause 3.
Table 8.3: α_6=1.5 (All reinforcement is lapped)

$\Rightarrow l_0$ = 1,0×1,0×1,0×1,0×1,5×608mm=912mm

$\Rightarrow$Select l_0 =950mm

5) Anchoring of main reinforcement:

It must be ensured the horizontal part of the front reinforcement is continued until the main reinforcement is sufficient anchored to carry the load.

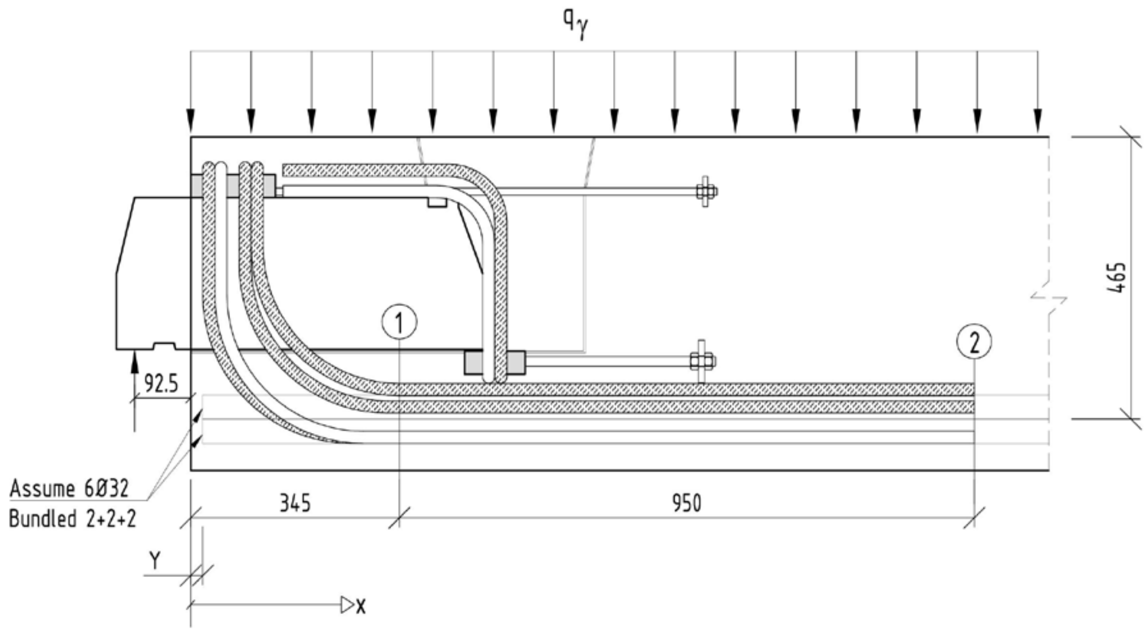


Figure 28: Anchoring.

Example, assuming:

- Main reinforcement at bottom: 6Ø32, bundled 2+2+2.
- Horizontal part of the front anchoring bars is 950mm (≈ equals the minimum calculated lap length). I.e. the bars end at x=345+950=1295mm.
- Y=30mm
- Transverse load (included safety factors) q_γ=100kN/m

Equivalent diameter of 2Ø32 bundled:

$$Ø_n = Ø \times \sqrt{2} = 32 \times \sqrt{2} = 45mm$$

Anchoring length of a bundle:

$$L_n = \frac{\pi \times 16^2 \times 435MPa \times 2}{\pi \times \O_n \times f_{bd}} = \frac{\pi \times 16^2 \times 435MPa \times 2}{\pi \times 45 \times 2{,}79MPa} = \frac{700kN}{0{,}394kN/mm} = 1776mm$$

<u>Section 1 (at x=345mm):</u>

Force anchored in Ø32:

$F_{Ø32}=f_{bd}×Ø_n×π×(345-Y)×3=2,79×45×π×(345-30)×3=372kN$

Force anchored in Ø16:

$F_{Ø16}=681,7kN$

Total anchored force:

$F=F_{Ø32}+F_{Ø16}=372kN+681,7kN=1053,7kN$

Tension in reinforcement at x=345mm: (clause 6.2.3(7))

Neglecting reduction due to transverse load in this point.

$S(x)=M(x)/z+0,5V_{Ed}× (cot(θ)-cot(α))$

$=M(x)/z+0,5×V_{Ed}× (cot(45)-cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0,5×V_{Ed}× (1-0)$

$= M(x)/z+0,5×V_{Ed}$

Bending moment at x=345:

M (x=345)=450kN×(345+92,5)mm=197kNm

Assume: z=0,9d=0,9×465mm=418mm (approximately)

S (x=345)=197kNm/0,418m+681,7kN/2=812kN

⇒ The anchoring at x=345mm is sufficient in this case.

<u>Section2 (at x=1295mm):</u>

Force anchored in Ø32:

$F_{Ø32}=f_{bd}×Ø_n×π×(1295-Y)×3=2,79×45×π×(1295-30)×3=1497kN$

Force anchored in Ø16:

$F_{Ø16}=0kN$

Total anchored force:

$F=F_{Ø32}+F_{Ø16}=1497kN+0kN=1497kN$

Cross section forces:

V(x=1295)=450kN-100kN/m×1,295m=321kN

M (x=1295)=450kN×(1,295+0,0925)m - 100kN/m×$1,295^2$/2=541kNm

Tension in reinforcement at x=1295mm: (clause 6.2.3(7))

$S(x)=M(x)/z+0,5V_{Ed}× (cot(θ)-cot(α))$

$=M(x)/z+0,5×V_{Ed}× (cot(45)-cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0,5×V_{Ed}× (1-0)$

$= M(x)/z+0,5×V_{Ed}$

Assume: z=0,9d=0,9×465mm=418mm (approximately)

S (x=1295)=541kNm/0,418m+321kN/2=1455kN

⇒ The anchoring at x=1295mm is sufficient in this case.

5.3 BEAM UNIT – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel in top R_{HO}=0,2xF_V=90kN:

Select: 2×M12 threaded bars 8.8 with nut & steel plate = 48kN×2=96kN

Machined thread length in half round steel according to Table 5.

Horizontal anchoring of half round steel at bottom R_{HU}=0,2xF_V=90kN:

Select: 1×M16 threaded bar 8.8 with nut & steel plate = 90kN

Machined thread length in half round steel according to Table 5.

5.4 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

5.4.1 *SHEAR STIRRUPS IN BEAM END*

Use a strut-and-tie model with compression diagonal at 45°. The shear force within the central part of the beam unit is assumed to be R_{VO}=681,7kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{681{,}7 \times 10^3 N}{0{,}9 \times 0{,}465m \times 435MPa} = 3745mm^2 / m$$

Assume height of beam h=550mm

Assume d=465mm

Assume z=0,9d

Assume stirrup diameter Ø12.

⇒ Ø12c60 (3770mm^2/m)

⇒Select Ø12 c/c60. This reinforcement should be brought approximately 200mm past the end of the beam unit in order to absorb any splitting effects from the threaded bars anchoring the horizontal force.

5.4.2 *SHEAR COMPRESSION IN BEAM END*

Shear compression: EC2, clause 6.2.3

$V_{Rd,max}$ = α_{cw}×b_w×z×υ_1×f_{cd}/(cot θ + tan θ)

b_w=b_{beam}-b_{unit}

Assume with of beam: b_{beam}=350mm

⇒ b_w =350mm-40mm=310mm

Assume height of beam h=550mm

Assume d=465mm

Assume z=0,9d

$V_{Rd,max}$ = {1,0×310×0,9×465×0,6×[1−(35/250)]×19,8/(1+1)} ×10^{-3}

$V_{Rd,max}$ = 662 kN (⇒ exceeded by 2%. Approximately ok.)

5.4.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model:

$$\frac{A_s}{s} = \frac{R_{VU}}{z \times f_{yd}}$$

Included if: h>(b+$Ø_{mandrel}$/2)/0,9 +2xconcrete cover=(422,5mm+450mm/2)/0,9+2×30=780mm

⇒ Simplified: Included if h>750mm

Example: if z=845mm:

$$\frac{A_s}{s} = \frac{231700N}{0{,}845m \times 435MPa} = 630mm^2 / m$$

Select u-bars: ø12c200=π×6^2×2/0,2m=1130mm^2/m. Distributed vertically below the unit.

Simplified: Horizontal length of bar: L=b+40Ø=422,5mm+40×12mm≈900mm

5.4.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

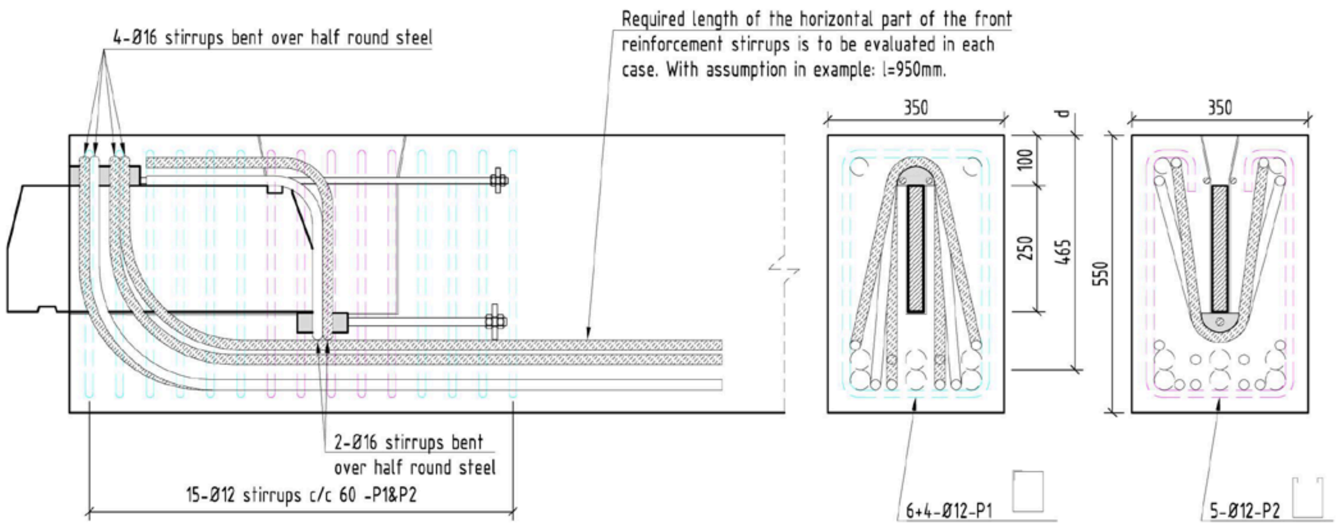


Figure 29: Reinforcement.

5.5 COLUMN UNIT

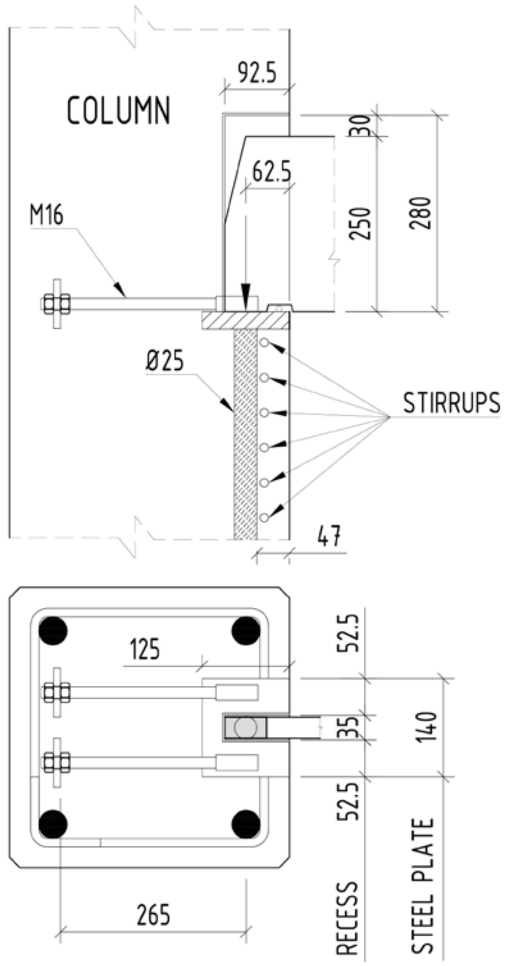


Figure 30: BSF450 column unit. (Centre stirrups are not illustrated.)

5.5.1 TRANSFER OF VERTICAL LOAD F_V

<u>I: Stress from knife:</u>

$$\sigma_{knife} = \frac{450000N}{30mm \times 60mm} = 250MPa$$

<u>II: Force going directly into Ø25 reinforcement bar:</u>

The anchored force will be the minimum of:

a) $$F_{\text{Ø}25} = \pi \times \frac{25^2}{4} \times 250MPa = 122{,}7kN$$

b)
$$F_{\O 25} = Circumference \times f_{bd} \times L_{bar,\max}$$
$$= \pi \times 25mm \times 2{,}79MPa \times 600mm = 132kN$$

III: Concrete stress:

$$\sigma = \frac{450kN - 122{,}7kN}{(17500 - 491)mm^2} = 19{,}3MPa$$

5.5.2 TRANSFER OF HORIZONTAL LOAD F_H

Horizontal load H=0,3×Fv=0,3×450kN=135kN

I: Threaded bars/inserts

2xM16 8.8 inserts/threaded bars with nut & steel plate: 2x 90kN=180kN⇒OK
Anchored to the rear of the column.

5.5.3 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Required reinforcement:

$$A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 450000N}{435MPa} = 414mm^2$$

Required amount of ø10 stirrups:

$$n = \frac{414mm^2}{78mm^2} = 5{,}3 \Rightarrow 6$$

Six stirrups Ø10 in Zone 1 are sufficient. See Section 2.6 and Figure 9 for principal and recommended reinforcement layout.

Example column 400x400:

Considering c/c 50mm will fit with both the strut & tie model and the split forces, and thus be adequate spacing for the stirrups in zone 1.
-> Height of zone 1= 250mm.

Control of location of reinforcement for horizontal force alone: 0,7d'=0,7x265mm=185mm

Sideways: All stirrups will be within this distance -> ok.
Below unit: Three of the stirrups will be outside this distance.
Capacity of reinforcement within 0,7d'. 3 stirrups=6 cross sections: 6x34kN=204kN>H-> OK.

⇒ Select 6ø10stirrups c/c 50. Select to use c/c 50 also for center stirrups.

PART 6 - BSF 700

6.1 BEAM UNIT - EQUILIBRIUM

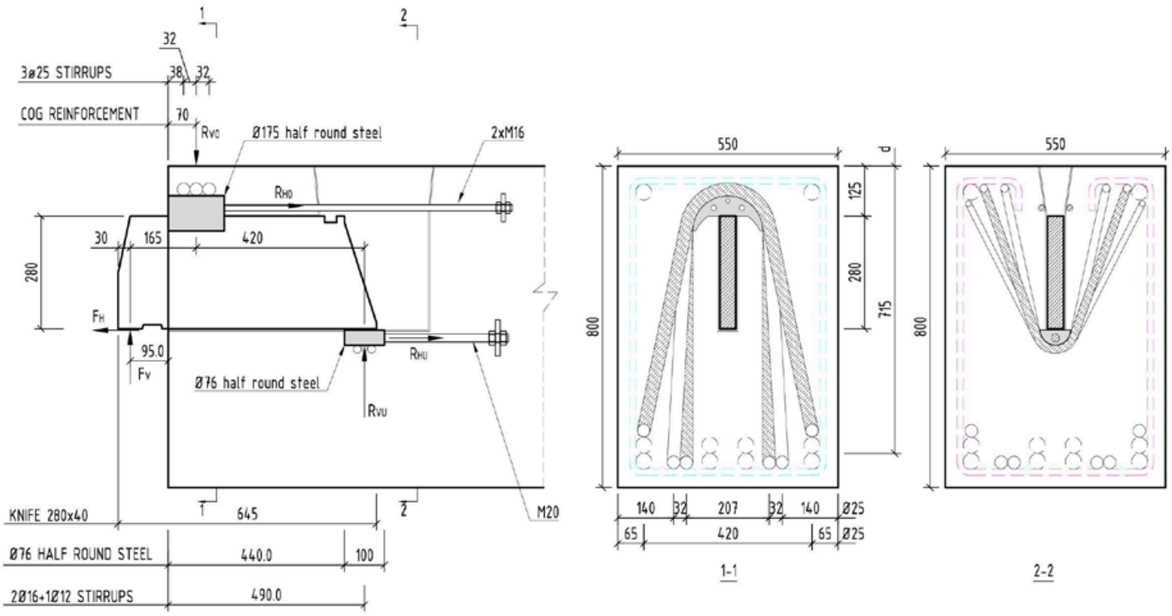


Figure 31: BSF 700 Beam unit. Situation I-nominal values on cantilever and location of anchoring reinforcement.

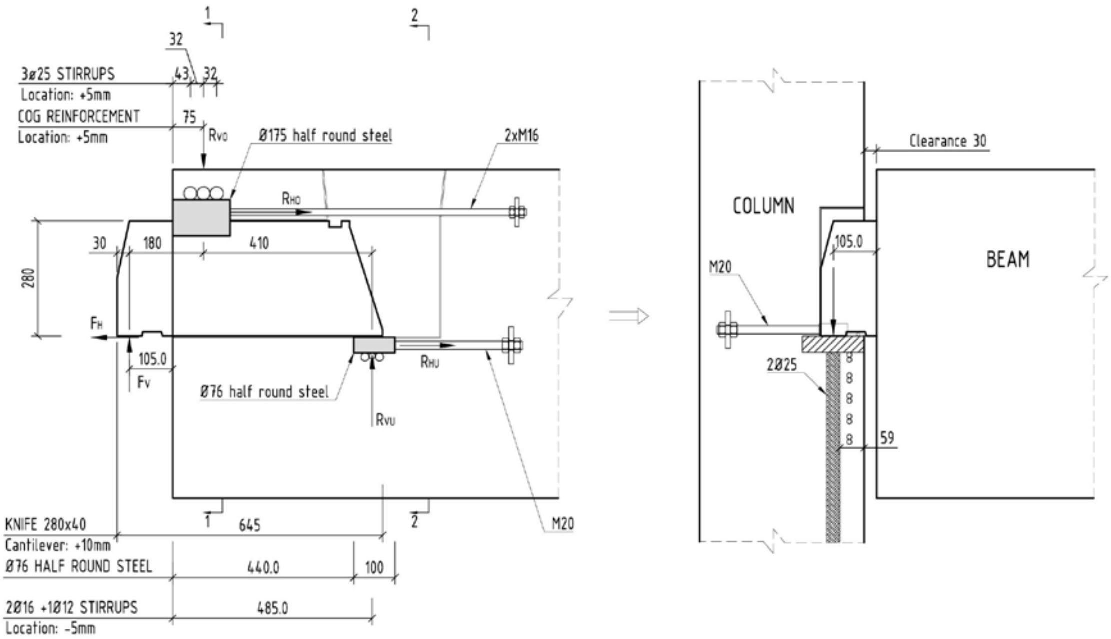


Figure 32: BSF 700 Beam unit. Situation II-unfavourable tolerances on cantilever and location of anchoring reinforcement.

Forces situation I:

Equilibrium:

$$R_{VO} = F_V \times \frac{165mm + 420mm}{420mm} + R_{HO} \times \frac{280mm}{420mm}$$

$$= 700kN \times \frac{165mm + 420mm}{420mm} + 0{,}2 \times 700kN \times \frac{280mm}{420mm} = 1068kN$$

$$R_{VU} = R_{VO} - 700kN = 1068kN - 700kN = 368kN$$

Forces situation II:

Equilibrium:

$$R_{VO} = F_V \times \frac{180mm + 410mm}{410mm} + R_{HO} \times \frac{280mm}{410mm}$$

$$= 700kN \times \frac{180mm + 410mm}{410mm} + 0{,}2 \times 700kN \times \frac{280mm}{410mm} = 1103kN$$

$$R_{VU} = R_{VO} - 700kN = 1103kN - 700kN = 403kN$$

6.2 BEAM UNIT – ANCHORING REINFORCEMENT

1) Vertical suspension reinforcement in front -Situation II is assumed:

Reinforcement:

$$A_s = \frac{R_{VO}}{f_{yd}} = \frac{1103kN}{435MPa} = 2536mm^2$$

3Ø25Stirrups= 490mm^{2}x6=2940mm^2

Capacity of selected reinforcement: 3Ø25Stirrups=2940mm^2×435MPa=1278kN

Minimum mandrel diameter:

$$\varnothing_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{1103000}{500 \times 0{,}6 \times (1 - \frac{35}{250}) \times 19{,}8MPa \times 0{,}5} = 432\,\text{mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=550mm-50mm=500mm

$Ø_{mf}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=450mm

2) Vertical suspension reinforcement at back -Situation II is assumed:

Reinforcement:

$$A_s = \frac{R_{VU}}{f_{yd}} = \frac{403kN}{435MPa} = 926mm^2$$

2Ø16Stirrups+1Ø12stirrup= 201mm^{2}x4+113mm^{2}x2=1030mm^2

Capacity of selected reinforcement: 1030mm^2×435MPa=448kN

Minimum mandrel diameter:

$$Ø_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0{,}6 \times (1-\frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{403000}{500 \times 0{,}6 \times (1-\frac{35}{250}) \times 19{,}8MPa \times 0{,}5} = 158\,\text{mm}$$

b_{eff}= effective beam width. Assume: b=b_{beam}-b_{unit}=550mm-50mm=500mm

$Ø_{mb}$= Mandrel diameter of reinforcement

Concrete strut assumed in 45degrees, see Part 2.

$\Rightarrow$ Select: Ø=200mm

3) Anchoring of stirrups in front, EC2 clause 8.4.3 and 8.4.4:

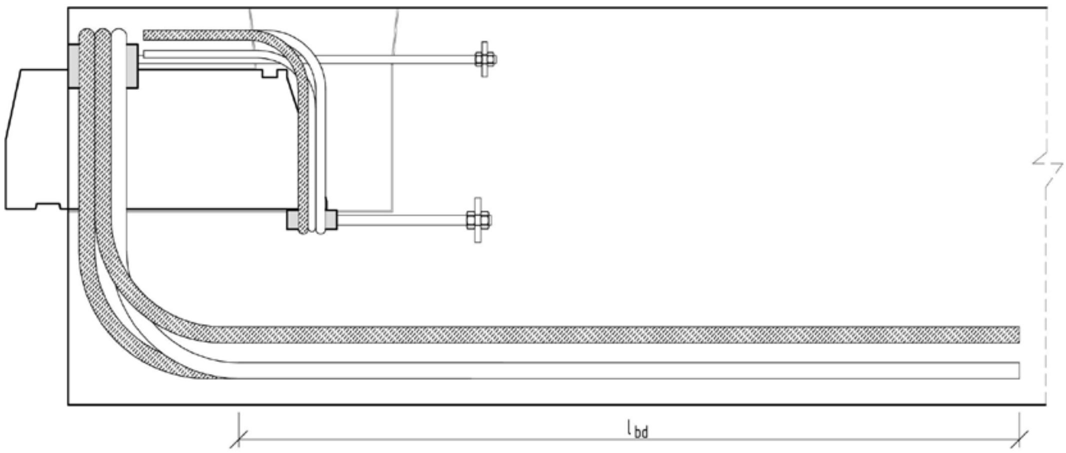


Figure 33: Anchoring of reinforcement.

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

$$l_{b,reqd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}}$$

Stress in stirrup: $\sigma_{sd} = \frac{1103kN}{2940mm^2} = 375MPa$

$l_{b,reqd} = \frac{25}{4} \times \frac{375}{2,79} = 840mm$

$l_{b,min} = max(0,3 \times l_{b,reqd}; 10 \times Ø; 100mm) = 252mm$

Table 8.2: Straight bar:

$\alpha_1 = 1,0$

Table 8.2: Concrete cover:

$\alpha_2 = 1 - 0,15 \times (c_d - 3 \times Ø)/Ø$

Neglecting any positive effect of concrete cover, selecting $\alpha_2 = 1,0$

Table 8.2: Confinement by reinforcement:

$\alpha_3 = 1 - K \times \lambda$

Neglecting any positive effect of transverse reinforcement, selecting $\alpha_3 = 1,0$

Table 8.2: Confinement by welded transverse reinforcement:

$\alpha_4 = 1,0$

Not relevant.

Table 8.2: Confinement by transverse pressure:

$\alpha_5 = 1,0$

Not relevant.

$\alpha_2 \times \alpha_3 \times \alpha_5 = 1,0 \times 1,0 \times 1,0 = 1,0 > 0,7$ – OK

$l_{bd} = 1,0 \times 1,0 \times 1,0 \times 1,0 \times 1,0 \times 840mm = 840mm$

4) Lap of stirrups, EC2 clause 8.7.3:

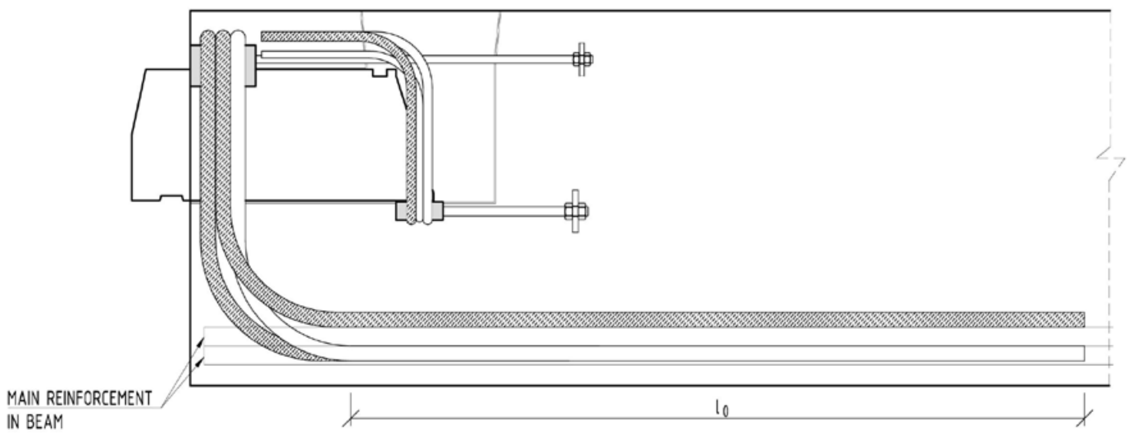


Figure 34: Lap of reinforcement.

$l_0 = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_5 \times \alpha_6 \times l_{b,reqd} \geq l_{0,min}$

Required lap length:

$l_{b,reqd} = 840mm$, see evaluation in clause 3.

$l_{0,min}$ = max(0,3×α_6×$l_{b,reqd}$; 15×Ø; 200mm)

Table 8.2: α_1, α_2, α_3 and α_5=1,0 as calculated in clause 3.

Table 8.3: α_6=1.5 (All reinforcement is lapped)

⇒l_0 = 1,0×1,0×1,0×1,0×1,5×840mm=1260mm

⇒Select l_0 = 1300mm

5) Anchoring of main reinforcement:

It must be ensured the horizontal part of the front reinforcement is continued until the main reinforcement is sufficient anchored to carry the load.

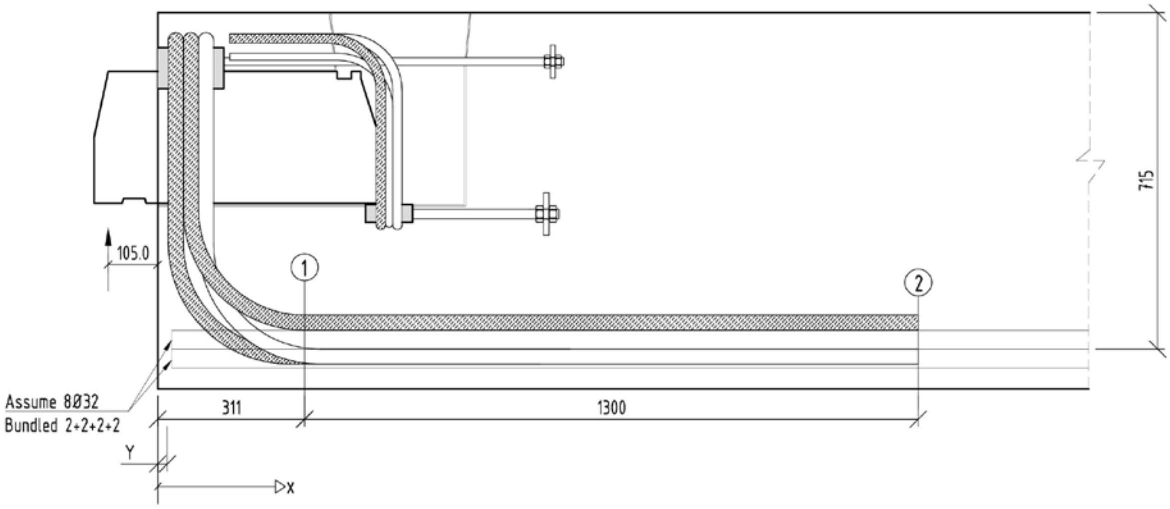


Figure 35: Anchoring.

Example, assuming:

- Main reinforcement at bottom: 8Ø32, bundled 2+2+2+2.
- Horizontal part of the front anchoring bars is 1300mm (≈ equals the minimum calculated lap length). I.e. the bars end at x=311+1300=1611mm.
- Y=30mm

Equivalent diameter of 2Ø32 bundled:

$$\O_n = \O \times \sqrt{2} = 32 \times \sqrt{2} = 45mm$$

Anchoring length of a bundle:

$$L_n = \frac{\pi \times 16^2 \times 435MPa \times 2}{\pi \times \O_n \times f_{bd}} = \frac{\pi \times 16^2 \times 435MPa \times 2}{\pi \times 45 \times 2{,}79MPa} = \frac{700kN}{0{,}394kN/mm} = 1776mm$$

Section 1 (at x=311mm):

Force anchored in Ø32:

$F_{Ø32}$=f_{bd}×$Ø_n$×π×(311-Y)×4=2,79×45×π×(311-30)×4=443kN

Force anchored in Ø25:

$F_{Ø25}$=1103kN

Total anchored force:

$F=F_{Ø32}+F_{Ø25}$=443kN+1103kN=1546kN

Tension in reinforcement at x=311mm: (clause 6.2.3(7))

$S(x)=M(x)/z+0,5V_{Ed}\times(\cot(\theta)-\cot(\alpha))$

$=M(x)/z+0,5\times V_{Ed}\times(\cot(45)-\cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0,5\times V_{Ed}\times(1-0)$

$= M(x)/z+0,5\times V_{Ed}$

Bending moment at x=311:

M (x=311)=700kN×(311+105)mm=291kNm

Assume: z=0,9d=0,9×715mm=643mm (approximately)

S (x=311)=291kNm/0,643m+1103kN/2=1004kN

⇒ The anchoring at x=311mm is sufficient in this case.

Section2 (at x=1611mm):

Force anchored in Ø32:

$F_{Ø32}=f_{bd}\times Ø_n\times\pi\times(1611-Y)\times3=2,79\times45\times\pi\times(1611-30)\times4=2494kN$

Force anchored in Ø25:

$F_{Ø25}$=0kN

Total anchored force:

$F=F_{Ø32}+F_{Ø25}$=2494kN+0kN=2494kN

Tension in reinforcement at x=1611mm: (clause 6.2.3(7))

$S(x)=M(x)/z+0,5V_{Ed}\times(\cot(\theta)-\cot(\alpha))$

$=M(x)/z+0,5\times V_{Ed}\times(\cot(45)-\cot(90))$ (assume 45degrees concrete struts and vertical links)

$= M(x)/z+0,5\times V_{Ed}\times(1-0)$

$= M(x)/z+0,5\times V_{Ed}$

Bending moment at x=1611:

M (x=1611)=700kN×(1611+105)mm=1201kNm

Assume: z=0,9d=0,9×0,715mm=643mm (approximately)

S (x=1611)=1201kNm/0,643m+700kN/2=2218kN

⇒ The anchoring at x=1611mm is sufficient in this case.

Note: No reduction in the bending moment due to distributed load on top of the beam is accounted for in this example. Normally this will be the case, thus the cross section forces in section 2 will normally be less than calculated here.

6.3 BEAM UNIT – HORIZONTAL ANCHORING

Horizontal anchoring of half round steel in top R_{HO}=0,2xF_V=140kN:

Select: 2×M16 threaded bars 8.8 with nut & steel plate = 90kN×2=180kN

Machined thread length in half round steel according to Table 5.

Horizontal anchoring of half round steel at bottom R_{HU}=0,2xF_V=140kN:

Select: 1×M20 threaded bar 8.8 with nut & steel plate = 141kN

Machined thread length in half round steel according to Table 5.

6.4 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

6.4.1 SHEAR STIRRUPS IN BEAM END

Use a strut-and-tie model with compression diagonal at 45°. The shear force within the central part of the beam unit is assumed to be R_{VO}=1103kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{1103 \times 10^3 N}{0{,}9 \times 0{,}715m \times 435MPa} = 3940mm^2 / m$$

Assume height of beam h=800mm

Assume d=715mm

Assume z=0,9d

Assume stirrup diameter Ø12.

⇒ Ø12c50 (4524mm^2/m)

⇒Select Ø12 c/c50. This reinforcement should be brought approximately 200mm past the end of the beam unit in order to absorb any splitting effects from the threaded bars anchoring the horizontal force.

6.4.2 SHEAR COMPRESSION IN BEAM END

Shear compression: EC2, clause 6.2.3

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

$b_w = b_{beam} - b_{unit}$

Assume with of beam: b_{beam}=550mm

⇒ b_w =550mm-50mm=500mm

Assume height of beam h=800mm

Assume d=715mm

Assume z=0,9d

$V_{Rd,max} = \{1,0 \times 500 \times 0,9 \times 715 \times 0,6 \times [1-(35/250)] \times 19,8/(1+1)\} \times 10^{-3}$

$V_{Rd,max}$ = 1643 kN ($>V_{Rd} \Rightarrow$ OK)

6.4.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model:

$$\frac{A_s}{s} = \frac{R_{VU}}{z \times f_{yd}}$$

Included if: h>(b+$Ø_{mandrel}$/2)/0,9 +2xconcrete cover=(410mm+450mm/2)/0,9+2×30=766mm

⇒ Simplified: Included if h>750mm

⇒ Horizontal bars are always recommended for this unit.

Example: if z=0,9x715mm=644mm:

$$\frac{A_s}{s} = \frac{403000N}{0,644m \times 435MPa} = 1439mm^2/m$$

Select u-bars: ø12c150=π×6²×2/0,15m=1507mm²/m. Distributed vertically below the unit.

Simplified: Horizontal length of bar: L=b+40Ø=410mm+40×12mm≈900mm

6.4.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

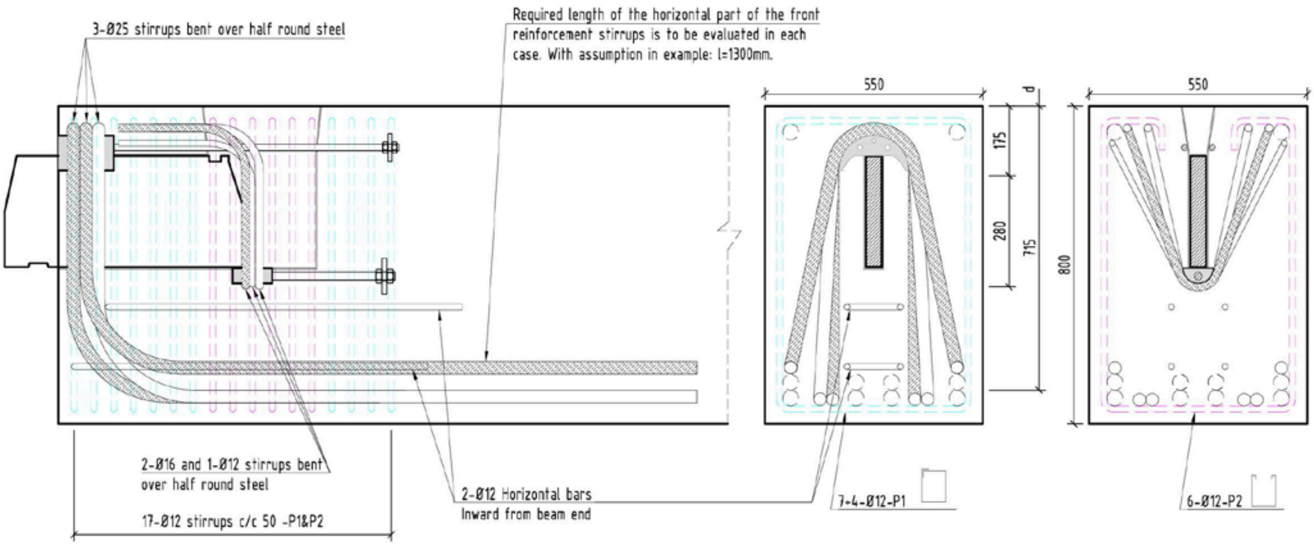


Figure 36: Reinforcement.

6.5 COLUMN UNIT

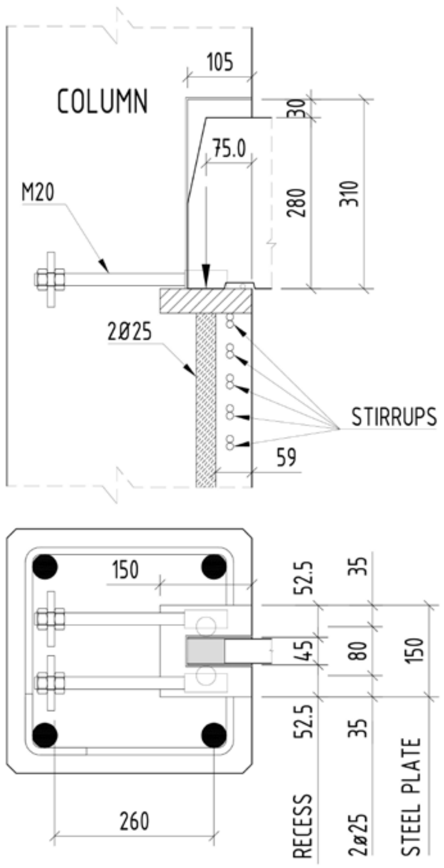


Figure 37: BSF700 column unit. (Centre stirrups are not illustrated.)

6.5.1 TRANSFER OF VERTICAL LOAD F_V *)

*) Two reinforcement bars are introduced below the steel plate. Thus, some of the evaluations in this chapter differ from the principal procedures outlined in the design section.

<u>I: Stress from knife:</u>

$$\sigma_{knife} = \frac{700000N}{40mm \times 60mm} = 292MPa$$

II: Force going directly into 2Ø25 reinforcement bars:

$$F_{\text{Ø}25} = Circumference \times f_{bd} \times L_{bar,\max} \times 2$$
$$= \pi \times 25mm \times 2{,}79MPa \times 795mm \times 2 = 348kN$$

III: Concrete stress:

$$\sigma = \frac{700kN - 348kN}{(22500 - 982)mm^2} = 16{,}4MPa$$

6.5.2 TRANSFER OF HORIZONTAL LOAD F_H

Horizontal load H=0,3×Fv=0,3×700kN=210kN

I: Threaded bars/inserts:

2xM20 8.8 inserts/threaded bars with nut & steel plate: 2x141kN=282kN⇒OK

Anchored to the rear of the column.

6.5.3 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Required reinforcement:

$$A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 700000N}{435MPa} = 644mm^2$$

Required amount of ø10 stirrups:

$$n = \frac{644mm^2}{78mm^2} = 8{,}3 \Rightarrow 9$$

⇒ Five double stirrups Ø10 in Zone 1 are sufficient. See Section 2.6 and Figure 9 for principal and recommended reinforcement layout.

Example column 400x400:

Considering double stirrups c/c 50mm will fit with both the strut & tie model and the split forces, and thus be adequate spacing for the stirrups in zone 1.

-> Height of zone 1= 200mm.

Control of location of reinforcement: 0,7d’=0,7x260mm=182mm

Sideways: All stirrups will be within this distance -> ok.

Below unit: Four of the stirrups will be outside this distance.

Capacity of reinforcement within 0,7d’. 6 stirrups=12 cross sections: 12x34kN=408kN>H-> OK.

⇒ Select 5x2 ø10stirrups c/c 50. Select to use c/c 50 also for center stirrups.

REVISION HISTORY	
Date:	**Description:**
17.04.2013	First Edition (for ETA)
12.06.2013	Updated before ETA. Corrected reinforcement quality notation from: B500C to 500C and included reference to EN10025-2 for steel quality. Page 5: Included sentence on requirements when using other reinforcement qualities. Page 10: Included reference to EN 1992-1-1 8.3 on minimum mandrel diameter.
10.10.2013	Reorganized Table 3. Included note on z-value in chapter 2.5.2
28.11.2013	Included comments from external review.
30.04.2014	Revised chapter 2.6. Referring to CEN/TS 1992-4-2 Headed Fasteners. Included example evaluation on location of stirrups below unit.
26.06.2014	Changed the half round steel on the BSF700 unit.
19.08.2014	Changed position of the M16 threaded bars in the half round steel BSF 700 unit.
13.01.2015	Updated Table 5. Required thread length in blind holes.
27.02.2015	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).
24.05.2016	New template