MEMO 524

MEMO 524 BSF – DESIGN OF REINFORCEMENT, UNITS USED IN PAIRS DESIGN	Date: 21.10.2013 Last rev.: 14.02.2020 Doc. no.: K4-10/524E	Sign.: sss Sign.: sss Control: ps

BSF – DESIGN OF REINFORCEMENT, UNITS USED IN PAIRS

CONTENT

PART 1 - BASIC ASSUMTIONS

This memo is based on memo 521, where all basic information is given. The relevant controls and calculations outlined in memo 521 shall be carried out also when using the BSF units in pairs. These are not repeated herein. In the 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.**

This memo highlights things to remember, and the extra design checks required when the BSF are used in pairs. As there are numerous different beam cross-sections, the exact load bearing mechanism and transfer of force from the unit into the main reinforcement may differ from beam to beam depending on the geometry. Thus, there may be aspects not covered by this Memo. The EC-2 shall always be applied as the governing design document for the beam reinforcement, and 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 behaviour of concrete and steel structures.

PART 2 PRINCIPAL DESIGN - REINFORCEMENT OF BSF UNITS USED IN PAIRS.

2.1 BEAM UNIT

See also Part 2 in memo 521.

Recommended minimum beam cross-section for units in pairs is defined applying the principals illustrated in Figure 1. The recommended minimum cross-section for a single unit forms the basis for the evaluation. In principle, the minimum beam height for units used in pairs will be the same as for single units if the beam width is doubled. However, the recommended minimum beam width for units in pairs is less than twice the width for single units. Thus, when utilizing the maximum capacity of both units, the recommended minimum beam height is increased for all the units. Sufficient space for the anchoring bars and shear reinforcement in-between the units must be ensured. The recommended minimum distance A is given in the relevant chapter for each unit.

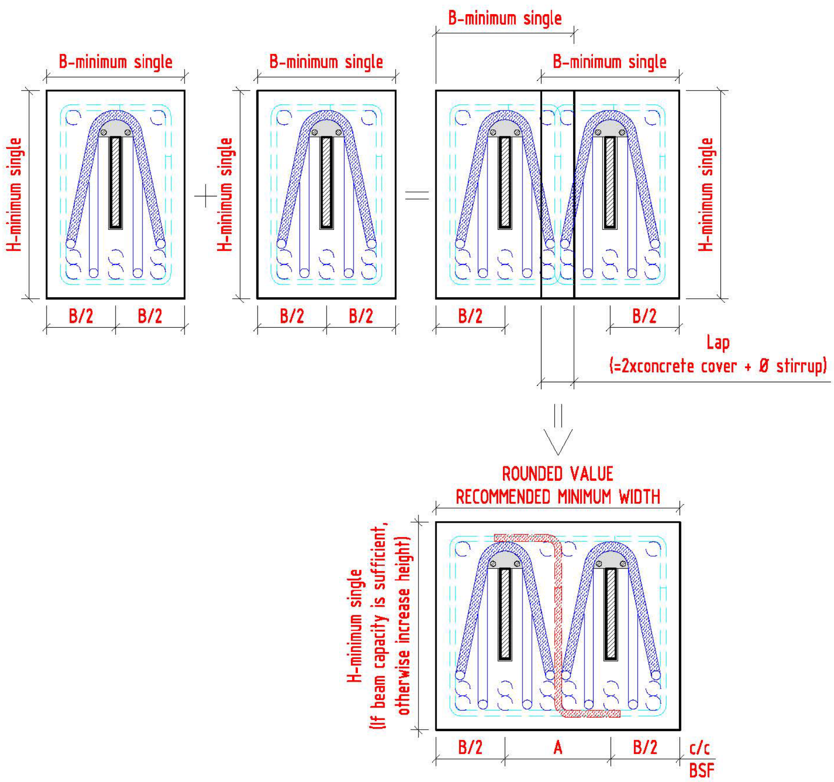

Figure 1: Principal procedure when defining recommended minimum beam cross-section and distance between units.

The following extra controls shall be carried out when using units in pairs.
Use of units in pairs will split the cross section vertically due to the mounting slots. This makes a separated concrete area in the center of the beam. The flow of forces in this central area shall be controlled separately. Looking at the beam in Figure 2, half of the anchoring force from each of the two units will go into the central area in-between the two units. Thus, the total force anchored in this area equals the force from one unit.

1: Mandel diameter of anchoring reinforcement:
On the outside of the units, towards the side edges of the beam, the forces will be as for a single unit. However, in-between the units the mandrel diameter has to be re-evaluated as the effective beam width (A_{eff}) in this area is less than the effective minimum beam width for a single unit, see Figure 2. This implies increased mean concrete stresses. The situation is equal for the anchoring reinforcement at back of the unit. Re-calculation of the required mandrel diameter has to be carried out also for these bars, applying the formulas outlined in memo 521.

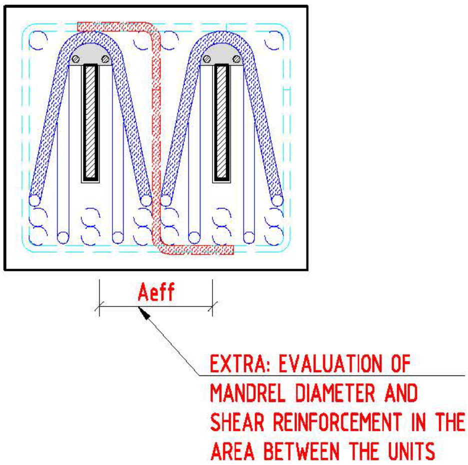

Figure 2: Effective concrete width in-between units.

2: Shear reinforcement
As half of the force is anchored in the central region of the beam cross section, half of the required shear reinforcement shall be placed here. In addition, sufficient cross section resistance for shear compression shall be evaluated for the area in-between the units.

EC2 clause 9.2.2 (8) applies for wide beams. Recommended distance between shear units in transverse direction: $s_{t,max}$=0,75d.

If general central stirrups is not required according to the above equation, it is still recommended to include the central stirrups at least an extra length z behind the units, or by other reinforcement ensure the central shear force is proper transferred into the stirrups at the side of the beam.

2.2 COLUMN UNIT

See also Part 2 in memo 521.

1: Extra stirrups in the center of column

When using a single BSF unit the force in the compression diagonals C_1 will end up in the main stirrups in the column. When the units are used in pairs, there will be two compression diagonals directed towards the center of the column, see Figure 3. The transverse part of the force in these diagonals will neutralize each other, while the summarized horizontal force will equal $2\times F_H/2= F_H$. Sufficient reinforcement in the central part of the column shall be specified in order to take this force. The general design of the column shall ensure proper transfer of the force to the column support.

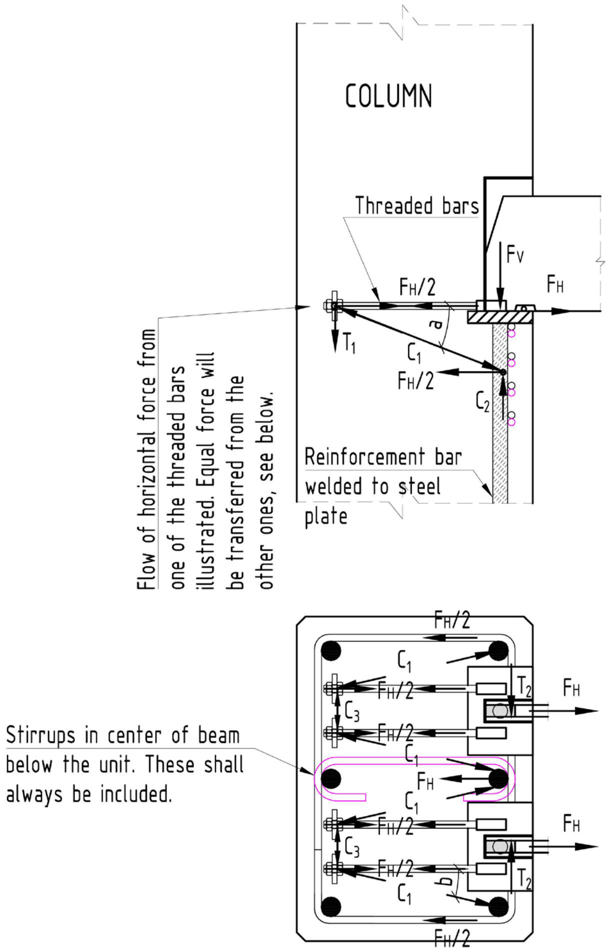

Figure 3: Principal transfer of forces in the column.

Required cross-section for stirrups between the units (below the steel plates):

$$A_s = \frac{F_H}{f_{yd}}$$

Required number of one-legged stirrups: (Narrow stirrups with two effective legs may also be used):

$$n = \frac{A_s}{\pi \times Ø_{stirrup}^2 / 4}$$

2: Principal reinforcement in column:

Figure 4 is to be compared with the corresponding figure in Memo521.

A wide column is required when using the BSF units in pairs. It is recommended to always have a part of the main longitudinal reinforcement placed in-between the units. Depending on the corner distance, there may be requirements to the bracing of these central bars with extra transverse stirrups. Regardless of such requirements, central transverse stirrups shall always be included in zone 1, below the units, in order to take the horizontal force F_H as outlined in the above chapter. It is recommended to always include such reinforcement also in zone 2, i.e along the full lengths of the anchoring bars welded to the steel plates. In addition to the central stirrups, there should be extra stirrups around the anchoring bars themself. These stirrups should be included in both Zone 1 and Zone 2 as recommended in Memo 521 for single units. The height of Zone 1 must be evaluated base on the geometry of the column and flow of forces, see Memo 521 and EC2, clause 6.5.3.

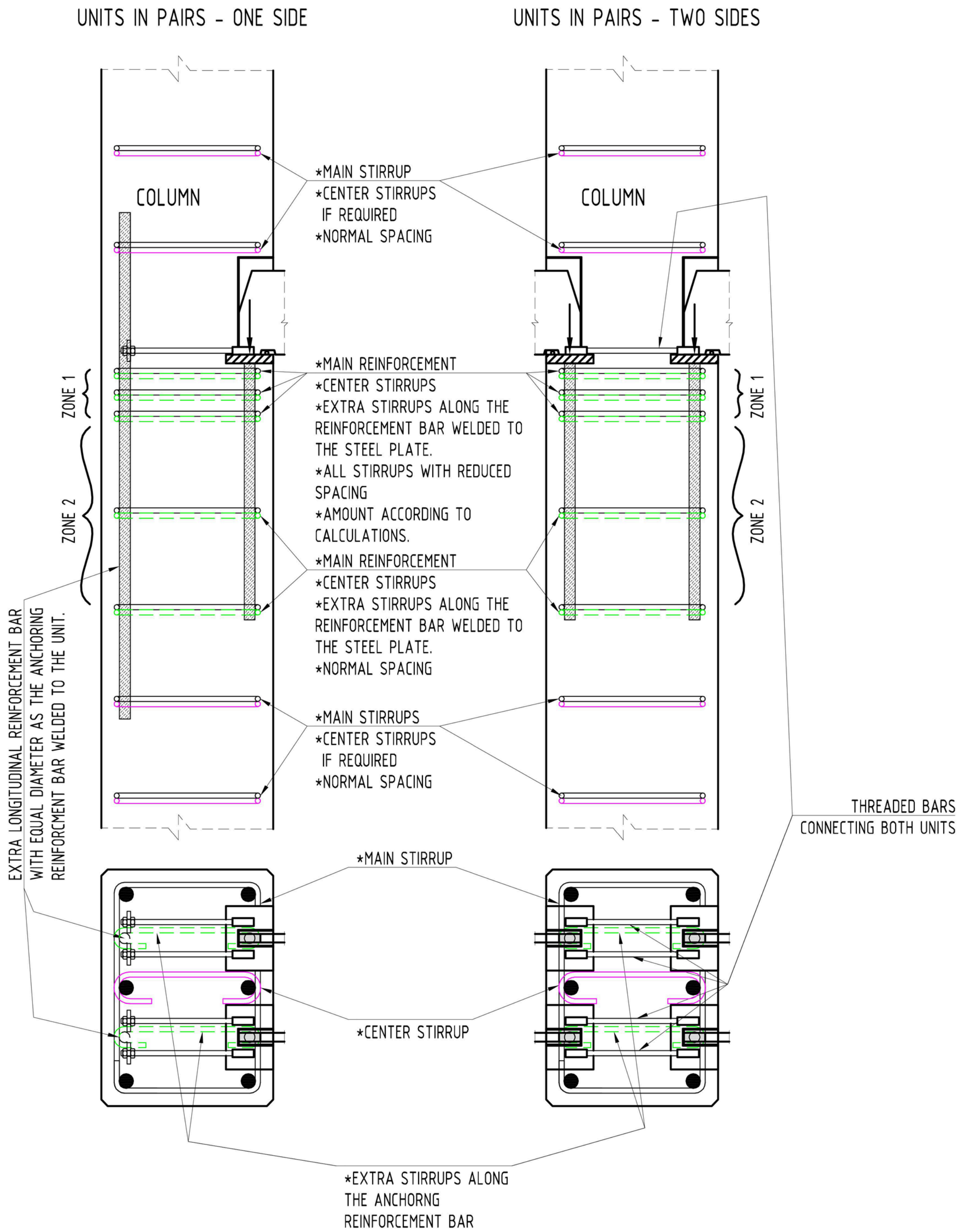

Figure 4: Principal reinforcement in the column.

PART 3 - BSF 225 USED IN PAIRS

3.1 BEAM – RECOMMENDED MINIMUM CROSS-SECTION

See also memo 521. Figure 5 illustrates the recommended minimum cross section and spacing between the units when used in pairs.

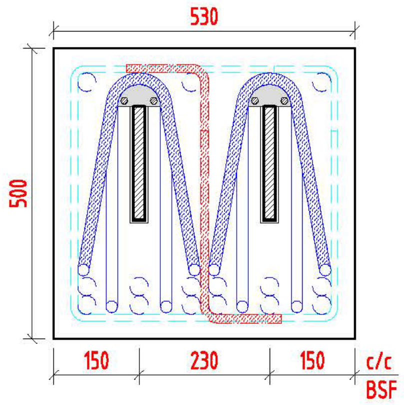

Figure 5: BSF 225 –Recommended minimum cross section and spacing between units when used in pairs.

3.2 BEAM – MANDREL DIAMETER OF ANCHORING REINFORCEMENT

Forces, from situation II, memo 521:

R_{vo}=340,2kN (per unit)

R_{vu}=115,2kN (per unit)

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

Minimum mandrel diameter in-between the units:

$$\O_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{340200}{200 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8 MPa \times 0,5} = 333\,\text{mm}$$

b_{eff}= effective beam width between units: b=230mm-(10+5)mmx2=200mm

$\O_{mf}$= Mandrel diameter of reinforcement.

Concrete strut assumed in 45degrees.

⇒ Select: Ø=320mm

2) Vertical suspension reinforcement at back:

Minimum mandrel diameter in-between the units:

$$\varnothing_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{115200}{200 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 113\,\text{mm}$$

⇒Select: Ø=125mm

(⇒Note: Use of units in pairs may require increased mandrel diameter for the suspension reinforcement compared to use of single unit.)

3.3 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

3.3.1 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: V_{Rd}=R_{VO}×2=340,2kN×2=680,4kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{340,2 \times 10^3 N \times 2}{0,9 \times 0,426m \times 435MPa} = 4080mm^2 / m$$

Assume height of beam h=500mm

Assume d=426mm

Assume z=0,9d

Maximum spacing of stirrups in transverse direction:

$s_{t,max}$=0,75×z=0,75×0,9×426mm=288mm

Half of the required shear reinforcment in-between the units:

⇒ Select Ø12c55 one-legged stirrups in center of cross section=2056 mm^2/m

⇒ Main stirrups (two legs): Ø10c55=2856 mm^2/m

⇒ Total amount of reinforcement=4912 mm^2/m

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. (Note also the recommendations in section 2.1.)

3.3.2 SHEAR COMPRESSION IN BEAM END

Full beam cross section:

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}=530mm

$\Rightarrow b_w$ =530mm-30mm×2=470mm

Assume height of beam: h=500mm

Assume: d=426mm

Assume: z=0,9d

$V_{Rd,max} = \{1,0 \times 470 \times 0,9 \times 426 \times 0,6 \times [1-(35/250)] \times 19,8/(1+1)\} \times 10^{-3}$

$V_{Rd,max}$ = 920 kN (>$V_{Rd} \Rightarrow$ OK)

Area in- between the units:

Effective width of beam: b_w=230mm-32mm=198mm

$V_{Rd,max}$ = 920kN×198mm/470mm=388kN (>$V_{Rd}/2 \Rightarrow$ OK!)

3.3.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model, see Figure 6 in memo 521:

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

Note. This will represents the reinforcement per unit. The same amount of reinforcement shall be included for both units, see example and calculations in Memo 521.

3.3.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

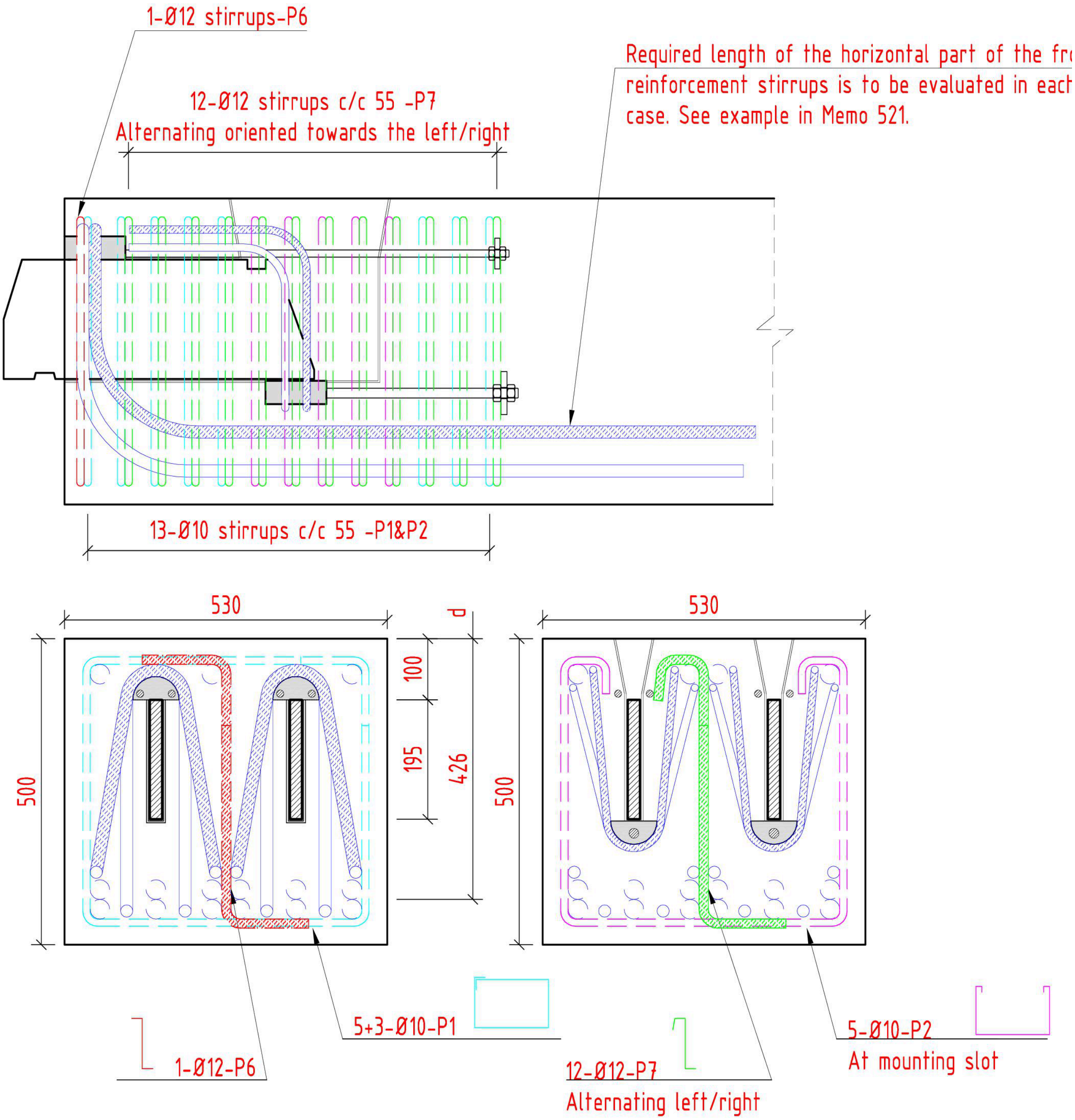

Figure 6: Reinforcement in beam end.

3.4 COLUMN UNIT

Figure 7 illustrates the recommended minimum column width.

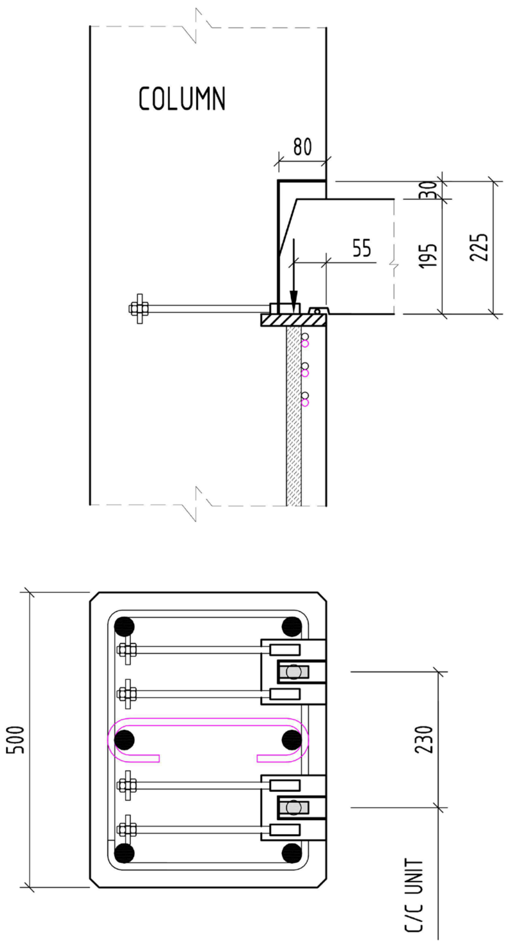

Figure 7: BSF225 column unit. (Reinforcement is not illustrated complete.)

3.4.1 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Main stirrups:

Required cross section of reinforcement: $A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 225000N}{435MPa} = 207mm^2$

Required amount of one-legged ø10 stirrups: $n = \frac{207mm^2}{78mm^2} = 2{,}6 \Rightarrow 3$

⇒ Three stirrups Ø10 in Zone 1 are sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

Stirrups in center of column:

Required cross section of reinforcement: $A_s = \frac{F_H}{f_{yd}} = \frac{67500}{435} = 155mm^2$

Required amount of one-legged ø10 stirrups: $n = \frac{155mm^2}{78mm^2} = 1{,}99 \Rightarrow 2$

⇒ Select three stirrups Ø10 in Zone 1. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

PART 4 - BSF 300 USED IN PAIRS

4.1 BEAM – RECOMMENDED MINIMUM CROSS-SECTION

See also memo 521. Figure 8 illustrates the recommended minimum cross section and spacing between the units when used in pairs.

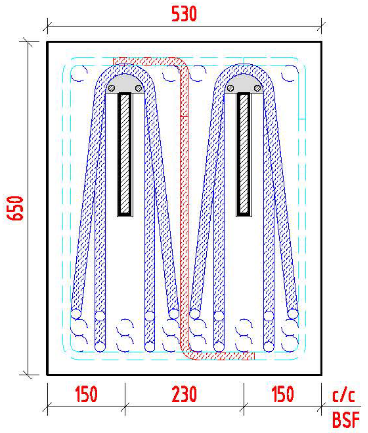

Figure 8: BSF 300 –Recommended minimum cross section and spacing between units when used in pairs.

4.2 BEAM – MANDREL DIAMETER OF ANCHORING REINFORCEMENT

Forces, from situation II, memo 521:

R_{vo}=475,3kN (per unit)

R_{vu}=175,3kN (per unit)

1) Vertical suspension reinforcement in front:

Minimum mandrel diameter in-between the units:

$$\varnothing_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{475300}{200 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 465\,\text{mm}$$

b_{eff}= effective beam width between units: b=230mm-(10+5)mmx2=200mm

$\varnothing_{mf}$= Mandrel diameter of reinforcement.

Concrete strut assumed in 45degrees.

⇒ Select: Ø=500mm

2) Vertical suspension reinforcement at back:

Minimum mandrel diameter in-between the units:

$$\varnothing_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{175300}{200 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 172\,\text{mm}$$

⇒ Select: Ø=200mm.

(⇒Note: Use of units in pairs may require increased mandrel diameter for the suspension reinforcement compared to use of single unit.)

4.3 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

4.3.1 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: V_{Rd}=R_{VO}×2=475,3kN×2=950,6kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{475,3 \times 10^3 N \times 2}{0,9 \times 0,573m \times 435MPa} = 4237mm^2 / m$$

Assume height of beam: h=650mm

Assume: d=573mm

Assume: z=0,9d

Maximum spacing of stirrups in transverse direction:

$s_{t,max}$=0,75×z=0,75×0,9×573mm=386mm

Half of the required shear reinforcment in-between the units:

⇒ Select Ø12c50 one-legged stirrups in center of cross section=2262 mm^2/m

⇒ Main stirrups (two legs): Ø12c100=2262 mm^2/m

⇒ Total amount of reinforcement=4524 mm^2/m

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. (Note also the recommendations in section 2.1.)

4.3.2 SHEAR COMPRESSION IN BEAM END

Full beam cross section:

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} =530mm

⇒ b_w =530mm-30mm×2=470mm

Assume height of beam: h=650mm

Assume: d=573mm

Assume: z=0,9d

$V_{Rd,max} = \{1{,}0 \times 470 \times 0{,}9 \times 573 \times 0{,}6 \times [1-(35/250)] \times 19{,}8/(1+1)\} \times 10^{-3}$

$V_{Rd,max}$ = 1238 kN (>V_{Rd}⇒ OK)

Area in- between the units:

Effective width of beam: b_w=230mm-32mm=198mm

$V_{Rd,max}$ = 1238kN x198/470=521kN (>V_{Rd}/2⇒ OK!)

4.3.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model, see Figure 6 in memo 521:

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

Note. This will represents the reinforcement per unit. The same amount of reinforcement shall be included for both units, see example and calculations in Memo 521.

4.3.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

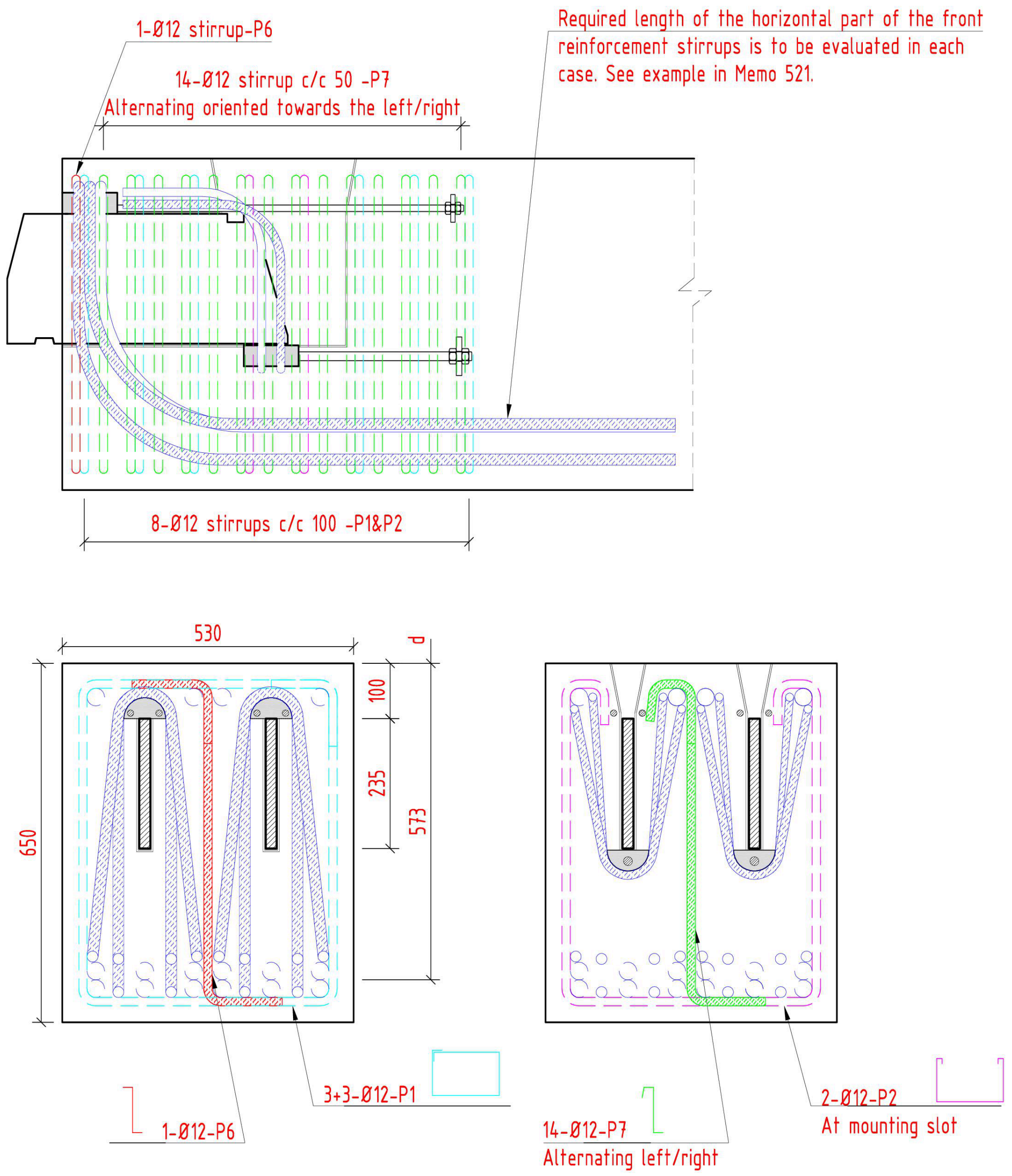

Figure 9: Reinforcement in beam end.

4.4 COLUMN UNIT

Figure 10 illustrates the recommended minimum column width.

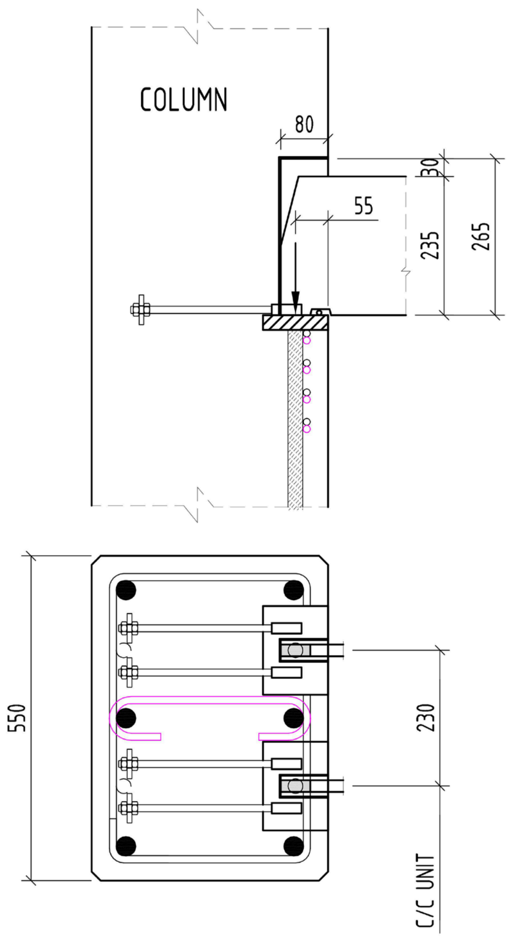

Figure 10: BSF300 column unit. (Reinforcement are not illustrated complete.)

4.4.1 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

<u>Main stirrups:</u>

Required cross section of reinforcement: $A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 300000N}{435MPa} = 276mm^2$

Required amount of one-legged ø10 stirrups: $n = \frac{276mm^2}{78mm^2} = 3{,}5 \Rightarrow 4$

⇒ Four stirrups Ø10 in Zone 1 are sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

Stirrups in center of column:

Required cross section of reinforcement: $A_s = \frac{F_H}{f_{yd}} = \frac{90000}{435} = 207mm^2$

Required amount of one-legged ø10 stirrups: $n = \frac{207mm^2}{78mm^2} = 2{,}66 \Rightarrow 3$

⇒ Select four stirrups Ø10 in Zone 1. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

PART 5 – BSF 450 USED IN PAIRS

5.1 BEAM – RECOMMENDED MINIMUM CROSS-SECTION

See also memo 521. Figure 11 illustrates the recommended minimum cross section and spacing between the units when used in pairs.

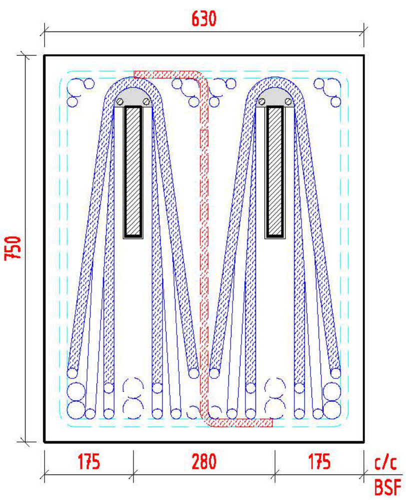

Figure 11: BSF 450 –Recommended minimum cross section and spacing between units when used in pairs.

5.2 BEAM – MANDREL DIAMETER OF ANCHORING REINFORCEMENT

Forces, from situation II, memo 521:

R_{vo}=681,7kN (per unit)

R_{vu}=231,7kN (per unit)

1) Vertical suspension reinforcement in front:

Minimum mandrel diameter in-between the units:

$$Ø_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{681700}{240 \times 0{,}6 \times (1 - \frac{35}{250}) \times 19{,}8 MPa \times 0{,}5} = 556\,\text{mm}$$

b_{eff}= effective beam width between units: b=280mm-(15+5)mmx2=240mm

$Ø_{mf}$= Mandrel diameter of reinforcement.

Concrete strut assumed in 45degrees.

⇒ Select: Ø=550mm

2) Vertical suspension reinforcement at back:

Minimum mandrel diameter in-between the units:

$$Ø_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0{,}6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0{,}5} = \frac{231700}{240 \times 0{,}6 \times (1 - \frac{35}{250}) \times 19{,}8 MPa \times 0{,}5} = 190\,\text{mm}$$

⇒ Select: Ø=200mm.

(⇒Note: Use of units in pairs may require increased mandrel diameter for the suspension reinforcement compared to use of single unit.)

5.3 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

5.3.1 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: V_{RD}=R_{VO}×2=681,7kN×2=1363,4kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{681{,}7 \times 10^3 N \times 2}{0{,}9 \times 0{,}665 m \times 435 MPa} = 5236 mm^2 / m$$

Assume height of beam: h=750mm

Assume: d=665mm

Assume: z=0,9d

Maximum spacing of stirrups in transverse direction:

$s_{t,max}$=0,75×z=0,75×0,9×665mm=449mm

Half of the required shear reinforcment in-between the units:

$\Rightarrow$ Select Ø12c40 one-legged stirrups in center of cross section=2827 mm^2/m

$\Rightarrow$ Main stirrups (two legs): Ø12c80=2827 mm^2/m

$\Rightarrow$ Total amount of reinforcement=5654 mm^2/m

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. (Note also the recommendations in section 2.1.)

5.3.2 SHEAR COMPRESSION IN BEAM END

Full beam cross section:

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_{eam} =630mm

$\Rightarrow b_w$ =630mm-40mm×2=550mm

Assume height of beam: h=750mm

Assume: d=665mm

Assume: z=0,9d

$V_{Rd,max} = \{1,0 \times 550 \times 0,9 \times 665 \times 0,6 \times [1-(35/250)] \times 19,8/(1+1)\} \times 10^{-3}$

$V_{Rd,max}$ = 1680 kN ((>$V_{Rd} \Rightarrow$ OK)

Area in- between the units:

Effective width of beam: b_w=280mm-40mm=240mm

$V_{Rd,max}$ = 1680kN×240mm/550mm=733kN (>$V_{Rd}/2 \Rightarrow$ OK!)

5.3.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model, see Figure 6 in memo 521:

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

Note. This will represents the reinforcement per unit. The same amount of reinforcement shall be included for both units, see example and calculations in Memo 521.

5.3.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

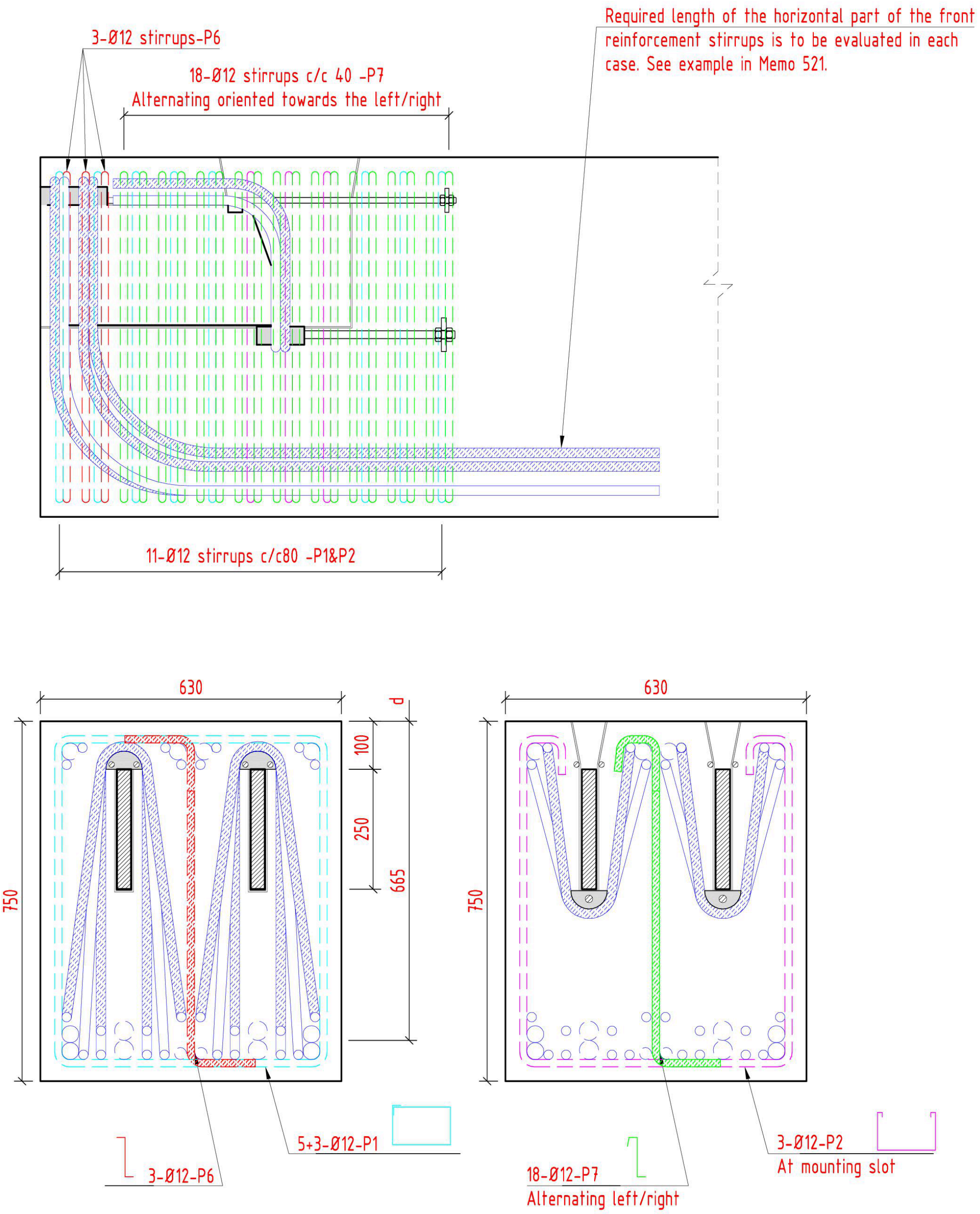

Figure 12: Reinforcement in beam end.

5.4 COLUMN UNIT

Figure 13 illustrates the recommended minimum column width.

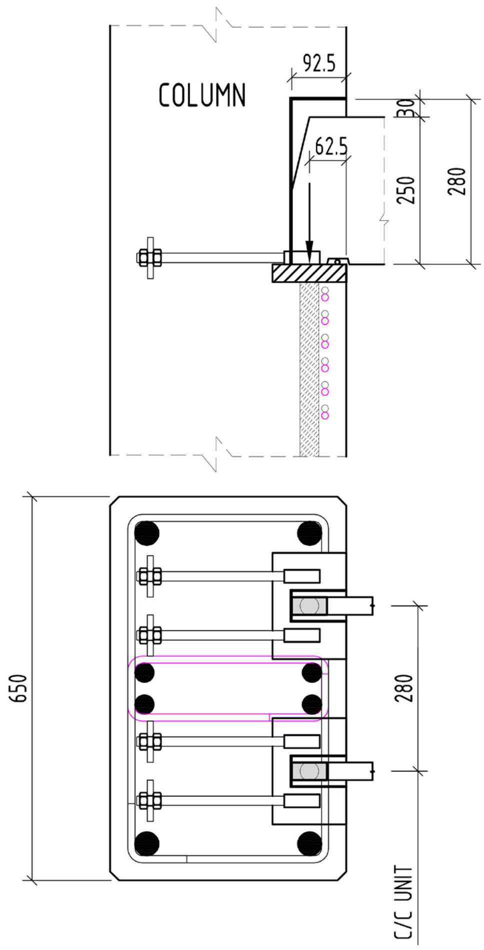

Figure 13: BSF450 column unit. (Reinforcement are not illustrated complete.)

5.4.1 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

<u>Main stirrups:</u>

Required cross section of reinforcement:
$$A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 450000N}{435MPa} = 414mm^2$$

Required amount of one-legged ø10 stirrups:
$$n = \frac{414mm^2}{78mm^2} = 5{,}3 \Rightarrow 6$$

⇒ Six stirrups Ø10 in Zone 1 are sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

Stirrups in center of column:

Required cross section of reinforcement: $A_s = \frac{F_H}{f_{yd}} = \frac{135000}{435} = 310mm^2$

Required amount of one-legged ø10 stirrups: $n = \frac{310mm^2}{78mm^2} = 3,98 \Rightarrow 4$

⇒ Selecting stirrups with two effective cross-sections. -> Only two of these stirrups are required (equals four cross sections). However, select to use the same amount of center stirrups as main stirrups in Zone 1, (->six center stirrups). See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

PART 6 – BSF 700 USED IN PAIRS

6.1 BEAM – RECOMMENDED MINIMUM CROSS-SECTION

See also memo 521. Figure 14 illustrates the recommended minimum cross section and spacing between the units when used in pairs.

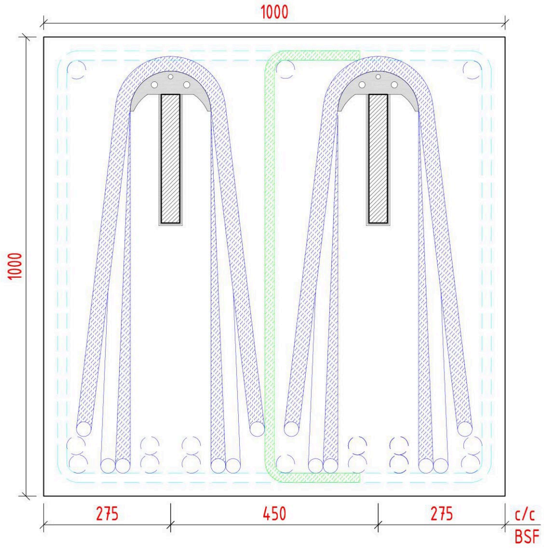

Figure 14: BSF 700 –Recommended minimum cross section and spacing between units when used in pairs.

6.2 BEAM – MANDREL DIAMETER OF ANCHORING REINFORCEMENT

Forces, from situation II, memo 521:

R_{vo}=1103kN (per unit)

R_{vu}=403kN (per unit)

1) Vertical suspension reinforcement in front:

Minimum mandrel diameter in-between the units:

$$\varnothing_{mf,\min} = \frac{R_{VO}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{1103000}{400 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 540\,\text{mm}$$

b_{eff}= effective beam width between units: b=450mm-(20+5)mmx2=400mm

$\varnothing_{mf}$= Mandrel diameter of reinforcement.

Concrete strut assumed in 45degrees.

⇒ Select: Ø=640mm

2) Vertical suspension reinforcement at back:

Minimum mandrel diameter in-between the units:

$$\varnothing_{mb,\min} = \frac{R_{VU}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{403000}{400 \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 198\,\text{mm}$$

⇒ Select: Ø=200mm

(⇒Note: Use of units in pairs may require increased mandrel diameter for the suspension reinforcement compared to use of single unit.)

6.3 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

6.3.1 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: $V_{RD}=R_{VO}\times2$=1103kN×2=2206kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{1103 \times 10^3\,N \times 2}{0,9 \times 0,910m \times 435MPa} = 6192mm^2/m$$

Assume height of beam h=1000mm

Assume d=910mm

Antar z=0,9d

Maximum spacing of stirrups in transverse direction:

$s_{t,max}$=0,75×z=0,75×0,9×910mm=614mm

Half of the required shear reinforcment in-between the units:

⇒ Select Ø16c60 one-legged stirrups in center of cross section=3351mm^2/m

⇒ Main stirrups (two legs): Ø16c120=3351mm^2/m

⇒ Total amount of reinforcement=6702 mm^2/m

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. (Note also the recommendations in section 2.1.)

6.3.2 SHEAR COMPRESSION IN BEAM END

Full beam cross section:

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: =1000mm

⇒ b_w =1000mm-50mm×2=900mm

Assume height of beam: h=1000mm

Assume: d=910mm

Assume: z=0,9d

$V_{Rd,max} = \{1{,}0 \times 900 \times 0{,}9 \times 910 \times 0{,}6 \times [1-(35/250)] \times 19{,}8/(1+1)\} \times 10^{-3}$

$V_{Rd,max}$ = 3765 kN (>V_{Rd}⇒ OK)

Area in- between the units:

Effective width of beam: b_w=450mm-50mm=400mm

$V_{Rd,max}$ = 3765kN×400mm/900mm=1673kN (>V_{Rd}/2⇒ OK!)

6.3.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model, see Figure 6 in memo 521:

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

Note. This will represents the reinforcement per unit. The same amount of reinforcement shall be included for both units, see example and calculations in Memo 521.

⇒Note: Horizontal stirrups is always recommended for this unit.

6.3.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

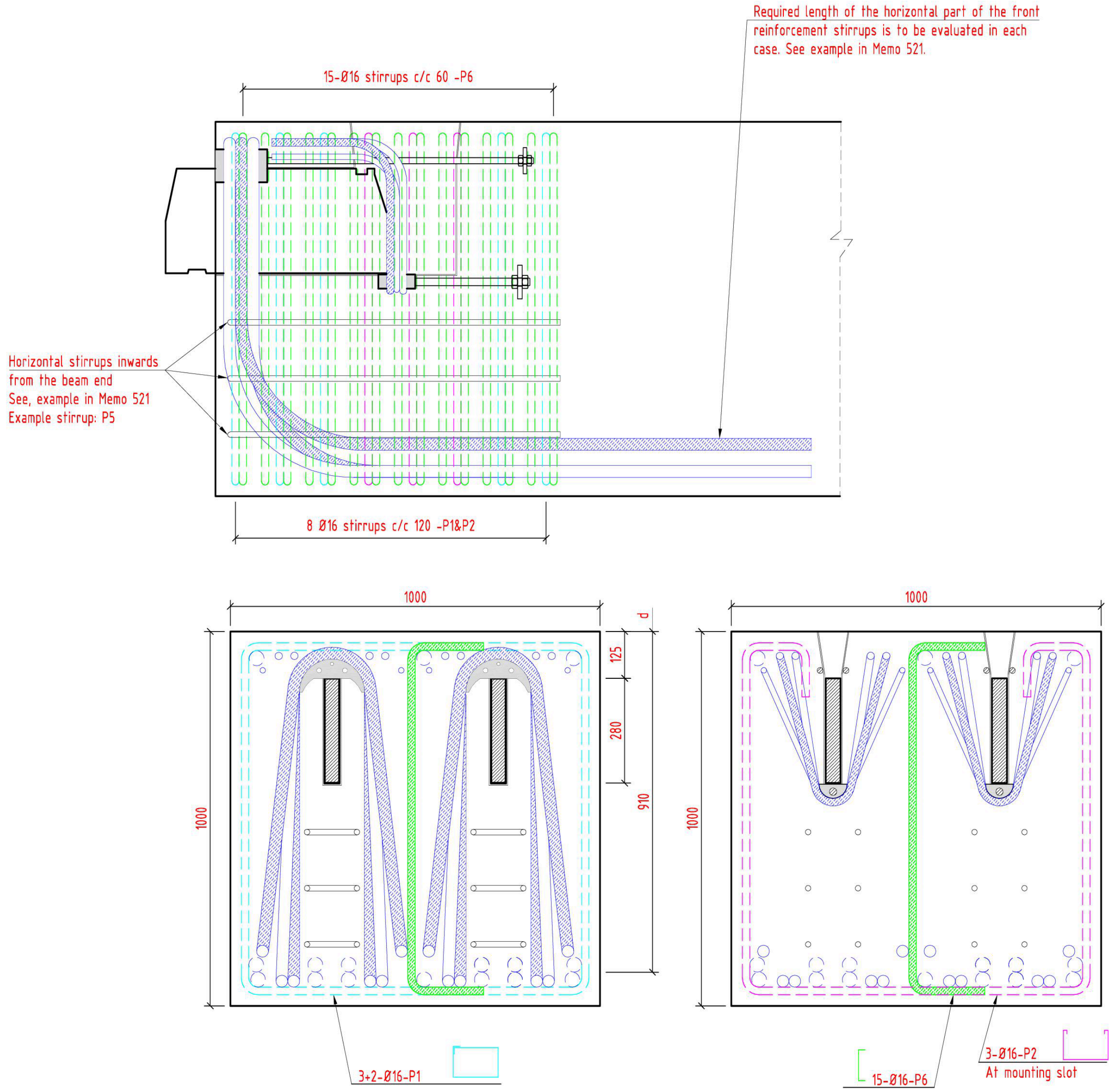

Figure 15: Reinforcement in beam end.

6.4 COLUMN UNIT

Figure 16 illustrates the recommended minimum column width.

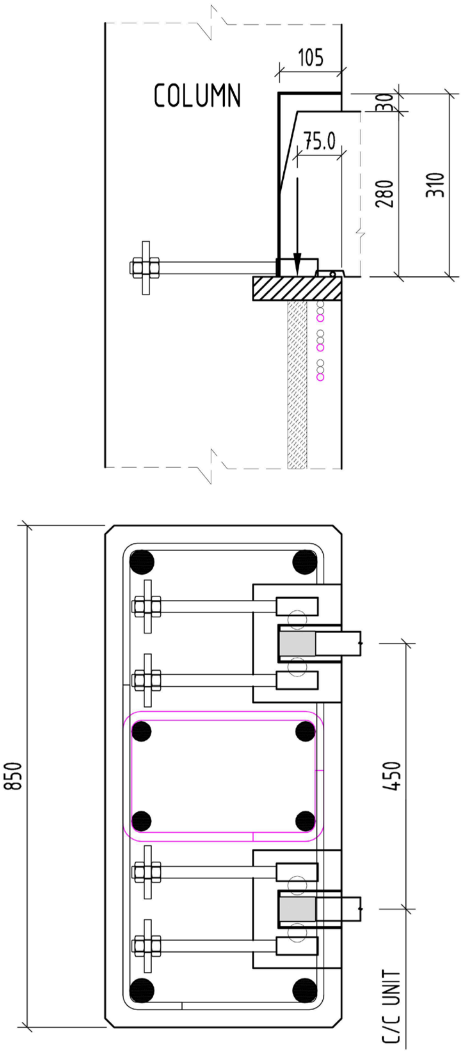

Figure 16: BSF700 column unit. (Reinforcement is not illustrated complete.)

6.4.1 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Main stirrups:

Required cross section of reinforcement: $A_s = \frac{0{,}4 \times F_V}{f_{yd}} = \frac{0{,}4 \times 700000N}{435MPa} = 644mm^2$

Required amount of one-legged ø12 stirrups: $n = \frac{644mm^2}{113mm^2} = 5{,}7 \Rightarrow 6$

⇒ Three double stirrups Ø12 in Zone 1 are sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

Stirrups in center of column:

Required cross section of reinforcement: $A_s = \frac{F_H}{f_{yd}} = \frac{210000}{435} = 483mm^2$

Required amount of one-legged ø12 stirrups: $n = \frac{483mm^2}{113mm^2} = 4{,}27 \Rightarrow \approx 5$

⇒ Select two-legged stirrups. Three stirrups Ø12 (six legs) is sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

PART 7 – BSF 1100 USED IN PAIRS

7.1 BEAM – RECOMMENDED MINIMUM CROSS-SECTION

See also memo 521. Figure 17 illustrates the recommended minimum cross section and spacing between the units when used in pairs.

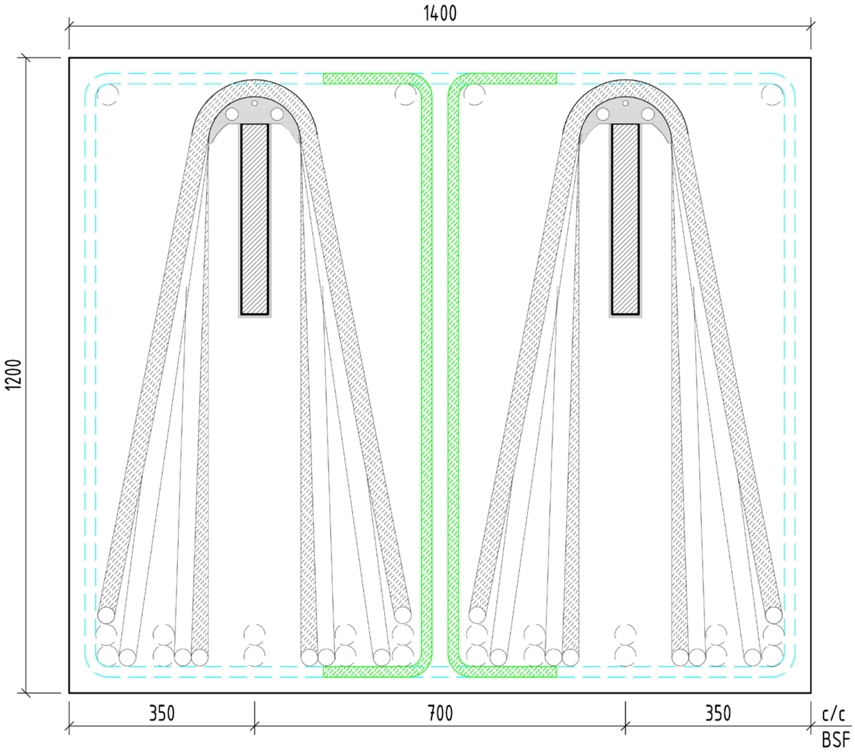

Figure 17: BSF 1100 –Recommended minimum cross section and spacing between units when used in pairs.

7.2 BEAM – MANDREL DIAMETER OF ANCHORING REINFORCEMENT

Forces, from situation II, memo 521:

R_{vo}=1587kN (per unit)

R_{vu}=487kN (per unit)

1) Vertical suspension reinforcement in front:

Minimum mandrel diameter in-between the units:

$$Ø_{mf,min} = \frac{R_{VO}}{b_{eff} \times 0,6 \times \left(1 - \frac{f_{ck}}{250}\right) \times f_{cd} \times 0,5} = \frac{1587000}{640 \times 0,6 \times \left(1 - \frac{35}{250}\right) \times 19,8 \times 0,5} = 485mm$$

b_{eff}= effective beam width between units: b=700mm-(25+5)mm x 2=640mm

$Ø_{mf}$= Mandrel diameter of reinforcement.

Concrete strut assumed in 45degrees.

⇒ Select: Ø=500mm

2) Vertical suspension reinforcement at back:

Minimum mandrel diameter in-between the units:

$$Ø_{mb,min} = \frac{R_{VU}}{b_{eff} \times 0,6 \times (1 - \frac{f_{ck}}{250}) \times f_{cd} \times 0,5} = \frac{487000N}{640mm \times 0,6 \times (1 - \frac{35}{250}) \times 19,8MPa \times 0,5} = 149mm$$

⇒ Select: Ø=200mm

(⇒Note: Use of units in pairs may require increased mandrel diameter for the suspension reinforcement compared to use of single unit.)

7.3 EVALUATION OF REINFORCEMENT IN THE END OF THE CONCRETE BEAM

7.3.1 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: V_{RD}=R_{VO}×2=1587kN×2=3174kN

$$\frac{A_s}{s} = \frac{V_{Rd,s}}{z \times f_{yd}} \approx \frac{1587 \times 10^3 N \times 2}{0,9 \times 1,110m \times 435MPa} = 7304mm^2$$

Assume height of beam h=1200mm

Assume d=1110mm

Antar z=0,9d

Maximum spacing of stirrups in transverse direction:

$s_{t,max}$=0,75×z=0,75×0,9×1110mm=749mm

Half of the required shear reinforcement in-between the units:

⇒ Select two Ø16c100 one-legged stirrups in center of cross section=4021mm^2/m

⇒ Main stirrups (two legs): Ø16c100=4021mm^2/m

⇒ Total amount of reinforcement=8042 mm^2/m

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. (Note also the recommendations in section 2.1.)

7.3.2 SHEAR COMPRESSION IN BEAM END

Full beam cross section:

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: =1400mm

⇒ b_w =1400mm-60mm×2=1280mm

Assume height of beam: h=1200mm

Assume: d=1110mm

Assume: z=0,9d

$V_{Rd,max} = \{1,0 \times 1280 \times 0,9 \times 1110 \times 0,6 \times [1-(35/250)] \times 19,8/(1+1)\} \times 10^{-3}$

$V_{Rd,max}$ = 6532 kN (>V_{Rd}⇒ OK)

Area in- between the units:

Effective width of beam: b_w=700mm-60mm=640mm

$V_{Rd,max}$ = 6532kN×640mm/1280mm=3266kN (>V_{Rd}/2⇒ OK!)

7.3.3 HORIZONTAL BARS IN BEAM END

According to the strut and tie model, see Figure 6 in memo 521:

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

Note. This will represents the reinforcement per unit. The same amount of reinforcement shall be included for both units, see example and calculations in Memo 521.

⇒Note: Horizontal stirrups is always recommended for this unit.

7.3.4 ILLUSTRATION OF REINFORCEMENT IN BEAM END

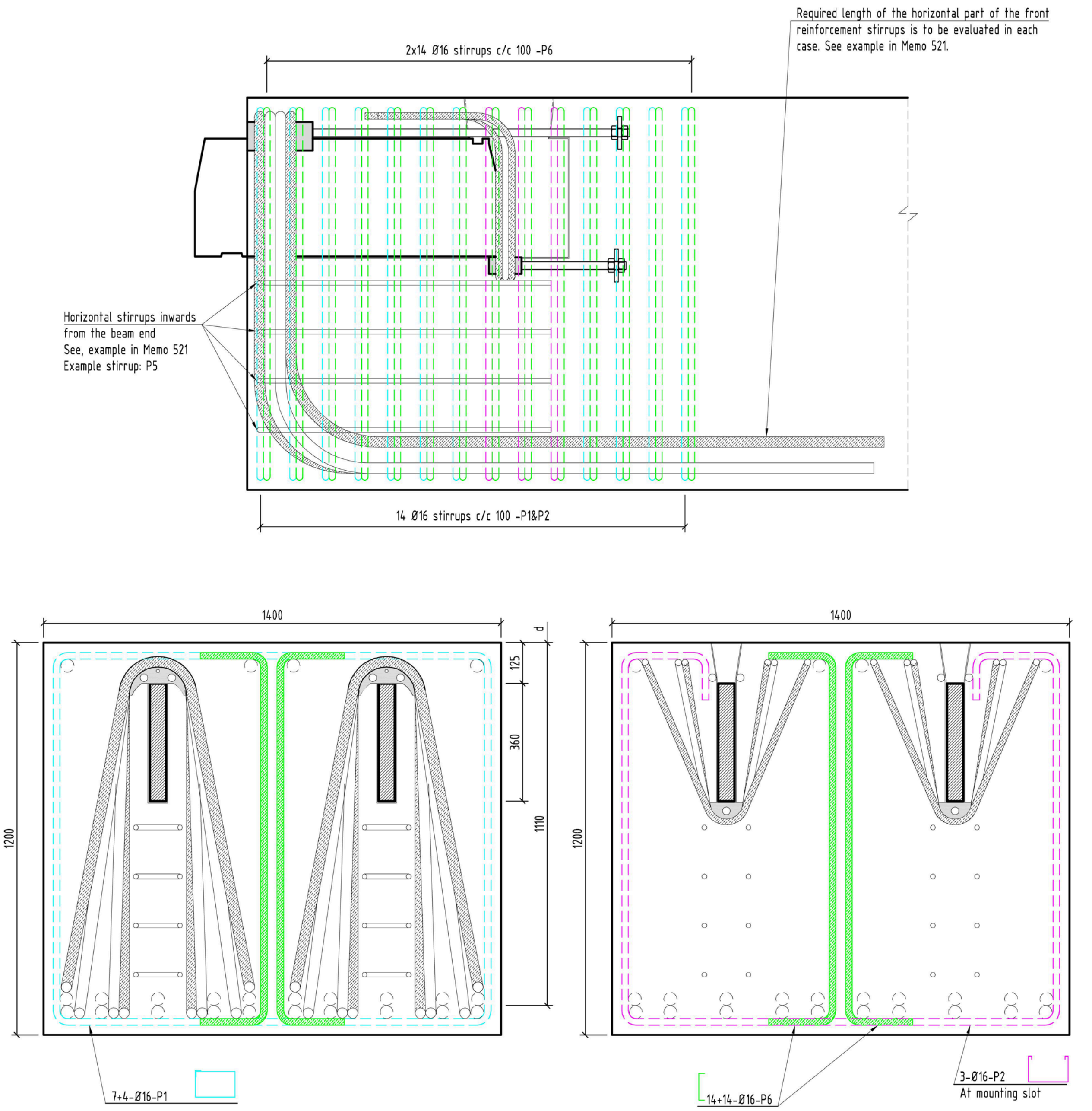

Figure 18: Reinforcement in beam end.

7.4 COLUMN UNIT

Figure 19 illustrates the recommended minimum column width.

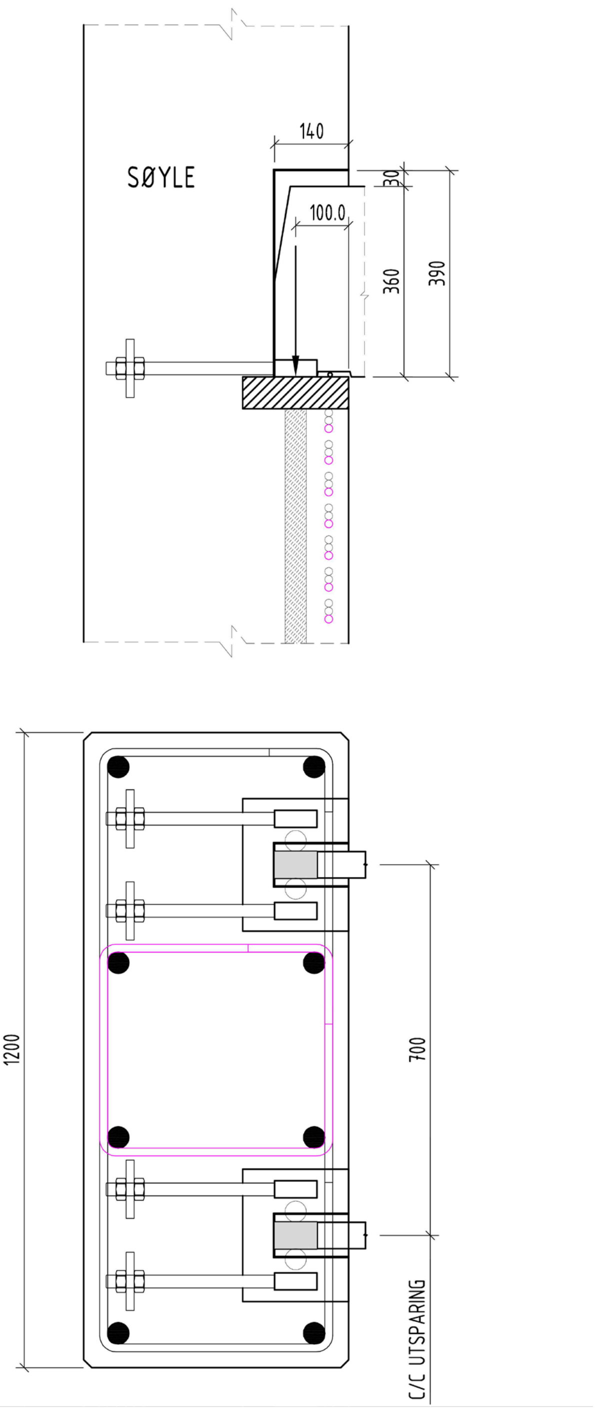

Figure 19: BSF1100 column unit. (Reinforcement is not illustrated complete.)

7.4.1 STIRRUPS IN THE COLUMN DIRECTLY BENEATH THE UNIT

Main stirrups:

Required cross section of reinforcement: $A_s = \frac{0,4 \times F_V}{f_{yd}} = \frac{0,4 \times 1100000N}{435MPa} = 1012mm^2$

Required amount of one-legged ø12 stirrups: $n = \frac{1012mm^2}{113mm^2} = 9$

⇒ Five double stirrups Ø12 in Zone 1 are sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

Stirrups in center of column:

Required cross section of reinforcement: $A_s = \frac{F_H}{f_{yd}} = \frac{330000N}{435MPa} = 759mm^2$

Required amount of one-legged ø12 stirrups: $n = \frac{759mm^2}{113mm^2} = 6,7 \Rightarrow 7$

⇒ Select two-legged stirrups. Four stirrups Ø12 (eight legs) is sufficient. See section 2.2 and Figure 4 for principal and recommended reinforcement layout.

REVISION	
Date:	**Description:**
21.10.2013	First edition
17.03.2014	Calculations in chapter 5.2 updated
27.06.2014	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.
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.
14.02.2020	Updated column unit. Included BSF1100