MEMO 830

MEMO 830 DTF / DTS EXAMPLE CALCULATIONS DESIGN	Dato: 19.09.2013 Siste rev.: 25.05.2016 Dok. nr.: K4-10/30E	Sign.: sss Sign.: Control: ps

EXAMPLE CALCULATIONS DTF / DTS

CONTENT

PART 1 – DTF120 USED IN DT450

1.1 GENERAL

1.1.1 QUALITIES

Concrete C45/55:

f_{ck} = 45,0 MPa — EC2, Table 3.1

$f_{cd} = \alpha_{cc} \times f_{ck}/\gamma_c$ = 0,85×45/1,5 = 25,5 MPa — EC2, Clause 3.15

$f_{ctd} = \alpha_{ct} \times f_{ctk,0,05}/\gamma_c$ = 0,85×2,70/1,5 = 1,53 MPa — EC2, Clause 3.16

$f_{bd} = 2,25 \times \eta_1 \times \eta_2 \times f_{ctd}$ = 2,25×0,7×1,0×1,53 = 2,41 MPa — EC2, Clause 8.4.2

Reinforcement 500C:

$f_{yd} = f_{yk}/\gamma_s$ = 500/1,15 = 435 MPa — EC2, Clause 3.2.7

Tendons:

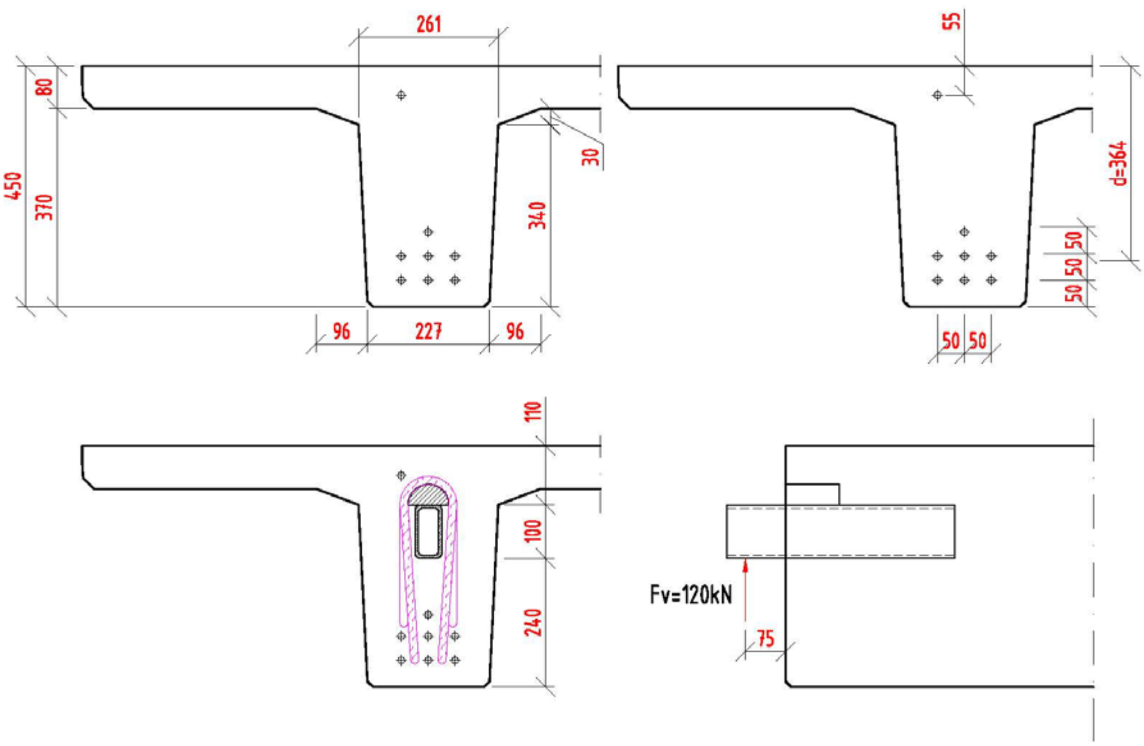
Diameter: Ø=12,7mm. (Nominal diameter. Real diameter=11,3mm)

Assumed tension after elastic loss: P=120kN.

1.1.2 LOAD

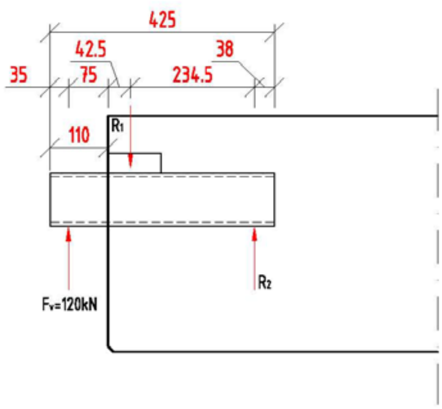
Design load F_v=120kN

1.1.3 GEOMETRY



1.2 CALCULATIONS

1) Equilibrium:



$$R_2 = \frac{F_V \times (75mm + 42,5mm)}{234,5mm} = \frac{120kN \times (75mm + 42,5mm)}{234,5mm} \approx 61kN$$

$$R_1 = F_v + R_2 = 120kN + 61kN = 181kN$$

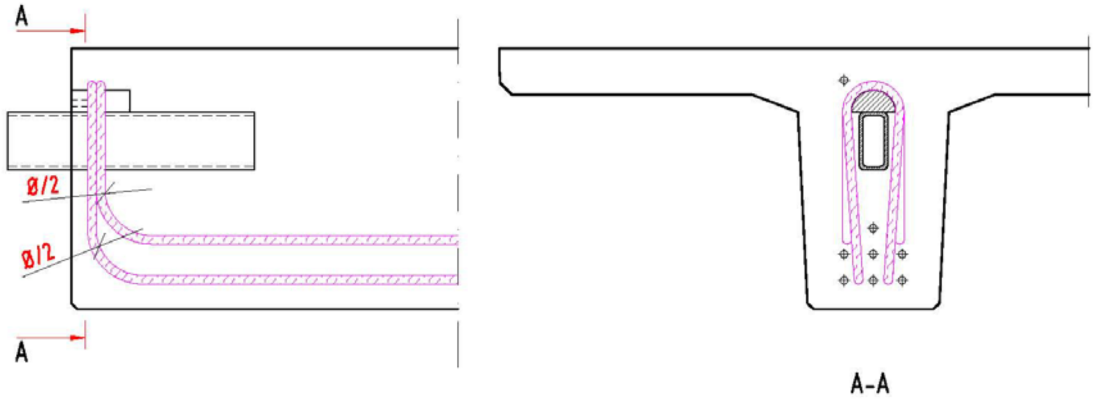
2) Reinforcement:

$$A_{R1} = \frac{181kN}{435MPa} = 416mm^2 \rightarrow 2ø12 stirrups = 452mm^2$$

$$A_{R2} = \frac{61kN}{435mm} \approx 140mm^2$$

3) Bending of anchoring reinforcement:

Minimum mandrel diameter, $Ø_{m,min}$:



Allowable concrete stress in node, EC2, clause 6.5.2:

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

$$= 0,6 \times (1 - \frac{45}{250}) \times 25,5$$

$$= 12,5MPa$$

Actual concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times \varnothing_m \times \sin\theta \times \cos\theta}$$

b=227mm

$\varnothing_m$= Mandrel diameter of front reinforcement

θ=assume concrete strut in 45degrees.

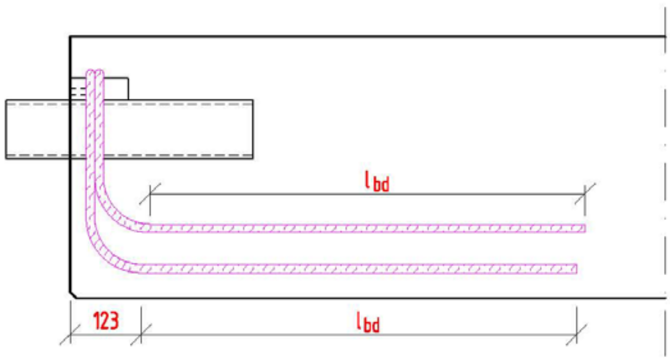
Solving for $\varnothing_m$:

$$\varnothing_m = \frac{R_1}{b \times \sigma_c \times \sin\theta \times \cos\theta}$$

$$\Rightarrow \varnothing_{m,\min} = \frac{181000N}{227mm \times 12{,}5MPa \times \sin(45) \times \cos(45)} = 128mm$$

⇒ Select mandrel diameter: $\varnothing_m$=160mm

4) Anchoring of Ø12 stirrups in front, EC2 clause 8.4.3 and 8.4.4:



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

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

Stress in stirrup: $\sigma_{sd} = \dfrac{181000/4}{\pi \times 6^2} = 400MPa$

$$l_{b,reqd} = \frac{12}{4} \times \frac{400}{2{,}41} = 497\text{mm}$$

$l_{b,min} = \max(0{,}3 \times l_{b,reqd};\ 10 \times \varnothing;\ 100\text{mm}) = 150$ mm

Table 8.2: Straight bar:

α_1= 1,0

Table 8.2: Concrete cover:

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

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:

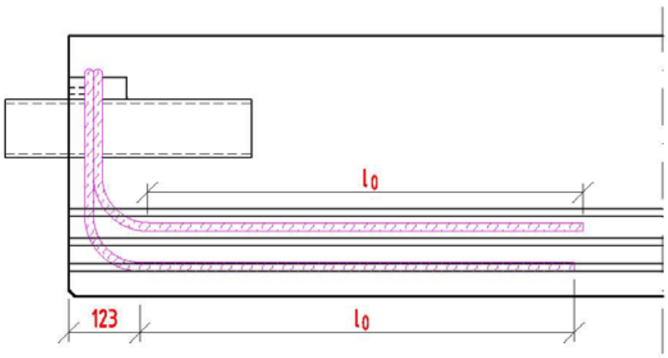
α_5 =1,0

Not relevant.

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

l_{bd} = 1,0×1,0×1,0×1,0×1,0×497mm= 497 mm

5) Lap of Ø12 stirrups, EC2 clause 8.7.3:



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

Required lap length, Ø12:

$$l_{b,reqd} = \frac{\text{Ø}}{4}\times\frac{\sigma_{sd}}{f_{bd}} = \frac{12}{4}\times\frac{400}{2{,}41} = 497\text{mm}$$

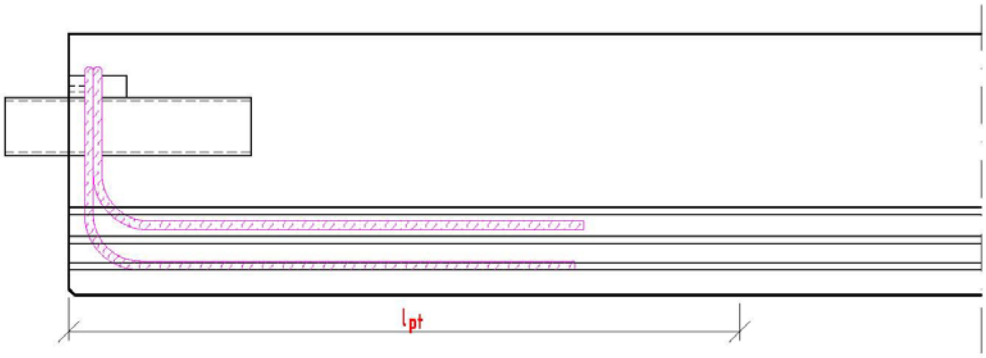
$l_{0,min}$ = max(0,3×α_6×$l_{b,reqd}$; 15×Ø; 200mm)=224mm

Table 8.2: α_1,α_2,α_3,og α_5=1,0 as calculated in clause 2).

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

$\Rightarrow l_0 = 1,0\times1,0\times1,0\times1,0\times1,5\times497mm=746mm \Rightarrow\approx750mm$

6) Transmission length – tendons, EC2 clause 8.10.2.2:



Bond stress:

$f_{bpt}=\eta_{p1}\times\eta_1\times f_{ctd}(t)$

η_{p1}=3,2 (assume 3 or7-wire tendons)

η_1=1,0 (assume "good bond conditions")

$f_{ctd}(t) =\alpha_{ct}\times0,7\times f_{ctm}(t)/\gamma_c$

α_{ct}=0,85

$f_{ctm}(t)=(\beta_{cc}(t))^{\alpha}\times f_{ctm}$

$\beta_{cc}(t)=exp(s(1-28/t)^{1/2})$

Assume: Release after t= 1day

Assume: s=0,2

$\Rightarrow\beta_{cc}(t)=exp[0,2\times\{1-(28/1)^{1/2}\}]=0,423$

α=1 (t<28days)

f_{ctm}=3,8MPa

$\Rightarrow f_{ctm}(t)=0,423^1\times3,8MPa=1,60MPa$

$f_{ctd}(t) =0,85\times0,7\times1,60MPa/1,5=0,635MPa$

$\Rightarrow f_{bpt}=3,2\times1,0\times0,635MPa=2,03MPa$

Transmission length:

$l_{pt}=\alpha_1\times\alpha_2\times Ø\times\sigma_{pmo}/ f_{bpt}$

α_1=1,0 (assume gradual release)

α_2=0,19 (assume 3 or7-wire tendons)

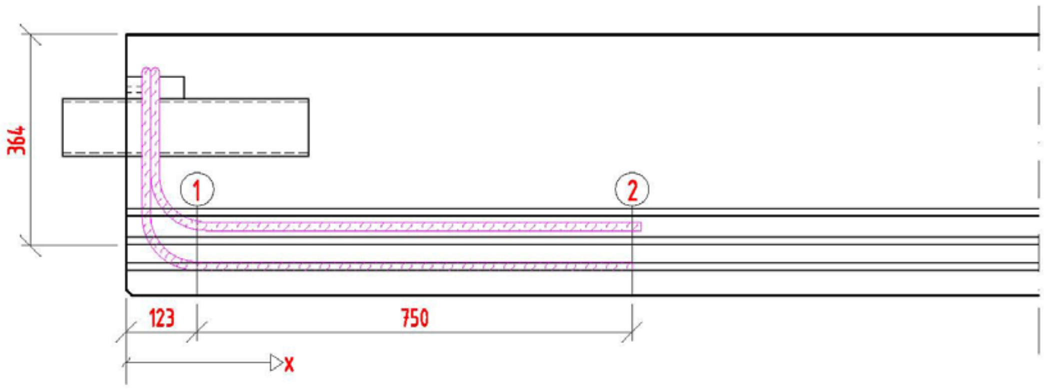
Ø=12,7mm (Nominal diameter of tendon. Real diameter=11,3mm)

σ_{pmo}= 1200MPa

$\Rightarrow l_{pt}$=1,0×0,19×12,7mm×1200MPa/2,03MPa=1426mm

$\Rightarrow l_{pt1}$=0,8× l_{pt} =0,8×1426mm=1141mm. To be used in evaluation of local cross section stresses.
$\Rightarrow l_{pt2}$=1,2× l_{pt} =1,2×1426mm=1711mm. To be used in evaluation of anchorage. Stress after all losses assumed as 0,9σ_{pmo}. (10% loss)

7) Anchoring:



Assuming the horizontal part of the front anchoring bar is 750mm (≈ equals the minimum calculated lap length). I.e. the bar ends at x=123+750=873mm.

Section 1:
Force anchored in the tendons (7 tendons) at x=123mm:
Assume 10% loss of pre-stressing force:
F_{sp1}=7×P×0,9×123mm/1711mm=7×120kN×0,9×123mm/1711mm=54kN
Force anchored in Ø12:
$F_{Ø12}$=181kN
Total anchored force:
F=F_{sp1}+$F_{Ø12}$=54kN+181kN=235kN
Tension in reinforcement at x=123mm: (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}
Moment at x=123:
M (x=123)=120kN×(123+75)mm=23,8kNm
Assume: z=0,9d=0,9×364mm=328mm (approximately)

S (x=123)=23,8kNm/0,328m+181kN/2=163kN

⇒ The anchoring at x=123mm is sufficient.

Section 2:

Force anchored in the tendons (7 tendons) at x=873mm:

Assume 10% loss of pre-stressing force:

F_{sp1}=7×P×0,9×873mm/1711mm=7×120kN×0,9×873mm/1711mm=386kN

Force anchored in Ø12:

$F_{Ø12}$=0kN

Total anchored force:

F=F_{sp1}+$F_{Ø12}$=386kN+0kN=386kN

Tension in reinforcement at x=873mm: (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}

Moment at x=873:

M (x=873)=120kN×(873+75)mm=113,8kNm

Assume: z=0,9d=0,9×364mm=328mm

S (x=873)=113,8kNm/0,328m+120kN/2=407kN

⇒ The tendons will not have sufficient anchorage at x=873mm.

Calculating the point where the tendons are sufficient anchored to carry the load:

Tension in reinforcement at x: S(x)=120kN×(x+75mm)/328mm+120kN/2

Force anchored in the tendons at x (if x<1711m): F(x)=7×120kN×0,9×x/1711mm

Hence:

$$120kN \times (x + 75mm) / 328mm + 120kN / 2 = 756kN \times x / 1711$$

$$0,366x + 87,4 = 0,442x$$

$$0,076x = 87,4$$

$$x = 87,4 / 0,076$$

$$x = 1150mm$$

⇒The horizontal part of the Ø12 anchoring bars has to be extended beyond the calculated required lap length (evaluated in clause 5), and end at x>=1150.

8) Reinforcement due to splitting stress:

A_s=0,22×P_{u1}/f_s

⇒A_s=0,22×7×120000N/300MPa

=616mm²

To be located within: 0,5×(l_{lpt1}+h_1)=0,5×(1141mm+450mm)=796mm ≤ h_1=450mm ⇒450mm

Corresponds to: 616mm²/0,450m=1369mm²/m

9) Links:

a) Required shear reinforcement x<277:

$$\frac{A_s}{s} = \frac{V_{Ed}}{z \times f_{ywd} \times \cot\theta} = \frac{R_1}{z \times f_{ywd} \times \cot\theta} = \frac{181000N}{0{,}328m \times 435MPa \times \cot(45)} = 1269mm^2/m$$

Shear compression:

$$V_{Rd} = \frac{\alpha_{cw} \times b_w \times z \times v_1 \times f_{cd}}{(\cot\theta + \tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)

b_w=227mm-50mm=177mm

z=328mm

υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492

θ=assume 45degrees

$$V_{Rd} = \frac{1{,}0 \times 177mm \times 328mm \times 0{,}492 \times 25{,}5MPa}{1+1} = 364{,}2kN > R_1 \rightarrow OK$$

b) Required shear reinforcement 277<x<606:

$$\frac{A_s}{s} = \frac{V_{Ed}}{z \times f_{ywd} \times \cot\theta} = \frac{F_V}{z \times f_{ywd} \times \cot\theta} = \frac{120000N}{0{,}328m \times 435MPa \times \cot(45)} = 841mm^2/m$$

Shear compression:

$$V_{Rd} = \frac{\alpha_{cw} \times b_w \times z \times v_1 \times f_{cd}}{(\cot\theta + \tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)

b_w=227mm

z=328mm

υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492 θ= assume 45degrees

$$V_{Rd} = \frac{1{,}0 \times 227mm \times 328mm \times 0{,}492 \times 25{,}5MPa}{1+1} = 467kN > F_v \rightarrow OK$$

Summary – reinforcement in end of the DT:

X<≈450mm: Links due to splitting stresses (8)

$$\frac{A_s}{s} = 1369mm^2 / m$$

Select Ø8 stirrups c/c70 (lapped with u-shaped Ø12 bars)

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0{,}07m} = 1436mm^2 / m$$

≈450<X<≈606mm: Links due to shear force (9).

$$\frac{A_s}{s} = 841mm^2 / m$$

Select Ø8 stirrups c/c100

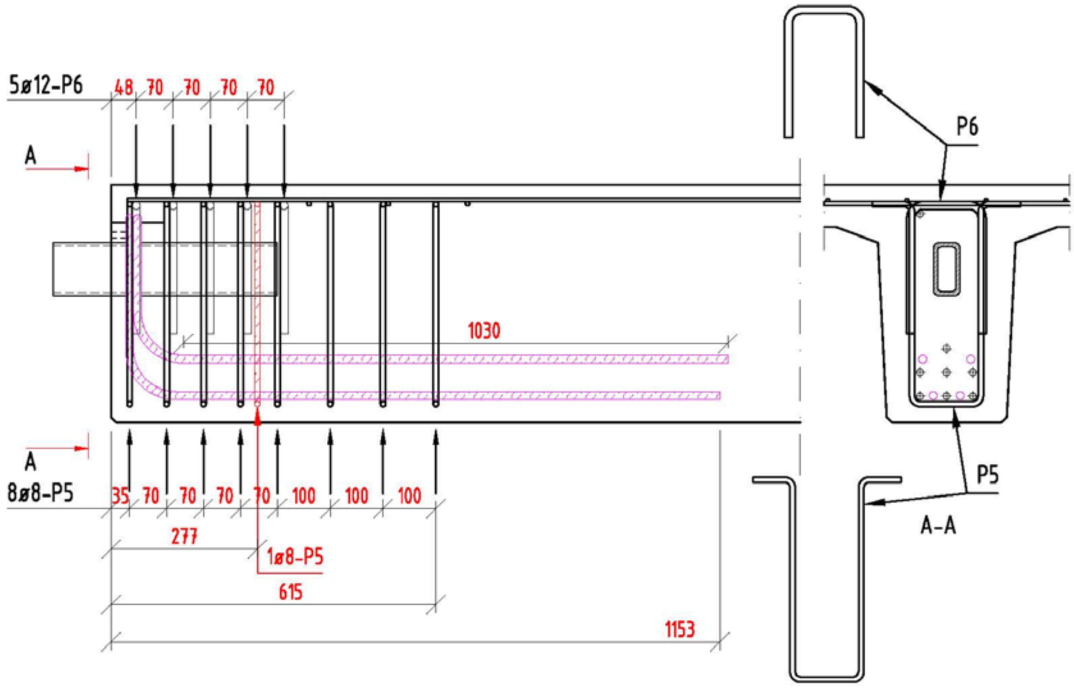
$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0{,}1m} = 1005mm^2 / m$$

606<X: Required shear reinforcement to be evaluated according to shear force distribution in the DT.

At x=277mm:

Required reinforcement: 140mm^2 ⇒1 extra Ø8 link (100mm^2) at this location. The remaining 40mm^2 can be carried by the specified distributed links.

Suggested reinforcement in end of the DT:



PART 2 – DTF200 USED IN A HIGH DT

2.1 GENERAL

2.1.1 QUALITIES

Concrete C45/55:

f_{ck} = 45,0 MPa EC2, Table 3.1

$f_{cd} = \alpha_{cc} \times f_{ck}/\gamma_c$ = 0,85×45/1,5 = 25,5 MPa EC2, Clause 3.15

$f_{ctd} = \alpha_{ct} \times f_{ctk,0,05}/\gamma_c$ = 0,85×2,70/1,5 = 1,53 MPa EC2, Clause 3.16

$f_{bd} = 2{,}25 \times \eta_1 \times \eta_2 \times f_{ctd}$ = 2,25×0,7×1,0×1,53 = 2,41 MPa EC2, Clause 8.4.2

Reinforcement B500C:

$f_{yd} = f_{yk}/\gamma_s$ = 500/1,15 = 435 MPa EC2, Clause 3.2.7

Tendons:

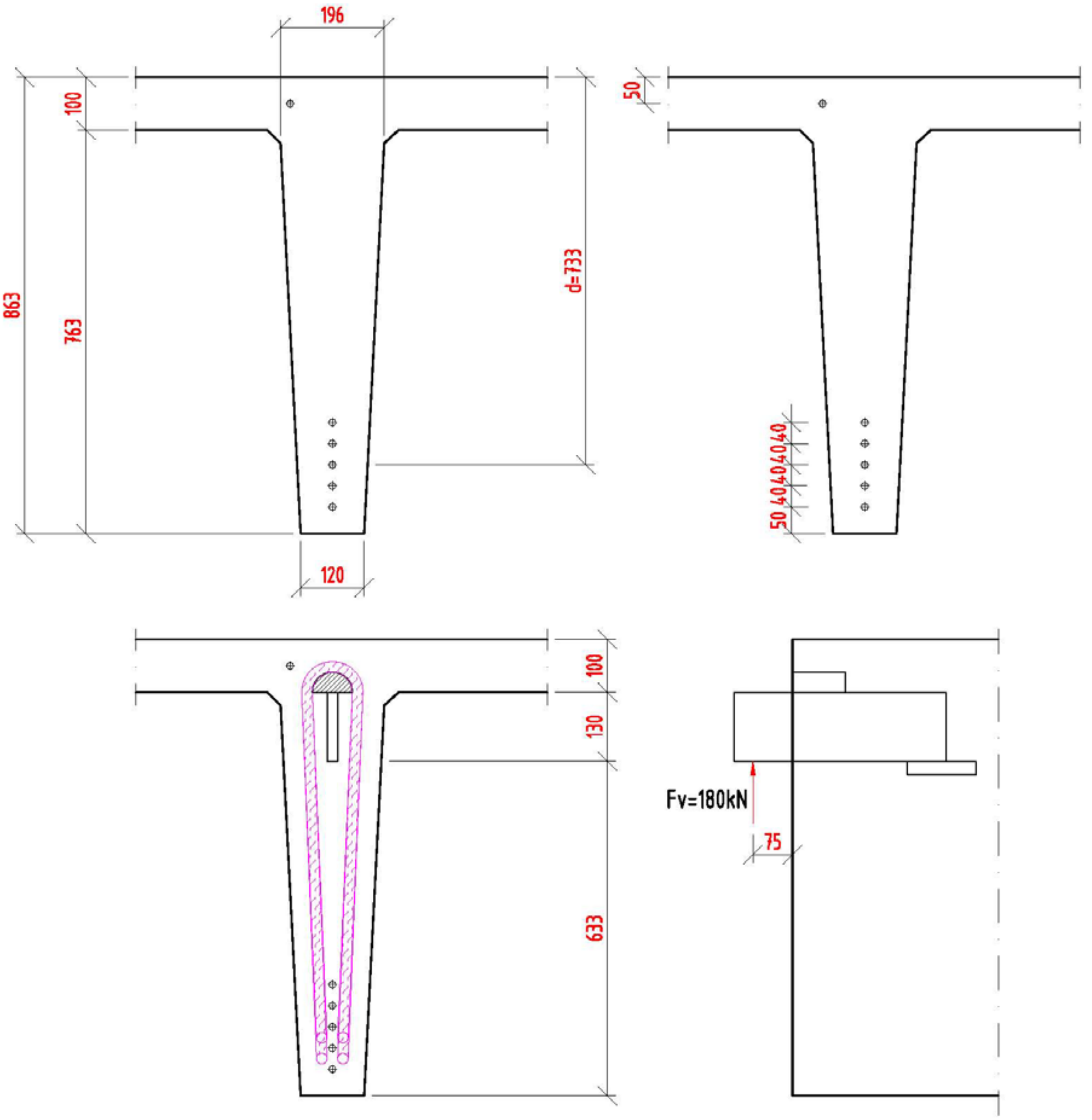
Diameter: Ø=12,7mm. (Nominal diameter. Real diameter=11,3mm)

Assumed tension after elastic loss: P=120kN.

2.1.2 LOAD

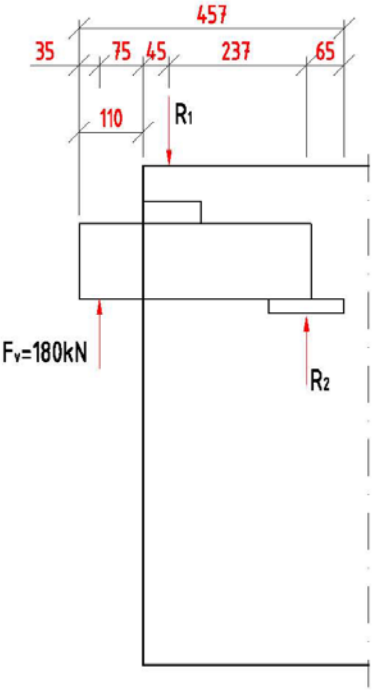
Design load F_V=180kN
(NB: The design load in the example is less than the ultimate limit load of the unit.)

2.1.3 GEOMETRY



2.2 CALCULATIONS

1) Equilibrium:



$$R_2 = \frac{F_V \times (75mm + 45mm)}{237mm} = \frac{180kN \times (75mm + 45mm)}{237mm} \approx 91kN$$

$$R_1 = F_v + R_2 = 180kN + 91kN = 271kN$$

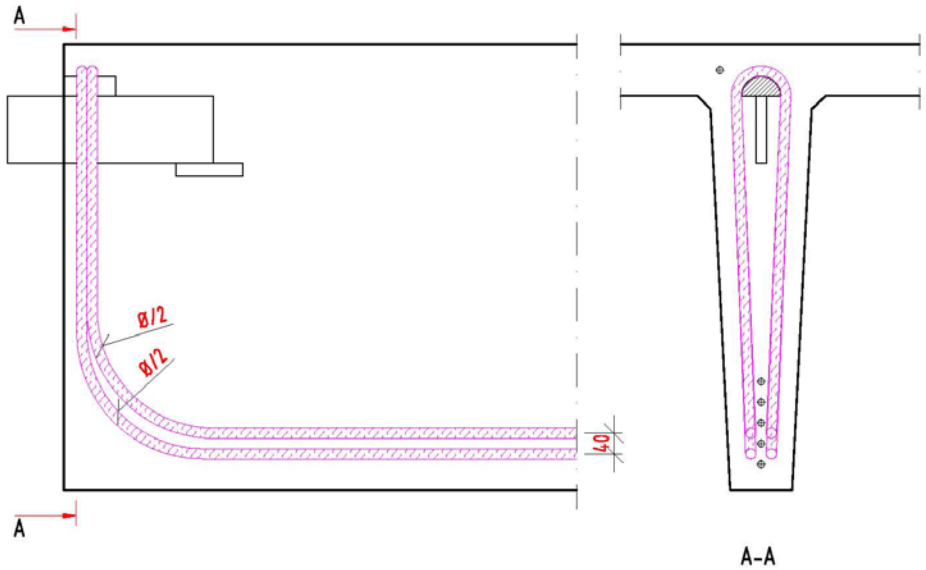
2) Reinforcement:

$$A_{R1} = \frac{271kN}{435MPa} = 623mm^2 \rightarrow 2ø16stirrups = 804mm^2$$

$$A_{R2} = \frac{91kN}{435mm} \approx 210mm^2$$

3) Bending of anchoring reinforcement:

Minimum mandrel diameter, $Ø_{m,min}$:



Allowable concrete stress in node, EC2, clause 6.5.2:

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

$$= 0,6 \times (1 - \frac{45}{250}) \times 25,5$$

$$= 12,5 MPa$$

Actual concrete stress in node:

$$\sigma_c = \frac{R_1}{b \times Ø_m \times \sin\theta \times \cos\theta}$$

b=120mm

$Ø_m$= Mandrel diameter of front reinforcement

θ=assume concrete strut in 45degrees.

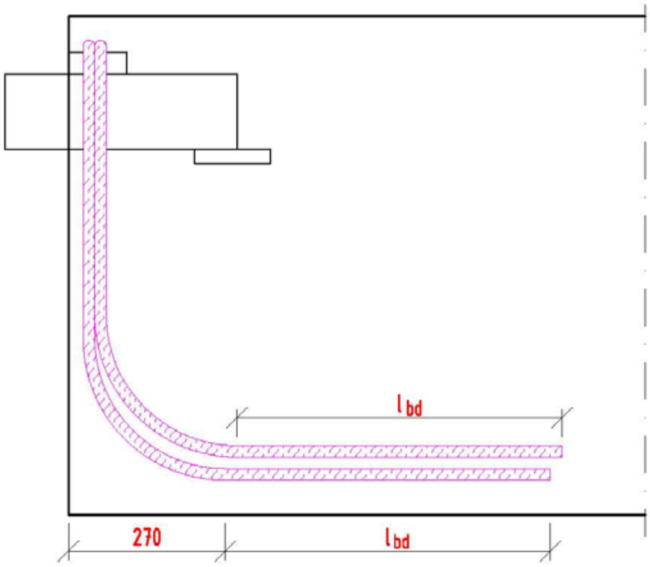
Solving for $Ø_m$:

$$Ø_m = \frac{R_1}{b \times \sigma_c \times \sin\theta \times \cos\theta}$$

$$\Rightarrow Ø_{m,\min} = \frac{271000N}{120mm \times 12,5MPa \times \sin(45) \times \cos(45)} = 361mm$$

⇒ Select mandrel diameter: $Ø_m$=450mm

4) Anchoring of Ø16 stirrups in front, EC2 clause 8.4.3 and 8.4.4:



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

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

Stress in stirrup: $\sigma_{sd} = \frac{271000/4}{\pi \times 8^2} = 337 MPa$

$l_{b,reqd} = \frac{16}{4} \times \frac{337}{2{,}41} = 560\text{mm}$

$l_{b,min}$ = max(0,3×$l_{b,reqd}$; 10×Ø; 100mm) = 168 mm

Table 8.2: Straight bar:

α_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 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:

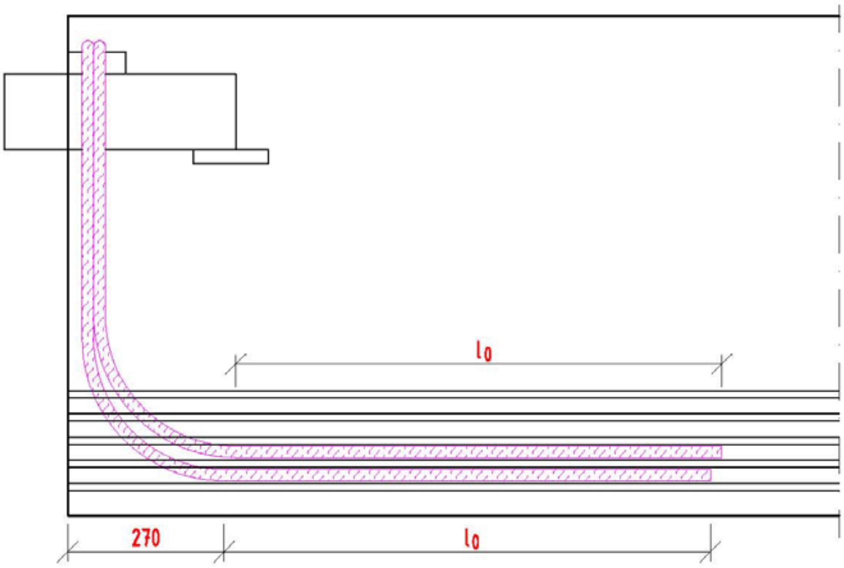
α_5 =1,0

Not relevant.

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

$l_{bd} = 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 560\text{mm} = 560$ mm

<u>5) Lap of Ø16 stirrups, EC2 clause 8.7.3:</u>



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

Required lap length, Ø16:

$$l_{b,reqd} = \frac{Ø}{4} \times \frac{\sigma_{sd}}{f_{bd}} = \frac{16}{4} \times \frac{337}{2{,}41} = 560\text{mm}$$

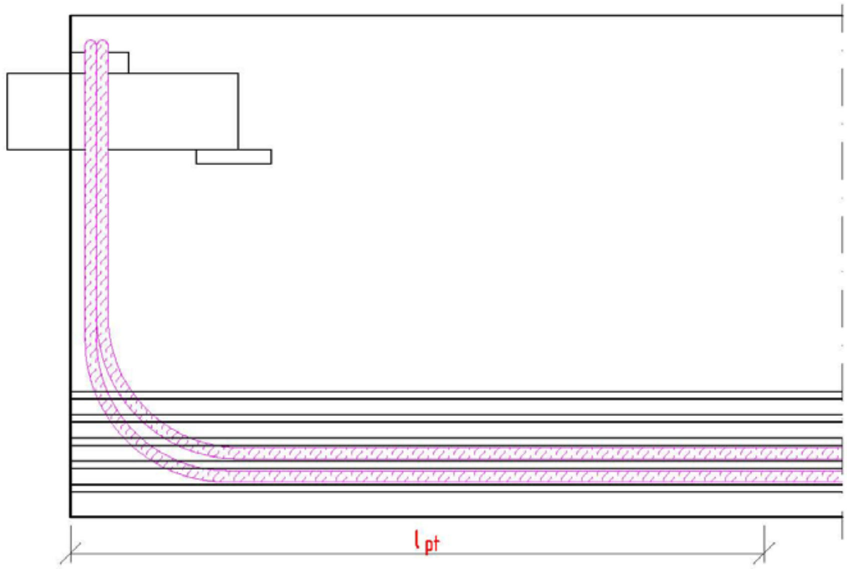
$l_{0,min} = \max(0{,}3 \times \alpha_6 \times l_{b,reqd};\ 15 \times Ø;\ 200\text{mm}) = 251\text{mm}$

Table 8.2: $\alpha_1, \alpha_2, \alpha_3$, og $\alpha_5 = 1{,}0$ as calculated in clause 2).

Table 8.3: $\alpha_6 = 1.5$ (All reinforcement is lapped)

$\Rightarrow l_0 = 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}0 \times 1{,}5 \times 560\text{mm} = 840\text{mm}$

6) Transmission length – tendons, EC2 clause 8.10.2.2:



Bond stress:

$f_{bpt}=\eta_{p1}\times\eta_1\times f_{ctd}(t)$

η_{p1}=3,2 (assume 3 or7-wire tendons)

η_1=1,0 (assume "good bond conditions")

$f_{ctd}(t)=\alpha_{ct}\times 0,7\times f_{ctm}(t)/\gamma_c$

α_{ct}=0,85

$f_{ctm}(t)=(\beta_{cc}(t))^{\alpha}\times f_{ctm}$

$\beta_{cc}(t)=\exp(s(1-28/t)^{1/2})$

Assume: Release after t= 1day

Assume: s=0,2

$\Rightarrow\beta_{cc}(t)=\exp[0,2\times\{1-(28/1)^{1/2}\}]=0,423$

α=1 (t<28days)

f_{ctm}=3,8MPa

$\Rightarrow f_{ctm}(t)=0,423^{1}\times 3,8$MPa=1,60MPa

$f_{ctd}(t)=0,85\times 0,7\times 1,60$MPa/1,5=0,635MPa

$\Rightarrow f_{bpt}=3,2\times 1,0\times 0,635$MPa=2,03MPa

Transmission length:

$l_{pt}=\alpha_1\times\alpha_2\times Ø\times\sigma_{pmo}/ f_{bpt}$

α_1=1,0 (assume gradual release)

α_2=0,19 (assume 3 or7-wire tendons)

Ø=12,7mm (Nominal diameter of tendon. Real diameter=11,3mm)

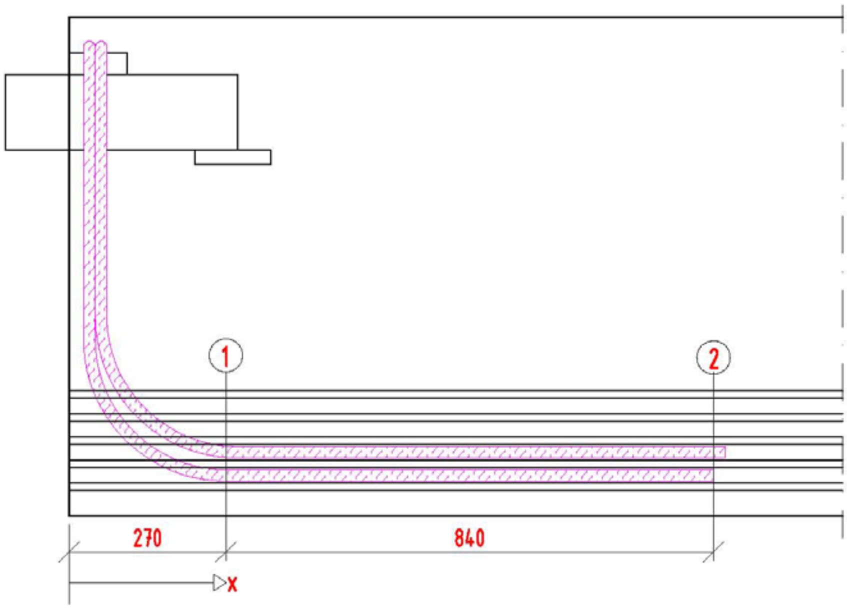
σ_{pmo}= 1200MPa

$\Rightarrow l_{pt}$=1,0×0,19×12,7mm×1200MPa/2,03MPa=1426mm

$\Rightarrow l_{pt1}$=0,8× l_{pt} =0,8×1426mm=1141mm. To be used in evaluation of local cross section stresses.

$\Rightarrow l_{pt2}$=1,2× l_{pt} =1,2×1426mm=1711mm. To be used in evaluation of anchorage. Stress after all losses assumed as 0,9σ_{pmo}. (10% loss)

7) Anchoring:



Assuming the horizontal part of the front anchoring bar is 840mm (≈ equals the minimum calculated lap length). I.e. the bar ends at x=270+840=1110mm.

Section 1:

Force anchored in the tendons (5 tendons) at x=270mm:

Assume 10% loss of pre-stressing force:

F_{sp1}=5×P ×0,9×270mm/1711mm=5×120kN×0,9×270mm/1711mm=85kN

Force anchored in Ø16:

$F_{Ø16}$=271kN

Total anchored force:

F=F_{sp1}+$F_{Ø16}$=85kN+271=356kN

Tension in reinforcement at x=270mm: (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)

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

Moment at x=270:

M (x=270)=180kN×(270+75)mm=62,1kNm

Assume z=0,9d=0,9×733mm=660mm (approximately)

S (x=270)=62,1kNm/0,660m+271kN/2=230kN

⇒ The anchoring at x=270mm is sufficient.

<u>Section 2:</u>

Force anchored in the tendons (5 tendons) at x=1110mm:

F_{sp1}=5×P ×0,9×1205mm/1711mm=5×120kN×0,9×1110mm/1711mm=350kN

Force anchored in Ø16:

$F_{Ø16}$=0kN

Total anchored force:

F=F_{sp1}+$F_{Ø16}$=350kN+0kN=350kN

Tension in reinforcement at x=1110mm: (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=1110:

M (x=1110)=180kN×(1110+75)mm=213,3kNm

Assume z=0,9d=0,9×733mm=660mm (approximately)

S (x=1110)=213,3kNm/0,660m+180kN/2=413kN

⇒ The tendons will not have sufficient anchorage at x=1110mm.

<u>Calculating the point where the tendons are sufficient anchored to carry the load:</u>

Tension in reinforcement at x: S(x)=180kN×(x+75mm)/660mm+180kN/2

Force anchored in the tendons at x:

If x<1711m: F(x)=5×120kN×0,9×x/1711mm

If x>1711m: $F(x)=5 \times 120kN \times 0,9+\Delta\sigma_{sp}(x) \times A_{sp} \times 5$

$\Delta\sigma_{sp}(x)=f_{bpd}/(\alpha_2 \times Ø) \times (x-1711) \times 10^{-3}$

$\Rightarrow F(x)= 5 \times 120kN \times 0,9+f_{bpd}/(\alpha_2 \times Ø) \times (x-1711) \times 10^{-3} \times A_{sp} \times 5$

$\Rightarrow F(x)= 540kN+2,03MPa/(0,19 \times 12,7) \times (x-1711) \times 10^{-3} \times 100mm^2 \times 5$

⇒F(x)= 540+0,420x-720=0,420x-180

Try if x<1711:

$$180kN \times (x + 75mm) / 660mm + 180kN / 2 = 540kN \times x / 1711$$
$$0{,}273x + 110{,}5 = 0{,}316x$$
$$0{,}043x = 110{,}5$$
$$x = 110{,}5 / 0{,}043$$
$$x = 2570mm$$

Calculated x>1711 $\Rightarrow$ the second expression shall be used:

$$180kN \times (x + 75mm) / 660mm + 180kN / 2 = 0{,}420x - 180$$
$$0{,}273x + 110{,}5 = 0{,}420x - 180$$
$$0{,}147x = 290{,}5$$
$$x = 290{,}5 / 0{,}147$$
$$x = 1976mm$$

$\Rightarrow$The horizontal part of the Ø16 anchoring bars has to be extended beyond the calculated required lap length (evaluated in clause 5), and end at x>=1976.

8) Reinforcement due to splitting stress:

A_s=0,22×P_{u1}/f_s

$\Rightarrow$$A_s$=0,22×5×120000N/300MPa

=440mm^2

To be located within: 0,5×(l_{lpt1}+h_1)=0,5×(1141mm+863mm)=1002mm ≤h_1=863mm$\Rightarrow$863mm

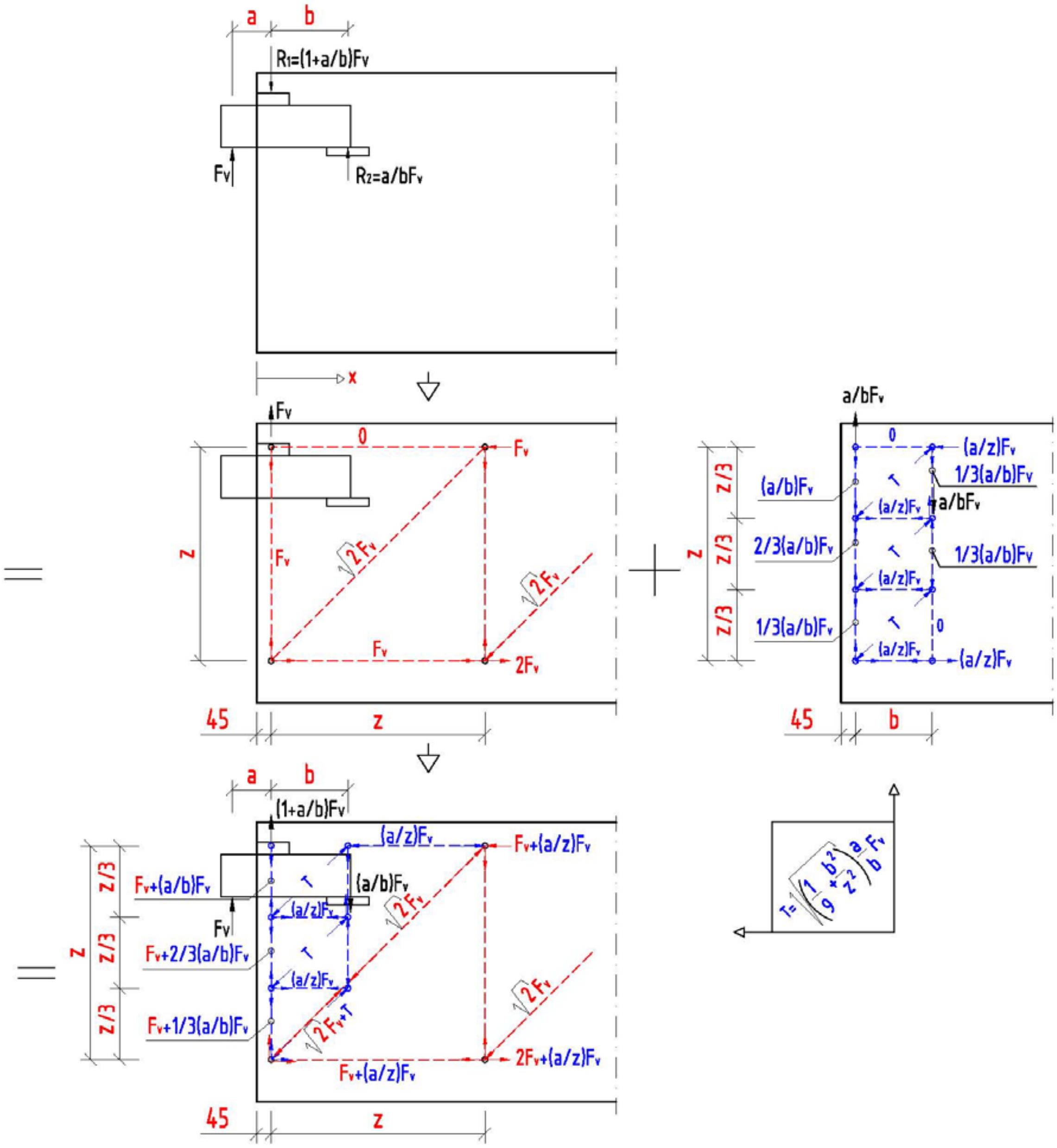
Corresponds to: 440mm^2/0,863m=510mm^2/m

9) Links/strut and tie model:

For this particular DT, the height z is approximately equal to 3xb. Hence, the bending moment from the cantilevering may be assumed transferred to the main reinforcement of the beam through a local truss with three levels. This is illustrated as a blue truss in the end of the DT, see below Figure. The compression struts in this truss will be angled in approximately 45 degrees.

The support reaction force/shear force itself may be carried by a truss with a height equal to z. This is illustrated as a red truss.

The two trusses are both in equilibrium, and the forces may be superimposed.



Evaluation of local strut and tie model:

- The model implies that only 1/3 of the force R_2 have to be carried by the vertical link at back of the unit. Nevertheless, it is chosen to calculate the required extra reinforcement at this point based on the value of R_2. (conservative assumption)

- Considering the two horizontal ties towards the end of the DT as smeared, the horizontal force per unit height of the DT becomes: $(a/z)\times F_v/(z/3)$. Where $z/3\approx b$, hence this corresponds to: $(a/z)\times F_v/b=(a/b)\times F_v/z=R_2/z$. $\Rightarrow$ Prescribe horizontal bars anchoring this force.

a) Required shear reinforcement x<45+b:

$$\frac{A_s}{s}=\frac{V_{Ed}}{z\times f_{ywd}\times\cot\theta}=\frac{R_1}{z\times f_{ywd}\times\cot\theta}=\frac{271000N}{0{,}660m\times 435MPa\times\cot(45)}=944mm^2/m$$

Shear compression:

$$V_{Rd}=\frac{\alpha_{cw}\times b_w\times z\times v_1\times f_{cd}}{(\cot\theta+\tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)

b_w=120mm

z=660mm

υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492

θ=assume 45grader

$$V_{Rd}=\frac{1{,}0\times 120mm\times 660mm\times 0{,}492\times 25{,}5MPa}{1+1}=497kN>R_1\rightarrow OK$$

b) Required shear reinforcement 45+b<x<45+z:

$$\frac{A_s}{s}=\frac{V_{Ed}}{z\times f_{ywd}\times\cot\theta}=\frac{F_V}{z\times f_{ywd}\times\cot\theta}=\frac{180000N}{0{,}660m\times 435MPa\times\cot(45)}=627mm^2/m$$

Shear compression:

$$V_{Rd}=\frac{\alpha_{cw}\times b_w\times z\times v_1\times f_{cd}}{(\cot\theta+\tan\theta)}$$

α_{cw}=1,0 (neglecting effect of pre-tensioning)

b_w=120mm

z=660mm

υ_1=0,6×(1-f_{ck}/250) =0,6×(1-45/250)=0,492

θ=assume 45grader

$$V_{Rd}=\frac{1{,}0\times 120mm\times 660mm\times 0{,}492\times 25{,}5MPa}{1+1}=497kN>F_v\rightarrow OK$$

c) Horizontal stirrups at the end of the DT:

$$\frac{A_s}{s}=\frac{R_2}{z\times f_{ywd}}=\frac{91000N}{0{,}660m\times 435MPa}=317mm^2/m$$

Amount of reinforcement below the unit:

$$A_s=317mm^2/m\times 2/3z=317mm^2/m\times 2/3\times 0{,}66m=140mm^2$$

⇒2 x U-shaped Ø8 bars (A_s=200mm²).

Summary – reinforcement in end of the DT:

The required amount of reinforcement due to splitting stresses is less than the required amount of shear reinforcement calculated in 9a and 9b.

$\Rightarrow$ X<≈282mm: Links due to shear force (9a)

$$\frac{A_s}{s} = 944mm^2 / m$$

Select Ø8 stirrups c/c75 (lapped with u-shaped Ø12 bars)

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0{,}075m} = 1340mm^2 / m$$

$\Rightarrow$ 282<X<≈705mm: Links due to shear force (9b)

$$\frac{A_s}{s} = 627mm^2 / m$$

Select Ø8 stirrups c/c150 (lapped with u-shaped Ø12 bars)

$$\frac{A_s}{s} = \frac{\pi \times (4mm)^2 \times 2}{0{,}150m} = 670mm^2 / m$$

705<X: Required shear reinforcement to be evaluated according to shear force distribution in the DT.

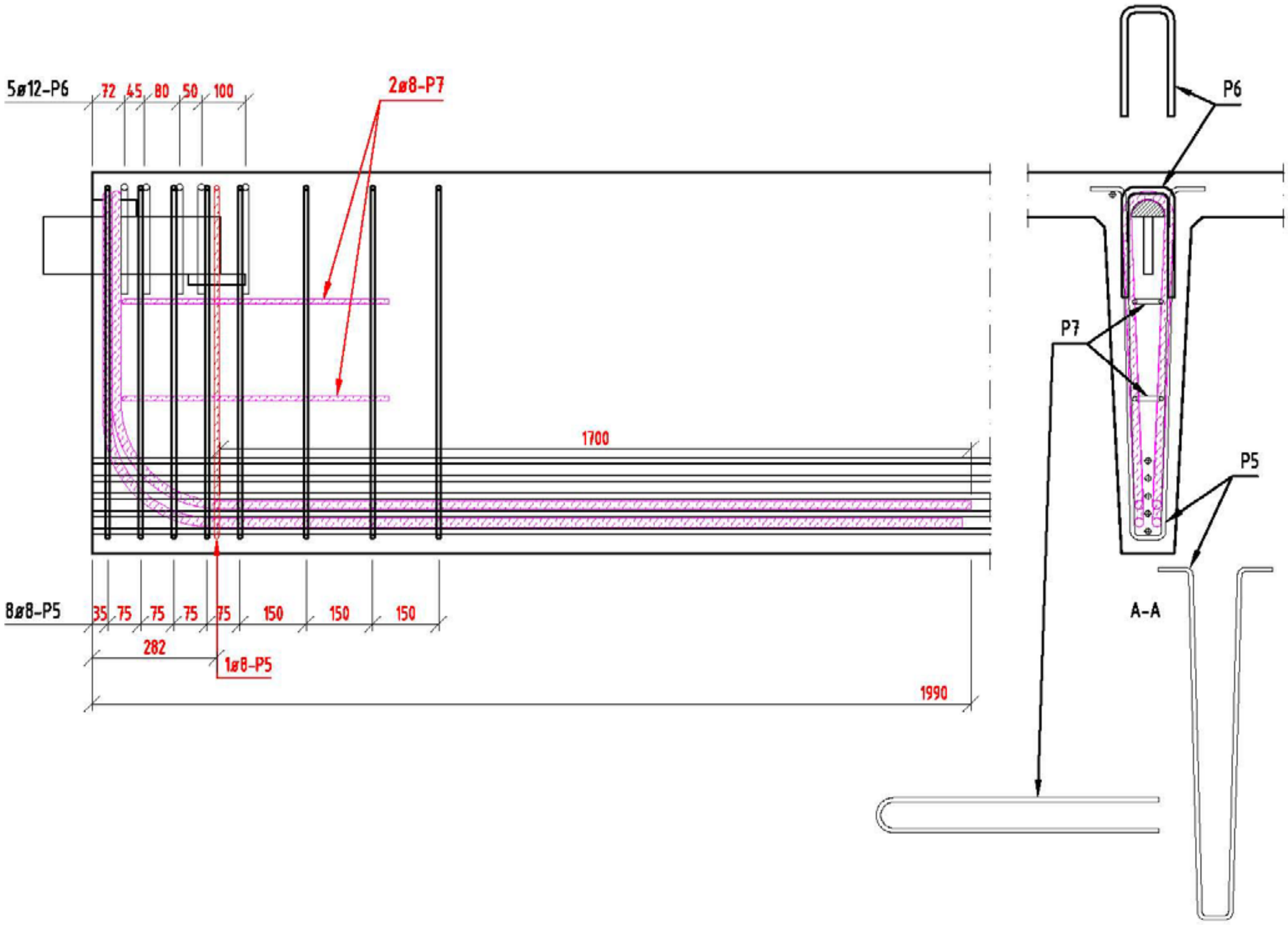
At X=282:

Required reinforcement: 210mm^2. $\Rightarrow$ 1 extra Ø8 (100mm^2) at this location. The remaining 110mm^2 can be carried by the specified distributed links.

Anchoring (7):

$\Rightarrow$ Horizontal part of Ø16 anchoring bars in front =1700mm. (Ends at x>1976mm)

Suggested reinforcement in end of the DT:



REVISION HISTORY	
Date:	**Description:**
19.09.2013	First Edition.
11.01.2016	Included revision history table. Updated reinforcement quality.
25.05.2016	New template