SECTION 6 ULTIMATE LIMIT STATES (ULS)

6.1 Bending with or without axial force

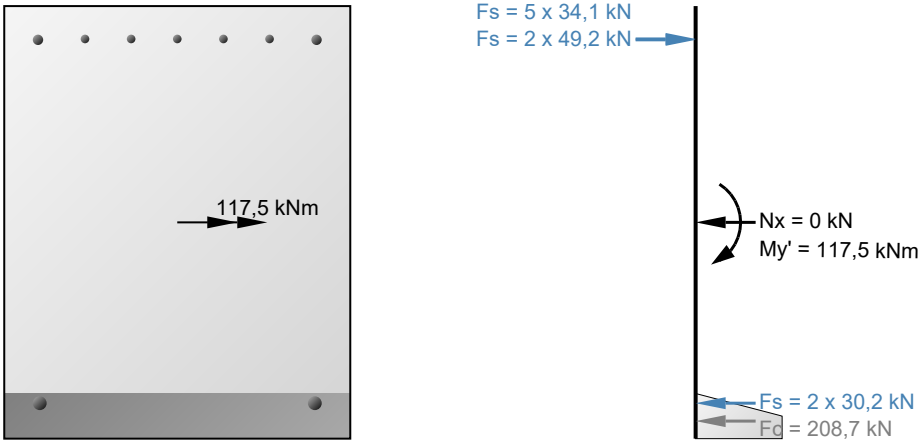
M_{Ed} (x = 2565 mm) = -103,07 kNm < M_{Rd} = -117,51 kNm (u.c.=0,88)

$$x_{u,max} = \frac{\delta - k_1}{k_2} d = \frac{1 - \frac{435}{500 + 435}}{1,00} d = 0,535 \times 461,6 = 246,9 \text{ mm} \quad ...(5.10a)$$

x_u = 52,2 mm < $x_{u;max}$ = 246,9 mm

Cross Section Calculation

εc=εcu3



Angle bending axis and neutral line α = 0,000 ^{0} ; xu = 52,2 mm; d = 461,6 mm
Centroid section y' = 0,0 z' = -250,0 (y = 0,0 z = 0,0)

y' [mm]	z' [mm]	Wap.	As [mm ^{2}]	Δε [o/oo]	σc [N/mm ^{2}]	Δσs [N/mm ^{2}]
-106,7	-38,0	1Ø10	79	27,485		434,8
-53,3	-38,0	1Ø10	79	27,485		434,8
0,0	-38,0	1Ø10	79	27,485		434,8
53,3	-38,0	1Ø10	79	27,485		434,8
106,7	-38,0	1Ø10	79	27,485		434,8
-161,0	-39,0	1Ø12	113	27,418		434,8
161,0	-39,0	1Ø12	113	27,418		434,8
-159,0	-459,0	1Ø16	201	-0,750		-150,0
159,0	-459,0	1Ø16	201	-0,750		-150,0
0,0	**-500,0**			**-3,500**	**-13,3**	

y' [mm]	z' [mm]	Fc [kN]	Fs [kN]	dy' [mm]	dz' [mm]	F [kN]	F.dy' [kNm]	F.dz' [kNm]
-106,7	-38,0		34,1	-106,7	212,0	34,1	-3,6	7,2
-53,3	-38,0		34,1	-53,3	212,0	34,1	-1,8	7,2
0,0	-38,0		34,1	0,0	212,0	34,1	0,0	7,2
53,3	-38,0		34,1	53,3	212,0	34,1	1,8	7,2
106,7	-38,0		34,1	106,7	212,0	34,1	3,6	7,2
-161,0	-39,0		49,2	-161,0	211,0	49,2	-7,9	10,4
161,0	-39,0		49,2	161,0	211,0	49,2	7,9	10,4
-159,0	-459,0		-30,2	-159,0	-209,0	-30,2	4,8	6,3
159,0	-459,0		-30,2	159,0	-209,0	-30,2	-4,8	6,3
0,0	-479,7	-208,7		0,0	-229,7	-208,7	0,0	48,0
					totaal:	0,0	0,0	117,5

6.2 Shear

Ø8-100 (2s.)

x = 2565 mm V_{Ed} = 97,12 kN T_{Ed} = 13,50 kNm

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{462}} = 1,658 \leq 2,0$$

$\rho_l = A_{sl} / (b_w\ d) = 226 /(400 \times 462) = 0,001 < 0,02$

$V_{Rd,c} = [C_{Rd,c}\ k\ (100\ \rho_l\ f_{ck})^{1/3} + k_1\ \sigma_{cp}]\ b_w\ d =$ ...(6.2.a)

$= [0,12 \times 1,658 \times (100 \times 0,001 \times 20)^{1/3} + 0,15 \times 0] \times 400 \times 462 \times 10^{-3} = 49,533$ kN

$v_{min} = 0,035\ k^{3/2}\ f_{ck}^{1/2} = 0,035 \times 1,658^{3/2} \times 20^{1/2} = 0,334$ N/mm^2 ...(6.3N)

$V_{Rd,c} = (v_{min} + k_1\ \sigma_{cp})\ b_w\ d = (0,334 + 0,15 \times 0) \times 400 \times 462 \times 10^{-3} = 61,717$ kN ...(6.2.b)

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{459}} = 1,66 \leq 2,0$$

$\rho_l = A_{sl} / (b_w\ d) = 226 /(400 \times 459) = 0,001 < 0,02$

$V_{Rd,c} = [C_{Rd,c}\ k\ (100\ \rho_l\ f_{ck})^{1/3} + k_1\ \sigma_{cp}]\ b_w\ d =$ ...(6.2.a)

$= [0,12 \times 1,66 \times (100 \times 0,001 \times 20)^{1/3} + 0,15 \times 0] \times 400 \times 459 \times 10^{-3} = 49,401$ kN

$v_{min} = 0,035\ k^{3/2}\ f_{ck}^{1/2} = 0,035 \times 1,66^{3/2} \times 20^{1/2} = 0,335$ N/mm^2 ...(6.3N)

$V_{Rd,c} = (v_{min} + k_1\ \sigma_{cp})\ b_w\ d = (0,335 + 0,15 \times 0) \times 400 \times 459 \times 10^{-3} = 61,469$ kN ...(6.2.b)

$A = b\ h = 400 \times 500 = 200000$ mm^2 $u = 2\ b + 2\ h = 2 \times 400 + 2 \times 500 = 1800$ mm

$t_{ef,i} = A / u = 200000 / 1800 = 111$ mm

$A_k = (b - ½\ t_{ef,i} - ½\ t_{ef,i})\ (h - ½\ t_{ef,i} - ½\ t_{ef,i}) =$

$= (400 - ½ \times 111 - ½ \times 111) \times (500 - ½ \times 111 - ½ \times 111) = 112346$ mm^2

$T_{Rd,c} = 2 A_k \tau_{T,i} t_{ef,i} = 2 \times 112346 \times 1,03 \times 111 = 25,753$ kNm ...(6.26)

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} = \frac{13,5}{25,753} + \frac{97,12}{61,469} = 2,10 > 1,00$$ ...(6.31)

$$\nu = 0,6 \left[1 - \frac{f_{ck}}{250} \right] = 0,6 \times \left[1 - \frac{20}{250} \right] = 0,552$$ ...(6.6N)

$V_{Rd,max} = \alpha_{cw} b_w z \nu_1 f_{cd} / (\cot\theta + \tan\theta)$ ...(6.9)

$= 1 \times 400 \times 413 \times 0,6 \times 13,3 / (1,192 + 0,839) = 650,92$ kN

$$\nu = 0,6 \left[1 - \frac{f_{ck}}{250} \right] = 0,6 \times \left[1 - \frac{20}{250} \right] = 0,552$$ ...(6.6N)

$T_{Rd,max} = 2 \nu_1 \alpha_{cw} f_{cd} A_k t_{ef,i} \sin\theta \cos\theta$ ...(6.30)

$= 2 \times 0,55 \times 1 \times 13,333 \times 112346 \times 111,1 \times 0,643 \times 0,766 = 90,478$ kNm

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} = \frac{13,5}{90,478} + \frac{97,12}{650,919} = 0,30 < 1,00$$ ...(6.29)

$$\frac{A_{sw}}{s} = \frac{V_{Ed}}{f_{ywd} z \cot\theta} = \frac{97 \times 10^3}{435 \times 413 \times 1,192} = 0,454 \text{ mm}^2/\text{mm}$$ ...(6.8)

$$\frac{A_{sw}}{s} = \frac{T_{Ed} \tan\theta}{2 b_1 h_1 f_{ywd}} = \frac{13 \times 0,839}{2 \times 289 \times 389 \times 435} = 0,116 \text{ mm}^2/\text{mm}$$

$$A_{s,l} = \frac{T_{Ed} \cot\theta u_k}{f_{ywd} 2 A_k} = \frac{13 \times 1,192 \times 1356}{435 \times 2 \times 112346} = 223 \text{ mm}^2$$ ...(6.28)

AswV = 0,227 mm2/mm AsT = 0,116 mm2/mm Asw_ben = 0,343 mm2/mm

Asw_ben = 0,343 mm2/mm < Asw_aanw = 0,503 mm2/mm

SECTION 7 SERVICEABILITY LIMIT STATES (SLS)

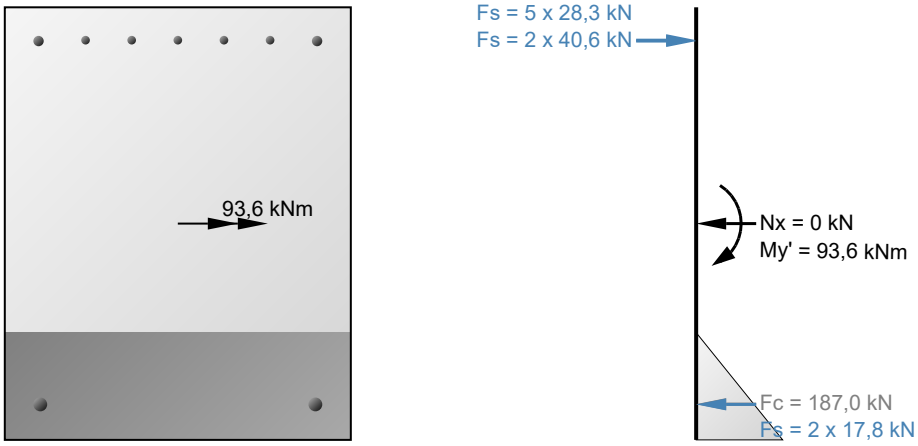
7.3.3 Control of cracking without direct calculation

M_k (x = 2565 mm) = -77,82 kNm < M_{Rk} = -93,56 kNm (u.c.=0,83)

$\sigma_s = 360$ N/mm^2 $w_k = 0,5$ mm $\rightarrow$ $s_{max} = 100$ mm ...(Tabel 7.3N)

$s_{prov} = 54,3$ mm $\leq s_{max} = 100$ mm

Cross Section Calculation



Angle bending axis and neutral line α = 0,000 ^{0} ; xu = 124,0 mm; d = 461,6 mm
Centroid section y' = 0,0 z' = -250,0 (y = 0,0 z = 0,0)

y' [mm]	z' [mm]	Wap.	As [mm ^{2}]	Δε [o/oo]	σc [N/mm ^{2}]	Δσs [N/mm ^{2}]
-106,7	**-38,0**	1Ø10	79	**1,800**		**360,0**
-53,3	**-38,0**	1Ø10	79	**1,800**		**360,0**
0,0	**-38,0**	1Ø10	79	**1,800**		**360,0**
53,3	**-38,0**	1Ø10	79	**1,800**		**360,0**
106,7	**-38,0**	1Ø10	79	**1,800**		**360,0**
-161,0	-39,0	1Ø12	113	1,795		358,9
161,0	-39,0	1Ø12	113	1,795		358,9
-159,0	-459,0	1Ø16	201	-0,442		-88,4
159,0	-459,0	1Ø16	201	-0,442		-88,4
0,0	-500,0			-0,660	-7,5	

y' [mm]	z' [mm]	Fc [kN]	Fs [kN]	dy' [mm]	dz' [mm]	F [kN]	F.dy' [kNm]	F.dz' [kNm]
-106,7	-38,0		28,3	-106,7	212,0	28,3	-3,0	6,0
-53,3	-38,0		28,3	-53,3	212,0	28,3	-1,5	6,0
0,0	-38,0		28,3	0,0	212,0	28,3	0,0	6,0
53,3	-38,0		28,3	53,3	212,0	28,3	1,5	6,0
106,7	-38,0		28,3	106,7	212,0	28,3	3,0	6,0
-161,0	-39,0		40,6	-161,0	211,0	40,6	-6,5	8,6
161,0	-39,0		40,6	161,0	211,0	40,6	6,5	8,6
-159,0	-459,0		-17,8	-159,0	-209,0	-17,8	2,8	3,7
159,0	-459,0		-17,8	159,0	-209,0	-17,8	-2,8	3,7
0,0	-458,7	-187,0		0,0	-208,7	-187,0	0,0	39,0
					totaal:	0,0	0,0	93,6