SECTION 6 ULTIMATE LIMIT STATES (ULS)

6.1 Bending with or without axial force

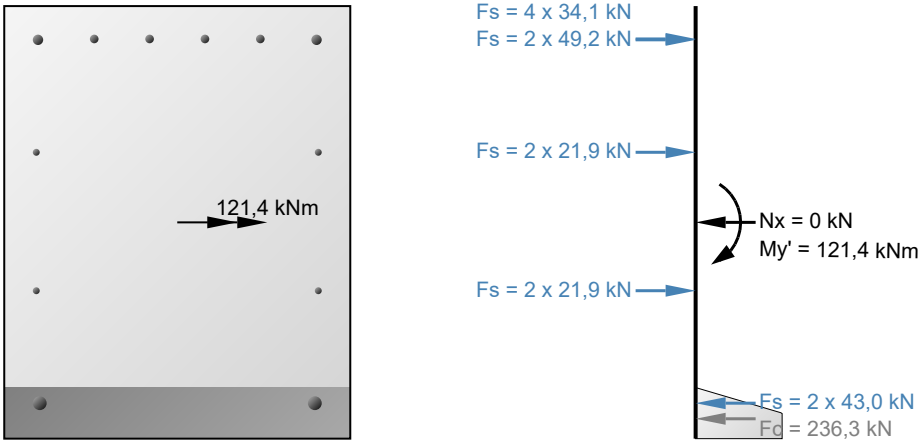
M_{Ed} (x = 2534 mm) = -103,07 kNm < M_{Rd} = -121,43 kNm (u.c.=0,85)

$$x_{u,max} = \frac{\delta - k_1}{k_2} d = \frac{1 - \frac{435}{500 + 435}}{1,00} d = 0,535 \times 404,5 = 216,3 \text{ mm} \quad ...(5.10a)$$

x_u = 59,1 mm < $x_{u;max}$ = 216,3 mm

Cross Section Calculation

εc=εcu3



Angle bending axis and neutral line α = 0,000 ^{0} ; xu = 59,1 mm; d = 404,5 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}]
-96,0	-38,0	1Ø10	79	23,876		434,8
-32,0	-38,0	1Ø10	79	23,876		434,8
32,0	-38,0	1Ø10	79	23,876		434,8
96,0	-38,0	1Ø10	79	23,876		434,8
-161,0	-39,0	1Ø12	113	23,817		434,8
161,0	-39,0	1Ø12	113	23,817		434,8
-163,0	-169,0	1Ø8	50	16,114		434,8
163,0	-169,0	1Ø8	50	16,114		434,8
-163,0	-329,0	1Ø8	50	6,633		434,8
163,0	-329,0	1Ø8	50	6,633		434,8
-159,0	-459,0	1Ø16	201	-1,070		-214,1
159,0	-459,0	1Ø16	201	-1,070		-214,1
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]
-96,0	-38,0		34,1	-96,0	212,0	34,1	-3,3	7,2
-32,0	-38,0		34,1	-32,0	212,0	34,1	-1,1	7,2
32,0	-38,0		34,1	32,0	212,0	34,1	1,1	7,2
96,0	-38,0		34,1	96,0	212,0	34,1	3,3	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
-163,0	-169,0		21,9	-163,0	81,0	21,9	-3,6	1,8
163,0	-169,0		21,9	163,0	81,0	21,9	3,6	1,8
-163,0	-329,0		21,9	-163,0	-79,0	21,9	-3,6	-1,7
163,0	-329,0		21,9	163,0	-79,0	21,9	3,6	-1,7
-159,0	-459,0		-43,0	-159,0	-209,0	-43,0	6,8	9,0
159,0	-459,0		-43,0	159,0	-209,0	-43,0	-6,8	9,0
0,0	-477,0	-236,3		0,0	-227,0	-236,3	0,0	53,6
					totaal:	0,0	0,0	121,4

6.2 Shear

Ø8-100 (2s.)

x = 2534 mm V_{Ed} = 97,12 kN T_{Ed} = 13,50 kNm

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{441}} = 1,673 \leq 2,0$$

$\rho_l = A_{sl} / (b_w\ d) = 226 /(400 \times 441) = 0,001 < 0,02$

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

$= [0,12 \times 1,673 \times (100 \times 0,001 \times 20)^{1/3} + 0,15 \times 0] \times 400 \times 441 \times 10^{-3} = 48,492$ kN

$v_{min} = 0,035\ k^{3/2}\ f_{ck}^{1/2} = 0,035 \times 1,673^{3/2} \times 20^{1/2} = 0,339$ N/mm ^{2} ...(6.3N)

$V_{Rd,c} = (v_{min} + k_1\ \sigma_{cp})\ b_w\ d = (0,339 + 0,15 \times 0) \times 400 \times 441 \times 10^{-3} = 59,781$ kN ...(6.2.b)

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{329}} = 1,78 \leq 2,0$$

$\rho_l = A_{sl} / (b_w\ d) = 226 /(400 \times 329) = 0,002 < 0,02$

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

$= [0,12 \times 1,78 \times (100 \times 0,002 \times 20)^{1/3} + 0,15 \times 0] \times 400 \times 329 \times 10^{-3} = 42,416$ kN

$v_{min} = 0,035\ k^{3/2}\ f_{ck}^{1/2} = 0,035 \times 1,78^{3/2} \times 20^{1/2} = 0,372$ N/mm ^{2} ...(6.3N)

$V_{Rd,c} = (v_{min} + k_1\ \sigma_{cp})\ b_w\ d = (0,372 + 0,15 \times 0) \times 400 \times 329 \times 10^{-3} = 48,905$ 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

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

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

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

$$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} = \frac{13,5}{25,753} + \frac{97,12}{48,905} = 2,51 > 1,00$$ ...(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)

$= 1 \times 400 \times 296 \times 0,6 \times 13,3 / (1,192 + 0,839) = 466,56 \text{ kN}$

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

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

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

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} = \frac{13,5}{90,478} + \frac{97,12}{466,563} = 0,36 < 1,00$$ ...(6.29)

$$\frac{A_{sw}}{s} = \frac{V_{Ed}}{f_{ywd} z \cot\theta} = \frac{97 \times 10^3}{435 \times 296 \times 1,192} = 0,633 \text{ mm}^2/\text{mm}$$ ...(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 = 0,317 mm2/mm AsT = 0,116 mm2/mm Asw_ben = 0,432 mm2/mm

Asw_ben = 0,432 mm2/mm < Asw_aanw = 0,503 mm2/mm

SECTION 7 SERVICEABILITY LIMIT STATES (SLS)

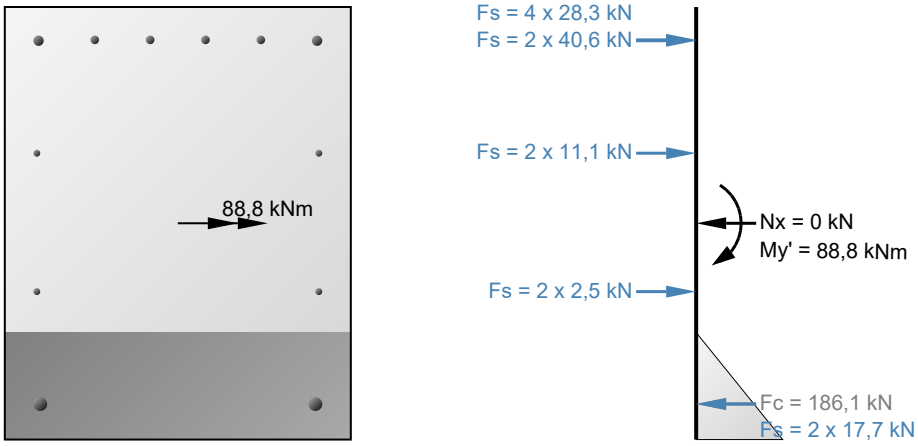
7.3.3 Control of cracking without direct calculation

M_k (x = 2534 mm) = -77,82 kNm < M_{Rk} = -88,76 kNm (u.c.=0,88)

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

s_{prov} = 65 mm ≤ s_{max} = 100 mm

Cross Section Calculation



Angle bending axis and neutral line α = 0,000 ^{0}; xu = 123,7 mm; d = 441,9 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}]
-96,0	**-38,0**	1Ø10	79	**1,800**		**360,0**
-32,0	**-38,0**	1Ø10	79	**1,800**		**360,0**
32,0	**-38,0**	1Ø10	79	**1,800**		**360,0**
96,0	**-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
-163,0	-169,0	1Ø8	50	1,103		220,6
163,0	-169,0	1Ø8	50	1,103		220,6
-163,0	-329,0	1Ø8	50	0,252		50,3
163,0	-329,0	1Ø8	50	0,252		50,3
-159,0	-459,0	1Ø16	201	-0,440		-88,0
159,0	-459,0	1Ø16	201	-0,440		-88,0
0,0	-500,0			-0,658	-7,5	

y' [mm]	z' [mm]	Fc [kN]	Fs [kN]	dy' [mm]	dz' [mm]	F [kN]	F.dy' [kNm]	F.dz' [kNm]
-96,0	-38,0		28,3	-96,0	212,0	28,3	-2,7	6,0
-32,0	-38,0		28,3	-32,0	212,0	28,3	-0,9	6,0
32,0	-38,0		28,3	32,0	212,0	28,3	0,9	6,0
96,0	-38,0		28,3	96,0	212,0	28,3	2,7	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
-163,0	-169,0		11,1	-163,0	81,0	11,1	-1,8	0,9
163,0	-169,0		11,1	163,0	81,0	11,1	1,8	0,9
-163,0	-329,0		2,5	-163,0	-79,0	2,5	-0,4	-0,2
163,0	-329,0		2,5	163,0	-79,0	2,5	0,4	-0,2
-159,0	-459,0		-17,7	-159,0	-209,0	-17,7	2,8	3,7
159,0	-459,0		-17,7	159,0	-209,0	-17,7	-2,8	3,7
0,0	-458,8	-186,1		0,0	-208,8	-186,1	0,0	38,9
					totaal:	0,0	0,0	88,8