Reinforced concrete beam

Structural members: **160 ,299 ,488 ,164**

Code: **Eurocode**

Load case: **Linear,(Auto) Critical**

Materials

Concrete: **C25/30** (f_{ck} = 25 MPa)

Rebar steel:

Longitudinal rebars: **B500A** (f_{yk} = 500 MPa)

Stirrup: **B500A** (f_{ywk} = 500 MPa)

Reinforcement parameters

Concrete covers: c = 1,5 cm

Top longitudinal rebars: ϕ_T = 16 mm ($A_{\phi,T}$ = 2,01 cm²)

Bottom longitudinal rebars: ϕ_B = 16 mm ($A_{\phi,B}$ = 2,01 cm²)

Top corner rebars: $\phi_{c,T}$ = 16 mm ($A_{\phi,c,T}$ = 2,01 cm²)

Bottom corner rebars: $\phi_{c,B}$ = 16 mm ($A_{\phi,c,B}$ = 2,01 cm²)

Side reinforcement against torsion: ϕ_T = 16 mm ($A_{\phi T}$ = 2,01 cm²)

Stirrup diameter: ϕ_w = 8 mm ($A_{\phi w}$ = 0,50 cm²)

Stirrup legs: $n_{\phi,w}$ = 2

Angle of the concrete compression strut: Θ = 45,00 ° ($\cot\Theta$ = 1)

Rebar position:

$$a_T = c + \phi_w + \frac{\phi_T}{2} = 1{,}5 + 0{,}8 + \frac{1{,}6}{2} = 3{,}1 \text{ cm}$$

$$a_B = c + \phi_w + \frac{\phi_B}{2} = 1{,}5 + 0{,}8 + \frac{1{,}6}{2} = 3{,}1 \text{ cm}$$

$$a_{cT} = c + \phi_w + \frac{\phi_{c,T}}{2} = 1{,}5 + 0{,}8 + \frac{1{,}6}{2} = 3{,}1 \text{ cm}$$

$$a_{cB} = c + \phi_w + \frac{\phi_{c,B}}{2} = 1{,}5 + 0{,}8 + \frac{1{,}6}{2} = 3{,}1 \text{ cm}$$

1. ULS (Ultimate Limit State)

Design parameters

Design situation: **Persistent and transient**

$$f_{cd} = \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_c} = 1 \cdot \frac{25}{1{,}5} = 16{,}667 \text{ MPa} = 1{,}66667 \cdot 10^4 \text{ KPa}$$ EN 1992-1-1 3.1.6. (1)P (3.15)

$$f_{cd,eff} = f_{cd} \cdot \eta = 1{,}66667 \cdot 10^4 \cdot 1 = 1{,}66667 \cdot 10^4 \text{ KPa}$$ EN 1992-1-1 3.1.7. (3)

$$f_{ctd} = \alpha_{ct} \cdot \frac{f_{ctk,0.05}}{\gamma_c} = 1 \cdot \frac{1{,}7955}{1{,}5} = 1{,}197 \text{ MPa} = 1197 \text{ KPa}$$ EN 1992-1-1 3.1.6. (2)P (3.16)

$$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1{,}15} = 434{,}78 \approx 435 \text{ MPa} = 4{,}35 \cdot 10^5 \text{ KPa}$$ EN 1992-1-1 3.2.7. (2) Fig. 3.8

$$f_{ywd} = \frac{f_{ywk}}{\gamma_s} = \frac{500}{1{,}15} = 434{,}78 \approx 435 \text{ MPa} = 4{,}35 \cdot 10^5 \text{ KPa}$$ EN 1992-1-1 3.2.7. (2) Fig. 3.8

1.1. Bending

Maximum tension reinforcement at the top

Position of the cross-section from the left end of the beam: cs_{pos} = 0 m

Load case/Combination: **[1,35*rc+1,35*covering+1,35*plumbing+1,35*wall+1,35*stair permanent] {1,5*0,7*variable inner+1,5*0,7*variable outer+1,5*0,7*stair variable} (1,5*0,5*snow+1,5*0,6*wind -y)**

Geometry

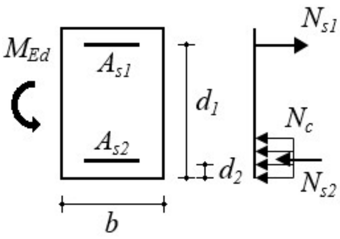
Depth of the cross-section: h = 39,0 cm

Width of the cross-section: b_w = 30,0 cm

Internal forces

M_{Ed} = 14,63 kNm

Design of bending reinforcement



Equilibrium equations for the cross-section

$$\sum N = 0 \rightarrow N_c + N_{s2} - N_{s1} = f_{cd} \cdot x_c \cdot b + A_{s2} \cdot |\sigma_{s2}| - A_{s1} \cdot \sigma_{s2} = 0$$

$$\sum M = 0 \rightarrow N_c \cdot z + N_{s2} \cdot z_s = f_{cd} \cdot x_c \cdot b \cdot \left(d_1 - \frac{x_c}{2}\right) + A_{s2} \cdot |\sigma_{s2}| \cdot z_s = M_{Ed}$$

Partial results

Effective depth:

d = 35,9 cm

Maximum pure moment resistance without compression reinforcement:

Maximum neutral axis depth:

$$\varepsilon_s = \frac{f_{yd}}{E_s}$$

$$x_0 = \frac{\varepsilon_{cu}}{\varepsilon_{cu} - \frac{f_{yd}}{E_s}} \cdot d = \frac{(-0{,}0035)}{(-0{,}0035) - \frac{4{,}35 \cdot 10^5}{2 \cdot 10^8}} \cdot 35{,}9 = 22{,}14 \text{ cm}$$

$$x_{c0} = \lambda \cdot x_0 = 0{,}8 \cdot 22{,}14 = 17{,}71 \text{ cm}$$ EN 1992-1-1 3.1.7. (3) Fig. 3.5.

$$M_{Rd,x0} = \left(d - \frac{x_{c0}}{2}\right) \cdot x_{c0} \cdot b_w \cdot f_{cd,eff} = \left(35{,}9 - \frac{17{,}71}{2}\right) \cdot 17{,}71 \cdot 30{,}0 \cdot 1{,}66667 \cdot 10^4 = 240 \text{ kNm} > M_{Ed} = 14{,}63 \text{ kNm}$$

Height of concrete compression zone:

x_c = 0,8245 cm

Calculated area of flexural reinforcement in tension:

$A_{s,1}$ = 1,436 cm² ($A_{s,min}$ = 1,44 cm²)

Maximum tension reinforcement at the bottom

Position of the cross-section from the left end of the beam: cs_{pos} = 2,500 m

Load case/Combination: **[1,35*rc+1,35*covering+1,35*plumbing+1,35*wall+1,35*stair permanent] {1,5*0,7*variable inner+1,5*0,7*variable outer+1,5*0,7*stair variable} (1,5*0,5*snow+1,5*0,6*wind -y)**

Geometry

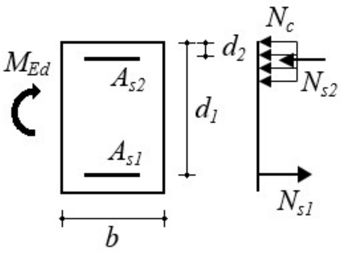
Depth of the cross-section: h = 39,0 cm

Width of the cross-section: b_w = 30,0 cm

Internal forces

M_{Ed} = 45,16 kNm

Design of bending reinforcement



Equilibrium equations for the cross-section

$$\sum N=0 \rightarrow N_c+N_{s2}-N_{s1}=f_{cd}\cdot x_c\cdot b+A_{s2}\cdot|\sigma_{s2}|-A_{s1}\cdot\sigma_{s2}=0$$

$$\sum M=0 \rightarrow N_c\cdot z+N_{s2}\cdot z_s=f_{cd}\cdot x_c\cdot b\cdot\left(d_1-\frac{x_c}{2}\right)+A_{s2}\cdot|\sigma_{s2}|\cdot z_s=M_{Ed}$$

Partial results

Effective depth:

d = 35,9 cm

Maximum pure moment resistance without compression reinforcement:

Maximum neutral axis depth:

$$\varepsilon_s = \frac{f_{yd}}{E_s}$$

$$x_0=\frac{\varepsilon_{cu}}{\varepsilon_{cu}-\frac{f_{yd}}{E_s}}\cdot d=\frac{(-0{,}0035)}{(-0{,}0035)-\frac{4{,}35\cdot 10^5}{2\cdot 10^8}}\cdot 35{,}9=22{,}14 \text{ cm}$$

$x_{c0}=\lambda\cdot x_0=0{,}8\cdot 22{,}14=17{,}71$ cm EN 1992-1-1 3.1.7. (3) Fig. 3.5.

$$M_{Rd,x0}=\left(d-\frac{x_{c0}}{2}\right)\cdot x_{c0}\cdot b_w\cdot f_{cd,eff}=\left(35{,}9-\frac{17{,}71}{2}\right)\cdot 17{,}71\cdot 30{,}0\cdot 1{,}66667\cdot 10^4=240 \text{ kNm} > M_{Ed} = 45{,}16 \text{ kNm}$$

Height of concrete compression zone:

x_c = 2,611 cm

Calculated area of flexural reinforcement in tension:

$A_{s,1}$ = 3,032 cm² ($A_{s,min}$ = 1,44 cm²)

1.2. Shear-Torsion

Position of the cross-section from the left end of the beam: 6,205 m

Load case/Combination: **[1,35*rc+1,35*covering+1,35*plumbing+1,35*wall+1,35*stair permanent] {1,5*0,7*variable inner+1,5*0,7*variable outer+1,5*0,7*stair variable} (1,5*0,5*snow+1,5*0,6*wind +y)**

Geometry

Depth of the cross-section: h = 39,0 cm

Width of the cross-section: b_w = 30,0 cm

Internal forces

M_{Ed} = 6,82 kNm V_{Ed} = 46,92 kN $V_{Ed,red}$ = 36,72 kN T_{Ed} = 3,60 kNm

The design shear resistance of the member without shear reinforcement: EN 1992-1-1 6.2.2. (1)

$V_{Rd,c,min} = (v_{min} + k_1 \cdot \sigma_{cp}) \cdot b_w \cdot d = (0{,}40388 + 0{,}15 \cdot 0) \cdot 30{,}0 \cdot 35{,}9 = 43{,}50$ kN (6.2.b)

$V_{Rd,c} = \left(C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{(1/3)} + k_1 \cdot \sigma_{cp}\right) \cdot b_w \cdot d = (0{,}12 \cdot 1{,}7464 \cdot (100 \cdot 0{,}0013338 \cdot 25)^{(1/3)} + 0{,}15 \cdot 0) \cdot 30{,}0 \cdot 35{,}9 = 33{,}72$ kN $<$ $V_{Rd,c,min}$ = 43,50 kN $\rightarrow$ $V_{Rd,c} = V_{Rd,c,min}$ = 43,50 kN

The torsional cracking moment:

$T_{Rd,c} = f_{ctd} \cdot t_{efi} \cdot 2 \cdot A_k = 1197 \cdot 8{,}478 \cdot 2 \cdot 656{,}9 = 13{,}33$ kNm EN 1992-1-1 6.3.2. (5)

The shear/torsional efficiency of concrete cross-section without design shear/torsional reinforcement:

$\frac{T_{Ed}}{T_{Rd,c}} + \frac{V_{Ed}}{V_{Rd,c}} = \frac{3{,}60}{13{,}33} + \frac{46{,}92}{43{,}50} = 1{,}3486$ EN 1992-1-1 6.3.2. (6.31) > 1 ‼

Shear / torsional reinforcement is required.

$\cot\Theta_{min} = 1 \leq \cot\Theta \leq \cot\Theta_{max} = 2{,}5$

The calculated spacing of the stirrups: EN 1992-1-1 (6.8.) (6.26) (6.27)

$$s = \frac{A_{s,w}}{V_{Ed,red} + 2 \cdot \frac{T_{Ed}}{2 \cdot A_k}} \cdot z \cdot f_{ywd} \cdot \cot\Theta = \frac{1{,}01}{36{,}72 + 2 \cdot \frac{3{,}60}{2 \cdot 656{,}9}} \cdot 32{,}3 \cdot 4{,}35 \cdot 10^5 \cdot \cot 45{,}00° = 38{,}46 \text{ cm} \rightarrow s = 35 \text{ cm}$$

Checking detailing rules for stirrups:

$\rho_w = \frac{A_{s,w}}{s \cdot b_w \cdot \sin\alpha} = \frac{1{,}01}{35 \cdot 30{,}0 \cdot \sin 90{,}00°} = 0{,}00095744 = 0{,}957$ ‰ EN 1992-1-1 9.2.2. (5) (9.4)

$\rho_{w,min} = 0{,}08 \cdot \frac{\sqrt{f_{ck}}}{f_{ywk}} = 0{,}08 \cdot \frac{\sqrt{25}}{500} = 0{,}0008 = 0{,}800$ ‰ EN 1992-1-1 9.2.2. (5) (9.5N)

ρ_w = 0,957 ‰ > $\rho_{w,min}$ = 0,800 ‰ ✔

$s_{clear,min} = \max(k_1 \cdot \phi_w ; d_g + k_2 ; k_3) = \max(1 \cdot 0{,}8 ; 1{,}6 + 0{,}5 ; 2) = 2{,}1$ cm EN 1992-1-1 8.2. (2)

$s_{clear} = s - \phi_w = 35 - 0{,}8 = 34{,}2$ cm > $s_{clear,min}$ = 2,1 cm ✔

$s_{l,max} = 0{,}75 \cdot d \cdot (1 + \cot\alpha) = 0{,}75 \cdot 35{,}9 \cdot (1 + \cot 90{,}00°) = 26{,}92$ cm EN 1992-1-1 9.2.2.1. (6) (9.6N)

s = 35 cm > $s_{l,max}$ = 26,92 cm ✗ $s = s_{l,max}$ = 26,92 cm $\rightarrow$ s = 25 cm

The design value of shear resistance:

$$V_{Rd,max} = \frac{\alpha_{cw} \cdot b_w \cdot z \cdot v_1 \cdot f_{cd}}{\cot\Theta + \tan\Theta} = \frac{1 \cdot 30{,}0 \cdot 32{,}3 \cdot 0{,}54 \cdot 1{,}66667 \cdot 10^4}{\cot 45{,}00° + \tan 45{,}00°} = 436{,}05 \text{ kN}$$ EN 1992-1-1 (6.9.)

The design torsional resistance moment based on the capacity of concrete struts:

$$T_{Rd,max} = 2 \cdot v \cdot \alpha_{cw} \cdot f_{cd} \cdot A_k \cdot t_{efi} \cdot \sin\Theta \cdot \cos\Theta = 2 \cdot 0{,}54 \cdot 1 \cdot 1{,}66667 \cdot 10^4 \cdot 656{,}9 \cdot 8{,}478 \cdot \sin 45{,}00° \cdot \cos 45{,}00° = 50{,}12 \text{ kNm}$$
EN 1992-1-1 (6.30)

Utilization of concrete compression struts: EN 1992-1-1 (6.29)

$$\frac{T_{Ed}}{T_{Rd,max}} + \frac{V_{Ed}}{V_{Rd,max}} = \frac{3{,}60}{50{,}12} + \frac{46{,}92}{436{,}05} = 0{,}17941 \;<\; 1 \text{ passed}$$

The resistance of the compressed concrete struts is satisfactory.

1.3. Additional longitudinal reinforcement for torsion

Position of the cross-section from the left end of the beam: $cs_{pos} = 5{,}900$ m

Geometry

Depth of the cross-section: $h = 39{,}0$ cm
Width of the cross-section: $b_w = 30{,}0$ cm

Load case/Combination: **[1,35*rc+1,35*covering+1,35*plumbing+1,35*wall+1,35*stair permanent] {1,5*0,7*variable outer+1,5*0,7*stair variable} (1,5*0,5*snow+1,5*0,6*wind +y)**

Internal forces

$M_{Ed} = 6{,}02$ kNm $T_{Ed} = 6{,}35$ kNm

Calculate reinforcement

The required cross-sectional area of the longitudinal reinforcement for torsion:

$$\Sigma A_{sl} = \frac{T_{Ed}}{2 \cdot A_k} \cdot \cot\Theta \cdot \frac{u_k}{f_{yd}} = \frac{6{,}35}{2 \cdot 656{,}9} \cdot \cot 45{,}00° \cdot \frac{104{,}1}{4{,}35 \cdot 10^5} = 1{,}157 \text{ cm}^2$$ EN 1992-1-1 (6.28)

The cross-section area of torsion reinforcement in tensioned and comporessive chords:

$$\Delta A_{s,l,T} = \frac{\Sigma A_{sl}}{2} = \frac{1{,}157}{2} = 0{,}5784 \text{ cm}^2$$

2. SLS (Serviceability Limit State)

Design parameters

Design situation: **SLS (Serviceability Limit State)**

$$f_{cd} = \alpha_{cc} \cdot \frac{f_{ck}}{\gamma_c} = 1 \cdot \frac{25}{1} = 25 \text{ MPa} = 2{,}5 \cdot 10^4 \text{ KPa}$$ EN 1992-1-1 3.1.6. (1)P (3.15)

Creep factor: $\varphi(\infty, t_0) = 2$ EN 1992-1-1 7.4.3. (5) (7.20) NOTE

$$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{500}{1} = 500 = 5 \cdot 10^5 \text{ KPa}$$ EN 1992-1-1 3.2.7. (2) Fig. 3.8

2.1. Crack control

Parameters EN 1992-1-1 7.3.4. (2)

2.1.1 Limiting crack width (top)

Position of the cross-section from the left end of the beam: cs_{pos} = 0 m

Load case/Combination: **[rc+covering+plumbing+wall+stair permanent] {0,3*variable inner+0,3*variable outer}**

Internal forces

M_{Ed} = 9,62 kNm

Geometry

Depth of the cross-section: h = 39,0 cm

Width of the cross-section: b_w = 30,0 cm

Longitudinal rebars:

Top reinforcement: $2\phi 16 \quad (4{,}02 cm^2)$

Bottom reinforcement: $2\phi 16 \quad (4{,}02 cm^2)$

The area of concrete cross section:

$A_c = b_w \cdot h = 30{,}0 \cdot 39{,}0 = 1170$ cm²

Distance of the center of gravity of the concrete cross-section from the top:

$$y_{s,c} = \frac{S_{x,c}}{A_c} = \frac{22815}{1170} = 19{,}5 \text{ cm}$$

Uncracked cross-secton (1st stress state)

Neutral axis depth from the top in uncracked state:

$$x_I = \frac{S_{x,c} + S_{x,s} \cdot (\alpha_e - 1)}{A_c + \Sigma A_s \cdot (\alpha_e - 1)} = \frac{22815 + 156{,}83 \cdot (6{,}3541 - 1)}{1170 + 8{,}042 \cdot (6{,}3541 - 1)} = 19{,}5 \text{ cm}$$

The second moment of area of the uncracked concrete cross-section:

$$I_I = I_{I,c} + I_{I,s} \cdot (\alpha_e - 1) = 148297 + 2163{,}1 \cdot (6{,}3541 - 1) = 159879 \text{ cm}^4$$

Cracked elastic cross-section (2nd stress state)

Neutral axis depth from the top in cracked elastic state: $\rightarrow x_{II1}$ = 6,681 cm ; x_{II2} = −9,82 cm

x_{II} = 6,681 cm

The second moment of area of the cracked elastic concrete cross-section:

$$I_{II} = I_{II,c} + I_{II,st} \cdot \alpha_e + I_{II,sc} \cdot (\alpha_e - 1) = 2981{,}83 + 3433{,}18 \cdot 6{,}3541 + 51{,}5605 \cdot (6{,}3541 - 1) = 25072{,}6 \text{ cm}^4$$

Cracking moment:

$$M_{cr} = \frac{I_I}{h - x_I} \cdot f_{ct,eff} = \frac{0{,}0016}{0{,}39 - 0{,}19} \cdot 2565 = 21{,}03 \text{ kNm} > M_{Ed} = 9{,}62 \text{ kNm}$$

The beam is uncracked.

2.1.2 Limiting crack width (bottom)

Position of the cross-section from the left end of the beam: cs_{pos} = 4,996 m

Load case/Combination: **[rc+covering+plumbing+wall+stair permanent] {0,3*variable inner+0,3*variable outer+0,3*stair variable}**

Internal forces

$M_{Ed} = 21{,}80$ kNm

Geometry

Depth of the cross-section: $h = 39{,}0$ cm

Width of the cross-section: $b_w = 30{,}0$ cm

Longitudinal rebars:

Top reinforcement: $2\phi16 \quad (4{,}02cm^2)$

Bottom reinforcement: $2\phi16 \quad (4{,}02cm^2)$

The area of concrete cross section:

$A_c = b_w \cdot h = 30{,}0 \cdot 39{,}0 = 1170$ cm²

Distance of the center of gravity of the concrete cross-section from the top:

$$y_{s,c} = \frac{S_{x,c}}{A_c} = \frac{22815}{1170} = 19{,}5 \text{ cm}$$

Uncracked cross-secton (1st stress state)

Neutral axis depth from the top in uncracked state:

$$x_I = \frac{S_{x,c} + S_{x,s} \cdot (\alpha_e - 1)}{A_c + \Sigma A_s \cdot (\alpha_e - 1)} = \frac{22815 + 156{,}83 \cdot (6{,}3541 - 1)}{1170 + 8{,}042 \cdot (6{,}3541 - 1)} = 19{,}5 \text{ cm}$$

The second moment of area of the uncracked concrete cross-section:

$I_I = I_{I,c} + I_{I,s} \cdot (\alpha_e - 1) = 148297 + 2163{,}1 \cdot (6{,}3541 - 1) = 159879$ cm⁴

Cracked elastic cross-section (2nd stress state)

Neutral axis depth from the top in cracked elastic state: $\rightarrow x_{II1} = 6{,}681$ cm ; $x_{II2} = -9{,}82$ cm

$x_{II} = 6{,}681$ cm

The second moment of area of the cracked elastic concrete cross-section:

$I_{II} = I_{II,c} + I_{II,st} \cdot \alpha_e + I_{II,sc} \cdot (\alpha_e - 1) = 2981{,}83 + 3433{,}18 \cdot 6{,}3541 + 51{,}5605 \cdot (6{,}3541 - 1) = 25072{,}6$ cm⁴

Cracking moment:

$$M_{cr} = \frac{I_I}{h - x_I} \cdot f_{ct,eff} = \frac{0{,}0016}{0{,}39 - 0{,}19} \cdot 2565 = 21{,}03 \text{ kNm} < M_{Ed} = 21{,}80 \text{ kNm}$$ The beam is cracked.

The moment resistance in elastic cracked state:

$$M_{Rd,II} = \frac{I_{II}}{x_{II}} \cdot E_{cm} \cdot \varepsilon_{c,max} = \frac{0{,}00025}{0{,}067} \cdot 3{,}14758 \cdot 10^7 \cdot 0{,}00057161 = 67{,}52 \text{ kNm} > M_{Ed} = 21{,}80 \text{ kNm}$$ The cross section is elastic.

Concrete cover of the longitudinal reinforcement:

$c_\phi = c + \phi_w = 1{,}5 + 0{,}8 = 2{,}3$ cm

The spacing of the bonded reinforcement within the tension zone:

$$s_{br,tz} = \frac{b_w - 2 \cdot \left(c + \phi_w + \frac{\phi_{c,B}}{2}\right)}{n_1 - 1} = \frac{30{,}0 - 2 \cdot \left(1{,}5 + 0{,}8 + \frac{1{,}6}{2}\right)}{2 - 1} = 23{,}8 \text{ cm}$$

$$s_{br,tz} = 23{,}8 \text{ cm} > 5 \cdot \left(c_\phi + \frac{\phi_{eq}}{2}\right) = 5 \cdot \left(2{,}3 + \frac{1{,}6}{2}\right) = 15{,}5 \text{ cm}$$

$S_{r,max} = 1{,}3 \cdot (h - x) = 1{,}3 \cdot (39{,}0 - 6{,}681) = 42{,}0$ cm EN 1992-1-1 7.3.4. (3) (7.14)

The stress in the tension reinforcement assuming a cracked section:

$$\sigma_s = \alpha_e \cdot \frac{M_{Ed}}{I_{II}} \cdot (d - x_{II}) = 6{,}3541 \cdot \frac{21{,}80}{25072{,}6} \cdot (35{,}9 - 6{,}681) = 1{,}61448 \cdot 10^5 \text{ KPa}$$

Average tension rebar strain:

$$\varepsilon_{sm} = \frac{\sigma_s - k_t \cdot \frac{f_{ct,eff}}{\rho_{p,eff}}}{E_s} = \frac{1{,}61448 \cdot 10^5 - 0{,}4 \cdot \frac{2565}{0{,}017296}}{2 \cdot 10^8} = 0{,}00051064$$

Average concrete strain:

$$\varepsilon_{cm} = \frac{k_t \cdot f_{ct,eff}}{E_{cm}} = \frac{0{,}4 \cdot 2565}{3{,}14758 \cdot 10^7} = 3{,}2596 \cdot 10^{-5}$$

$$\Delta\varepsilon_{(sm,cm)} = \max\left(\varepsilon_{sm} - \varepsilon_{cm}\,;\, 0{,}6 \cdot \frac{\sigma_s}{E_s}\right) = \max\left(0{,}00051064 - 3{,}2596 \cdot 10^{-5}\,;\, 0{,}6 \cdot \frac{1{,}61448 \cdot 10^5}{2 \cdot 10^8}\right) = 0{,}00048434 = 0{,}484\ ‰$$

EN 1992-1-1 7.3.4. (7.9)

The crack width: EN 1992-1-1 7.3.4. (7.8)

$$w_k = S_{r,max} \cdot \Delta\varepsilon_{(sm,cm)} = 420{,}15 \cdot 0{,}00048434 = 0{,}20 \text{ mm} < w_{max} = 0{,}30 \text{ mm passed}$$

2.2. Deflection

Parameters EN 1992-1-1 7.4.3. (6)

Result summary

Span 1 :

Span l_0 = 2,110 m

Load case/Combination: **[rc+covering+plumbing+wall+stair permanent] {0,3*variable inner+0,3*variable outer}**

	left support	Span			right support
	right edge	zero moment location	max	zero moment location	left edge
Loc. [m]	0,195	0,538	1,500	2,305	2,305
$l_0[m]$	2,110				
Longitudinal rebars top	2ϕ16		2ϕ16		2ϕ16
Longitudinal rebars bottom	2ϕ16		2ϕ16		3ϕ16
$I_c[cm^4]$	148297		148297		148297
$I_I[cm^4]$	187368		196873		196873
$I_{II}[cm^4]$	64877,7		88705,2		66459,4

$M_{cr}\,[kNm]$	24,65		26,49		25,32
$M_{Rd,II}\,[kNm]$	65,61		96,92		65,89
$M\,[kNm]$	9,27		−29,83		−29,83
ζ	0		0,60557	0,63966	
α_I	2,3744		2,2598	2,2598	
α_{II}	6,8574		5,0154	6,6942	
α	2,3744		3,9285	5,0963	
$e_0\,[mm]$	0,902 (↓)	1,217 (↓)	2,048 (↓)	2,506 (↓)	2,506 (↓)
$e_{0,rel}\,[mm]$	0	0	0,130 (↓)	0	0
$e_{abs}\,[mm]$	0,902 (↓)	1,290 (↓)	2,462 (↓)	2,506 (↓)	2,506 (↓)
$e_{rel}\,[mm]$	**0** ✔	**0,127** (↓) ✔	**0,568** (↓) ✔	**0** ✔	**0** ✔
$e_{lim}\,[mm]$	7,033				

Span 2 :

Span l_0 = 0,478 m

Load case/Combination: **[rc+covering+plumbing+wall+stair permanent] {0,3*variable inner}**

	left support	Span			right support
	right edge	zero moment location	max	zero moment location	left edge
Loc. [m]	2,500	2,500	2,659	2,978	2,978
$l_0\,[m]$	0,478				
Longitudinal rebars top	$2\phi16$		$2\phi16$		$2\phi16$
Longitudinal rebars bottom	$3\phi16$		$2\phi16$		$2\phi16$
$I_c\,[cm^4]$	148297		148297		148297
$I_I\,[cm^4]$	196873		196873		187368
$I_{II}\,[cm^4]$	66459,4		88705,2		64877,7
$M_{cr}\,[kNm]$	25,32		26,49		24,65
$M_{Rd,II}\,[kNm]$	65,89		96,92		65,61
$M\,[kNm]$	−29,50		−30,21		−23,99
ζ	0,63161		0,61538	0	
α_I	2,2598		2,2598	2,3744	
α_{II}	6,6942		5,0154	6,8574	
α	5,0606		3,9555	2,3744	
$e_0\,[mm]$	2,544 (↓)	2,544 (↓)	2,583 (↓)	2,629 (↓)	2,629 (↓)
$e_{0,rel}\,[mm]$	0	0	0,011 (↓)	0	0

$e_{abs}[mm]$	2,544 (↓)	2,544 (↓)	2,615 (↓)	2,629 (↓)	2,629 (↓)
$e_{rel}[mm]$	**0** ✔	**0** ✔	**0,042** (↓) ✔	**0** ✔	**0** ✔
$e_{lim}[mm]$	1,594				

Span 3 :

Span l_0 = 0,609 m

Load case/Combination: **[rc+covering+plumbing+wall+stair permanent] {0,3*variable inner}**

	left support	Span			right support
	right edge	zero moment location	max	zero moment location	left edge
Loc. [m]	3,291	3,291	3,517	3,900	3,900
$l_0[m]$	0,609				
Longitudinal rebars top	2ϕ16		2ϕ16		2ϕ16
Longitudinal rebars bottom	2ϕ16		2ϕ16		2ϕ16
$I_c[cm^4]$	148297		148297		148297
$I_I[cm^4]$	187368		187368		187368
$I_{II}[cm^4]$	64877,7		64877,7		64877,7
$M_{cr}[kNm]$	24,65		24,65		24,65
$M_{Rd,II}[kNm]$	65,61		65,61		65,61
$M[kNm]$	−18,75		−25,40		−25,40
ζ	0		0,52936	0,52936	
α_I	2,3744		2,3744	2,3744	
α_{II}	6,8574		6,8574	6,8574	
α	2,3744		4,7476	4,7476	
$e_0[mm]$	2,640 (↓)	2,640 (↓)	2,634 (↓)	2,587 (↓)	2,587 (↓)
$e_{0,rel}[mm]$	0	0	0,013 (↓)	0	0
$e_{abs}[mm]$	2,640 (↓)	2,640 (↓)	2,684 (↓)	2,587 (↓)	2,587 (↓)
$e_{rel}[mm]$	**0** ✔	**0** ✔	**0,063** (↓) ✔	**0** ✔	**0** ✔
$e_{lim}[mm]$	2,029				

Span 4 :

Span l_0 = 2,110 m

Load case/Combination: **[rc+covering+plumbing+wall+stair permanent] {0,3*variable inner+0,3*variable outer}**

	left support	Span			right support
	right edge	zero moment location	max	zero moment location	left edge

Loc. [m]	4,095	4,095	4,900	6,035	6,205
$l_0 [m]$	2,110				
Longitudinal rebars top	$2\phi16$		$2\phi16$		$2\phi16$
Longitudinal rebars bottom	$2\phi16$		$2\phi16$		$2\phi16$
$I_c [cm^4]$	148297		148297		148297
$I_I [cm^4]$	187368		187368		187368
$I_{II} [cm^4]$	64877,7		64877,7		64877,7
$M_{cr} [kNm]$	24,65		24,65		24,65
$M_{Rd,II} [kNm]$	65,61		65,61		65,61
$M [kNm]$	$-25{,}97$		$-26{,}65$		4,36
ζ	0,54978		0,57238	0	
α_I	2,3744		2,3744	2,3744	
α_{II}	6,8574		6,8574	6,8574	
α	4,8391		4,9404	2,3744	
$e_0 [mm]$	2,571 (↓)	2,571 (↓)	2,222 (↓)	1,380 (↓)	1,241 (↓)
$e_{0,rel} [mm]$	0	0	0,145 (↓)	0	0
$e_{abs} [mm]$	2,571 (↓)	2,571 (↓)	2,812 (↓)	1,423 (↓)	1,241 (↓)
$e_{rel} [mm]$	**0** ✔	**0** ✔	**0,748** (↓) ✔	**0,075** (↓) ✔	**0** ✔
$e_{lim} [mm]$	7,034				