VEDLEGG 8

DIMENSJONERING AV SLAKKARMERING,

TVERRETNING

Beregningene i vedlegget tar utgangspunkt i at vi ser per meter inn i planet.

Bruddgrensetilstand:

Maksimalt opptredende moment og skjærkraft:

$M_{Ed} = 454{,}65$ kNm (Vedlegg 3, s. 6)
$V_{Ed} = 485{,}34$ kN (Vedlegg 3, s. 6)

Strekkarmering:

Overslagsberegninger ble gjort for å finne omtrentlig mengde nødvendig armering:

Strekkarmering: 9ϕ16 i ett lag

Skjærbøyler: 2ϕ10

Overdekning:

Velger dimensjonerende brukstid: 100år

Eksponeringsklasser: overkant og sidene av brua = XD3, underkant av brua = XC4 (Standard Norge, 2004, tabell 4.1)

$c_{min,dur} = 50$ mm (overkant og sidene) (Standard Norge, 2008, tabell NA.4.4N)

$c_{min,dur} = 35$ mm (underkant) (Standard Norge, 2008, tabell NA.4.4N)

$\Delta c_{dev} = 10$ mm (Standard Norge, 2008, pkt. NA.4.4.1.3(1))

$c_{min,b} = \max\{\phi, 10 \text{ mm}\} = \max\{16 \text{ mm}, 10 \text{ mm}\} = 16$ mm (Standard Norge, 2008, tabell NA.4.2)

$\Delta c_{dur,\gamma} = 0$ mm (Standard Norge, 2008, pkt. NA.4.4.1.2(6))

$\Delta c_{dur,st} = 0$ mm (Standard Norge, 2008, pkt. NA.4.4.1.2(7))

$\Delta c_{dur,add} = 0$ mm (Standard Norge, 2008, pkt. NA.4.4.1.2(8))

$c_{min} = max \begin{Bmatrix} c_{min,b} \\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add} \\ 10 \text{ mm} \end{Bmatrix}$ (Standard Norge, 2004, pkt. 4.4.1.2(2))

$$c_{min} = max \begin{Bmatrix} c_{min,b} \\ c_{min,dur} \\ 10 \text{ mm} \end{Bmatrix} = max \begin{Bmatrix} 16 \text{ mm} \\ 50 \text{ mm} \\ 10 \text{ mm} \end{Bmatrix} = 50 \text{ mm}$$

$c_{nom} = c_{min} + \Delta c_{dev}$ (Standard Norge, 2004, pkt. 4.4.1.1(1))

$$c_{nom} = 50 \text{ mm} + 10 \text{ mm}$$

$$c_{nom} = 60{,}00 \text{ mm}$$

Avstandskrav:

Setter $d_g = 20$ mm (Sørensen, 2013, s.42)

Fri avstand horisontalt:

$a_{h,krav} = max \begin{Bmatrix} k_1 * \phi \\ d_g + k_2 \\ 20 \text{ mm} \end{Bmatrix}$ (Standard Norge, 2004, pkt. 8.2.(2); Standard Norge, 2008, pkt. NA.8.2(2))

$$a_{h,krav} = max \begin{Bmatrix} 2 * 16 \text{ mm} \\ 20 \text{ mm} + 5 \text{ mm} \\ 20 \text{ mm} \end{Bmatrix} = \max \begin{Bmatrix} 32 \text{ mm} \\ 25 \text{ mm} \\ 20 \text{ mm} \end{Bmatrix} = 32{,}00 \text{ mm}$$

Tverrsnittets nødvendige effektive høyde:

$d = h - (c_{nom} + \phi_{bøyler} + \phi_{lengde})$

$d = 800 - \left(60{,}00 + 10 + \frac{16}{2}\right)$

$d = 722{,}00$ mm

Indre momentarm:

$z = (1 - 0{,}5\lambda\alpha) * d$ (Sørensen, 2013, s.39)

$z = (1 - 0{,}5 * 0{,}79 * 0{,}383) * 722{,}00$

$z = 612{,}77$ mm

Nødvendig armeringsmengde i strekksonen mht. opptredende moment:

$A_{s,nødvendig} = \frac{M_{Ed}}{z * f_{yd}}$ (Sørensen, 2013 s.39)

$A_{s,nødvendig} = \frac{454{,}65 * 10^6}{612{,}77 * 434{,}78}$

$A_{s,nødvendig} = 1706{,}52$ mm^2

Nødvendig antall stenger:

$n \geq \frac{A_{s,nødvendig}}{\pi * r_\phi^2}$ (Sørensen, 2013, s.41)

$n \geq \frac{1706{,}52}{\pi * \left(\frac{16}{2}\right)^2}$

$n \geq 8{,}49 \Rightarrow n = 9$ stenger

Faktisk armeringsmengde:

$A_s = n * \pi * r_\phi^2$

$A_s = 9 * \pi * \left(\frac{16}{2}\right)^2$

$A_s = 1809{,}56\ \text{mm}^2$

Kontroll av avstand horisontalt:

$a_{h,opptredende} = \frac{b-(2*c_{nom}+2*Ø_{bøyler}+n_{lag}*Ø_{lengde})}{n_{lag}-1}$

$a_{h,opptredende} = \frac{1000-(2*60{,}00+2*10+9*16)}{9-1}$

$a_{h,opptredende} = 89{,}50\ \text{mm} > a_{h,krav} = 32{,}00\ \text{mm} \Rightarrow OK$

Minimumsarmering:

$A_{s,min} = 0{,}26 * \frac{f_{ctm}}{f_{yk}} * b_t * d > 0{,}0013 * b_t * d$ (Standard Norge, 2008, pkt. NA.9.2.1.1)

$A_{s,min} = 0{,}26 * \frac{4{,}2}{500} * 1000 * 722{,}00 > 0{,}0013 * 1000 * 722{,}00$

$A_{s,min} = 1576{,}85\ \text{mm}^2 > 938{,}60\ \text{mm}^2 \Rightarrow OK$

Maksimumsarmering:

$A_{s,max} = 0{,}04 * A_c$ (Standard Norge, 2008, pkt. NA.9.2.1.1)

$A_{s,max} = 0{,}04 * 1000 * 800$

$A_{s,max} = 32\ 000{,}00\ \text{mm}^2$

Armeringskrav:

$A_{s.min} \leq A_s \leq A_{s,max}$

$1576{,}85\ \text{mm}^2 < 1809{,}56\ \text{mm}^2 < 32\ 000{,}00\ \text{mm}^2 \Rightarrow OK$

Trykkarmering:

$M_{Rd} = K * f_{cd} * b * d^2$ (Sørensen, 2013, s.38)

$M_{Rd} = 0{,}250 * 31{,}17 * 1000 * 722{,}00^2$

$M_{Rd} = 4062{,}11$ kNm $> M_{Ed} = 454{,}65$ kNm $\Rightarrow$ ikke behov for trykkarmering (Sørensen, 2013, s.46)

Skjærarmering:

$C_{Rd,c} = \frac{k_2}{\gamma_c} = \frac{0,18}{1,5} = 0,12$ (Standard Norge, 2008, pkt. NA.6.2.2(1))

$k = 1 + \sqrt{\frac{200}{d}} \leq 2,0$ (Standard Norge, 2004, pkt. 6.2.2(1))

$k = 1 + \sqrt{\frac{200}{722,00}} = 1,53 < 2,0 \Rightarrow OK$

$\rho_L = \frac{A_{sL}}{b_w * d} \leq 0,02$ (Standard Norge, 2004, pkt. 6.2.2(1))

$\rho_L = \frac{1809,56}{1000*722,00} = 2,51 * 10^{-3} < 0,02 \Rightarrow OK$

$\sigma_{cp} = 0$

$V_{Rd,c} = \left[c_{Rd,c} * k * (100 * \rho_L * f_{ck})^{\frac{1}{3}} + k_1 * \sigma_{cp}\right] * b_w * d$ (Standard Norge, 2004, pkt. 6.2.2(1))

$V_{Rd,c} = \left[0,12 * 1,53 * (100 * 2,51 * 10^{-3} * 55)^{\frac{1}{3}} + 0\right] * 1000 * 722,00$

$V_{Rd,c} = 318.00$ kN

$V_{Rd,c,min} = 0,035 * k^{\frac{3}{2}} * f_{ck}^{\frac{1}{2}} * b * d$ (Sørensen, 2013, s.62)

$V_{Rd,c,min} = 0,035 * 1,53^{\frac{3}{2}} * 55^{\frac{1}{2}} * 1000 * 722,00$

$V_{Rd,c,min} = 354,67$ kN

Krav:

$V_{Rd,c} \geq V_{Rd,c,min}$

$318{,}00 \text{ kN} < 354{,}67 \text{ kN} \Rightarrow Ikke\ OK, bruker\ V_{Rd,c,min}$

$V_{Rd,c,min} < V_{Ed} \Rightarrow$ Beregningsmessig behov for skjærarmering (Sørensen, 2013, s.77)

$354{,}67 \text{ kN} < 485{,}34 \text{ kN} \Rightarrow$ Beregningsmessig behov for skjærarmering

Nødvendig mengde skjærarmering per mm:

$\frac{A_{s,w}}{s} \geq \frac{V_{Ed}}{f_{ywd} * z * cot\theta}$ (Sørensen, 2013, s.77)

$\frac{A_{s,w}}{s} \geq \frac{485{,}34 * 10^3}{434{,}48 * 612{,}77 * 1}$

$\frac{A_{s,w}}{s} \geq 1{,}83 \frac{\text{mm}^2}{\text{mm}}$

Minimumskrav til skjærarmering per mm:

$\frac{A_{sw,min}}{s} = 0{,}1 * \frac{\sqrt{f_{ck}}}{f_{yk}} * b_w$ (Sørensen, 2013, s.77)

$\frac{A_{sw,min}}{s} = 0{,}1 * \frac{\sqrt{55}}{500} * 1000$

$\frac{A_{sw,min}}{s} = 1{,}48 \frac{\text{mm}^2}{\text{mm}}$

Krav:

$\frac{A_{sw}}{s} > \frac{A_{sw,min}}{s}$

$1{,}83 \frac{\text{mm}^2}{\text{mm}} > 1{,}48 \frac{\text{mm}^2}{\text{mm}} \Rightarrow OK$

Nødvendig senteravstand mellom skjærbøylene:

$s \leq \frac{A_{s,w}}{V_{Ed}} * f_{ywd} * z * cot\theta$ (Standard Norge, 2004, pkt. 6.2.3(3))

$s = \frac{2*\pi*\left(\frac{10}{2}\right)^2}{485{,}34*10^3} * 434{,}78 * 612{,}77 * 1$

$s = 86{,}23 \text{ mm} \Rightarrow 80{,}00 \text{ mm}$

Krav til minimum senteravstand:

$s_{L,min} = max \begin{Bmatrix} k_1 * \phi \\ d_g + k_2 \\ 20 \text{ mm} \end{Bmatrix}$ (Standard Norge, 2004, pkt. 8.2.(2); Standard Norge, 2008, pkt. NA.8.2(2))

$s_{L,min} = max \begin{Bmatrix} 1 * 10 \text{ mm} \\ 20 \text{ mm} + 5 \text{ mm} \\ 20 \text{ mm} \end{Bmatrix} = max \begin{Bmatrix} 10 \text{ mm} \\ 25 \text{ mm} \\ 20 \text{ mm} \end{Bmatrix}$

$s_{L,min} = 25{,}00 \text{ mm}$

Krav til maksimum senteravstand:

$s_{L,max} = 0{,}6 * z$ (Standard Norge, 2008, pkt. NA9.2.2(6))

$s_{L,max} = 0{,}6 * 612{,}77$

$s_{L,max} = 367{,}66 \text{ mm}$

Krav til senteravstand:

$s_{L,min} \leq s \leq s_{L,max}$

$25{,}00 \text{ mm} < 80{,}00 \text{ mm} < 367{,}66 \text{ mm} \Rightarrow OK$

Skjærtrykkapasitet:

$\alpha_{cw} = 1$ (Standard Norge, 2004, pkt. 6.2.3(3))

$\nu_1 = 0{,}6$ gjelder for $f_{ck} \leq 60 \frac{\mathrm{N}}{\mathrm{mm}^2}$ (Standard Norge, 2008, pkt. NA.6.2.3(3))

$V_{Rd,max} = \frac{\alpha_{cw}*b_w*z*v_1*f_{cd}}{cot\theta+tan\theta}$ (Standard Norge, 2004, pkt. 6.2.3(3))

$V_{Rd,max} = \frac{1*1000*612{,}77*0{,}6*31{,}17}{1+1}$

$V_{Rd,max} = 5730{,}01$ kN

Krav:

$V_{Rd,max} > V_{Ed}$

$5730{,}01$ kN $> 485{,}34$ kN $\Rightarrow OK$

Bruksgrensetilstand:

Nedbøying:

Kryp:

$t = \infty \rightarrow t = 500\,000$ timer (Standard Norge, 2004, pkt. 3.3.2(8))

Velger følgende verdier:

Egenvekt og rekkverk $\rightarrow t_{0,1} = 28$ døgn

Trafikklast $\rightarrow t_{0,2} = 90$ døgn

$RH = 80\%$

$h_0 = \frac{2*A_c}{u}$ (Standard Norge, 2004, Tillegg B, B1)

$h_0 = \frac{2*1000*800}{2*(1000+800)}$

$h_0 = 444{,}44$ mm

$\alpha_1 = \left[\frac{35}{f_{cm}}\right]^{0,7}$ (Standard Norge, 2004, Tillegg B, B1)

$\alpha_1 = \left[\frac{35}{63}\right]^{0,7}$

$\alpha_1 = 0{,}66$

$\alpha_2 = \left[\frac{35}{f_{cm}}\right]^{0,2}$ (Standard Norge, 2004, Tillegg B, B1)

$\alpha_2 = \left[\frac{35}{63}\right]^{0,2}$

$\alpha_2 = 0{,}89$

$\alpha_3 = \left[\frac{35}{f_{cm}}\right]^{0,5}$ (Standard Norge, 2004, Tillegg B, B1)

$\alpha_3 = \left[\frac{35}{63}\right]^{0,5}$

$\alpha_3 = 0,75$

For $f_{cm} \geq 35\ MPa$:

$\varphi_{RH} = \left[1 + \frac{RH/100}{0,1 * \sqrt[3]{h_0}} * \alpha_1\right] * \alpha_2$ (Standard Norge, 2004, Tillegg B, B1)

$\varphi_{RH} = \left[1 + \frac{80/100}{0,1 * \sqrt[3]{444,44}} * 0,66\right] * 0,89$

$\varphi_{RH} = 1,51$

$\beta(f_{cm}) = \frac{16,8}{\sqrt{f_{cm}}}$ (Standard Norge, 2004, Tillegg B, B1)

$\beta(f_{cm}) = \frac{16,8}{\sqrt{63}}$

$\beta(f_{cm}) = 2,12$

$\beta(t_0) = \frac{1}{0,1 + t_0^{0,20}}$ (Standard Norge, 2004, Tillegg B, B1)

$\beta\left(t_{0,1}\right) = \frac{1}{0,1 + 28^{0,20}}$

$\beta\left(t_{0,1}\right) = 0,49 \beta\left(t_{0,2}\right) = \frac{1}{0,1 + 90^{0,20}}$

$\beta\left(t_{0,2}\right) = 0,39$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$ (Standard Norge, 2004, Tillegg B, B1)

$\varphi_{0,1} = 1{,}51 * 2{,}12 * 0{,}49$

$\varphi_{0,1} = 1{,}57$

$\varphi_{0,2} = 1{,}51 * 2{,}12 * 0{,}39$

$\varphi_{0,2} = 1{,}25$

For $f_{cm} \geq 35\ MPa$:

$\beta_H = 1{,}5 * [1 + (0{,}012\ RH)^{18}] * h_0 + (250 * \alpha_3) \leq 1500 * \alpha_3$ (Standard Norge, 2004, Tillegg B, B1)

$\beta_H = 1{,}5 * [1 + (0{,}012 * 80)^{18}] * 444{,}44 + (250 * 0{,}75) \leq 1500 * 0{,}75$

$\beta_H = 1173{,}89 > 1125{,}00$

$\beta_H = 1125{,}00$

$\beta_c(t, t_0) = \left[\frac{t - t_0}{\beta_H + t - t_0}\right]^{0,3}$ (Standard Norge, 2004, Tillegg B, B1)

$\beta_c(t, t_{0,1}) = \left[\frac{500\,000 - 28}{1125{,}00 + 500\,000 - 28}\right]^{0,3}$

$\beta_c(t, t_{0,1}) = 1{,}00$

$\beta_c(t, t_{0,2}) = \left[\frac{500\,000 - 90}{1125{,}00 + 500\,000 - 90}\right]^{0,3}$

$\beta_c(t, t_{0,2}) = 1{,}00$

$\varphi(t, t_0) = \varphi_0 * \beta_c(t, t_0)$ (Standard Norge, 2004, Tillegg B, B1)

$\varphi(t, t_{0,1}) = 1{,}57 * 1{,}00$

$\varphi(t, t_{0,1}) = 1{,}57$

$\varphi(t, t_{0,2}) = 1{,}25 * 1{,}00$

$\varphi(t, t_{0,2}) = 1{,}25$

$E_{c,eff} = \frac{E_{cm}}{1+\varphi(t,t_0)}$ (Standard Norge, 2004, pkt. 7.4.3(5))

$E_{c1} = \frac{38\ 000}{1+1{,}27}$

$E_{c1} = 14\ 785{,}99 \frac{\mathrm{N}}{\mathrm{mm}^2}$

$E_{c2} = \frac{38\ 000}{1+1{,}25}$

$E_{c2} = 16\ 888{,}89 \frac{\mathrm{N}}{\mathrm{mm}^2}$

$M_g = 148{,}88$ kNm (Vedlegg 5, s. 1)

$M_{q,trafikk} = 34{,}23$ kNm (Vedlegg 5, s. 1)

$M_{Q,rekkverk} = 2{,}26$ kNm (Vedlegg 5, s. 1)

$$E_{middel} = \frac{\sum M_i}{\sum \frac{M_i}{E_i}}$$ (Sørensen, 2013, s. 129)

$$E_{middel} = \frac{148{,}88*10^6 + 34{,}23*10^6 * 2{,}26*10^6}{\frac{148{,}88*10^6}{14\,785{,}99} + \frac{34{,}23*10^6}{16\,888{,}89} + \frac{2{,}26*10^6}{14\,785{,}99}}$$

$$E_{middel} = 15\,133{,}96\,\frac{\mathrm{N}}{\mathrm{mm}^2}$$

$$\eta = \frac{E_s}{E_{c,middel}}$$ (Sørensen, 2013, s. 130)

$$\eta = \frac{2*10^5}{15\,133{,}96}$$

$$\eta = 13{,}22$$

$$\rho = \frac{A_s}{b*d}$$ (Sørensen, 2013, s. 130)

$$\rho = \frac{9*\pi*8^2}{1000*722{,}00}$$

$$\rho = 2{,}51 * 10^{-3}$$

$$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho$$ (Sørensen, 2013, s. 116)

$$\alpha = \sqrt{(13{,}22 * 2{,}51 * 10^{-3})^2 + 2 * 13{,}22 * 2{,}51 * 10^{-3}} - 13{,}22 * 2{,}51 * 10^{-3}$$

$$\alpha = 0{,}23$$

Nedbøying pga. kryp for uopprisset tverrsnitt:

$a = \frac{A_c * 0,5 * h + \eta * A_s * d}{A_c + \eta * A_s}$ (Sørensen, 2013, s. 122)

$a = \frac{1000*800*0,5*800+13,22*9*\pi*8^2*722,00}{1000*800+13,22*9*\pi*8^2}$

$a = 409,35$ mm

$I_{c1} = \frac{1}{12} * b * h^3 + b * h * \left(a - \frac{h}{2}\right)^2$ (Sørensen, 2013, s. 122)

$I_{c1} = \frac{1}{12} * 1000 * 800^3 + 1000 * 800 * \left(409,35 - \frac{800}{2}\right)^2$

$I_{c1} = 4,27 * 10^{10}$ mm^4

Felt 1:

$\delta_{kryp,u} = \frac{q*L^4}{8*EI} + \frac{P*L^3}{3*EI}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.3)

$\delta_{kryp,u} = \frac{(21,75+5)*3700^4}{8*15\ 133,96*4,27*10^{10}} + \frac{0,61*10^3*3700^3}{3*15\ 133,96*4,27*10^{10}}$

$\delta_{kryp,u} =$ 0,99 mm

Felt 2 og 3:

$\delta_{kryp,u} = \frac{1}{384} * \frac{q*L^4}{EI}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$\delta_{kryp,u} = \frac{1}{384} * \frac{(21,75+5,4)*2900^4}{15\ 133,96*4,27*10^{10}}$

$\delta_{kryp,u} = 7,73 * 10^{-3}$ mm

Felt 4:

$\delta_{kryp,u} = \frac{q*L^4}{8*EI} + \frac{P*L^3}{3*EI}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.3)

$\delta_{kryp,u} = \frac{(21{,}75+5{,}4)*1200^4}{8*15\ 133{,}96*4{,}27*10^{10}} + \frac{0{,}61*10^3*1200^3}{3*15\ 133{,}96*4{,}27*10^{10}}$

$\delta_{kryp,u} = 0{,}011$ mm

Nedbøying pga. kryp for opprisset tverrsnitt:

$I_c = \frac{1}{2} * \alpha^2 \left(1 - \frac{\alpha}{3}\right) b * d^3$ (Sørensen, 2013, s. 118)

$I_c = \frac{1}{2} * 0{,}23^2 \left(1 - \frac{0{,}23}{3}\right) * 1000 * 722{,}00^3$

$I_c = 0{,}92 * 10^{10}$ mm^4

Felt 1:

$\delta_{kryp,o} = \frac{q*L^4}{8*EI} + \frac{P*L^3}{3*EI}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.3)

$\delta_{kryp,o} = \frac{(21{,}75+5)*3700^4}{8*15\ 133{,}96*0{,}92*10^{10}} + \frac{0{,}61*10^3*3700^3}{3*15\ 133{,}96*0{,}92*10^{10}}$

$\delta_{kryp,o} = 4{,}57$ mm

Felt 2 og 3:

$\delta_{kryp,o} = \frac{1}{384} * \frac{q*L^4}{EI}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$\delta_{kryp,o} = \frac{1}{384} * \frac{(21{,}75+5{,}4)*2900^4}{15\ 133{,}96*0{,}92*10^{10}}$

$\delta_{kryp,o} = 0{,}035$ mm

Felt 4:

$\delta_{kryp,o} = \frac{q*L^4}{8*EI} + \frac{P*L^3}{3*EI}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.3)

$\delta_{kryp,o} = \frac{(21{,}75+5{,}4)*1200^4}{8*15\ 133{,}96*0{,}92*10^{10}} + \frac{0{,}61*10^3*1200^3}{3*15\ 133{,}96*0{,}92*10^{10}}$

$\delta_{kryp,o} = 0{,}053$ mm

Svinn:

$t = \infty$

Velger sementklasse N

$\alpha_{ds1} = 4$ (Standard Norge, 2004, Tillegg B, B2(1))

$\alpha_{ds2} = 0.12$ (Standard Norge, 2004, Tillegg B, B2(1))

$f_{cm0} = 10\,\frac{\mathrm{N}}{\mathrm{mm}^2}$ (Standard Norge, 2004, Tillegg B, B2(1))

$RH_0 = 100\%$ (Standard Norge, 2004, Tillegg B, B2(1))

Svinntøyning ved uttørking:

$\beta_{ds}(t, t_s) = \frac{(t-t_s)}{(t-t_s)+0{,}04\sqrt{h_0{}^3}}$ (Standard Norge, 2004, pkt. 3.1.4(6))

$For\ t \to \infty\ blir\ \beta_{ds}(t, t_s) = 1$ (Sørensen, 2013, s. 132)

Interpolerer for å finne k_h (Standard Norge, 2004, tabell 3.3):

$$\frac{500-300}{0,70-0,75} = \frac{500-444,44}{0,70-k_h}$$

$$0,70 - k_h = -\frac{55,56}{4000}$$

$$k_h = 0,70 + \frac{55,56}{4000}$$

$$k_h = 0,71$$

$\beta_{RH} = 1,55\left[1 - \left(\frac{RH}{RH_0}\right)^3\right]$ (Standard Norge, 2004, Tillegg B, B2(1))

$$\beta_{RH} = 1,55\left[1 - \left(\frac{80}{100}\right)^3\right]$$

$$\beta_{RH} = 0,76$$

$\varepsilon_{cd,0} = 0,85\left[(220 + 110\alpha_{ds1}) * \exp\left(-\alpha_{ds2} * \frac{f_{cm}}{f_{cm0}}\right)\right] * 10^{-6} * \beta_{RH}$ (Standard Norge, 2004, Tillegg B, B2(1))

$$\varepsilon_{cd,0} = 0,85\left[(220 + 110 * 4) * \exp\left(-0,12 * \frac{63}{10}\right)\right] * 10^{-6} * 0,76$$

$$\varepsilon_{cd,0} = 2,00 * 10^{-4}$$

$\varepsilon_{cd}(t) = \beta_{ds}(t, t_s) * k_h * \varepsilon_{cd,0}$ (Standard Norge, 2004, pkt. 3.1.4(6))

$$\varepsilon_{cd}(t) = 1 * 0,71 * 2,00 * 10^{-4}$$

$$\varepsilon_{cd}(t) = 1,42 * 10^{-4}$$

Autogen svinntøyning:

$\beta_{as}(t) = 1 - \exp\,(-0{,}2\sqrt{t})$ (Standard Norge, 2004, pkt. 3.1.4(6))

$For\ t \rightarrow \infty\ blir\ \beta_{as}(t) = 1$ (Sørensen, 2013, s. 132)

$\varepsilon_{ca}(\infty) = 2{,}5(f_{ck} - 10) * 10^{-6}$ (Standard Norge, 2004, pkt. 3.1.4(6))

$\varepsilon_{ca}(\infty) = 2{,}5(55 - 10) * 10^{-6}$

$\varepsilon_{ca}(\infty) = 1{,}13 * 10^{-4}$

$\varepsilon_{ca}(t) = \beta_{as}(t) * \varepsilon_{ca}(\infty)$ (Standard Norge, 2004, pkt. 3.1.4(6))

$\varepsilon_{ca}(t) = 1 * 1{,}13 * 10^{-4}$

$\varepsilon_{ca}(t) = 1{,}13 * 10^{-4}$

Total svinntøyning:

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca}$ (Standard Norge, 2004, pkt. 3.1.4(6))

$\varepsilon_{cs} = 1{,}42 * 10^{-4} + 1{,}13 * 10^{-4}$

$\varepsilon_{cs} = 2{,}55 * 10^{-4}$

Svinnkrumning:

$a = \frac{A_c * 0{,}5 * h + \eta * A_s * d}{A_c + \eta * A_s}$ (Sørensen, 2013, s. 122)

$$a = \frac{1000*800*0{,}5*800+13{,}22*9*\pi*8^2*722{,}00}{1000*800+13{,}22*9*\pi*8^2}$$

$a = 409{,}35$ mm

$e = d - a$ (Sørensen, 2013, s.135)

$e = 722{,}00 - 409{,}35$

$e = 312{,}65$ mm

$I = \frac{bh^3}{12} + bh * \left(a - \frac{h}{2}\right)^2 + \eta A_s e^2$ (Sørensen, 2013, s. 136)

$I = \frac{1000*800^3}{12} + 1000 * 800 * \left(409{,}35 - \frac{800}{2}\right)^2 + 13{,}22 * 9 * \pi * 8^2 * 312{,}65^2$

$I = 4{,}51 * 10^{10}$ mm^4

$\kappa_s = \varepsilon_{cs} * \eta * \frac{A_s e}{I}$ (Sørensen, 2013, s. 135)

$\kappa_s = 2{,}55 * 10^{-4} * 13{,}22 * \frac{9*\pi*8^2*312{,}65}{4{,}51*10^{10}}$

$\kappa_s = 4{,}23 * 10^{-8}$ mm^{-1}

Nedbøying pga. svinn:

$P_{virtuell} = 1$ (Sørensen, 2013, s. 136)

$M_{virtuell} = \frac{1*L}{4}$ (Sørensen, 2013, s. 136)

Nedbøying svinn felt 1:

$\delta_{svinn} = \int_L \kappa_s * M_{virtuell}\, dx$ (Sørensen, 2013, s. 136)

$\delta_{svinn} = \frac{1}{2} * \kappa_s * \frac{L}{4} * L$

$\delta_{svinn} = \frac{1}{2} * 4{,}23 * 10^{-8} * \frac{3700}{4} * 3700$

$\delta_{svinn} = 0{,}072$ mm

Nedbøying svinn felt 2 og 3:

$\delta_{svinn} = \int_L \kappa_s * M_{virtuell}\, dx$ (Sørensen, 2013, s. 136)

$\delta_{svinn} = \frac{1}{2} * \kappa_s * \frac{L}{4} * L$

$\delta_{svinn} = \frac{1}{2} * 4{,}23 * 10^{-8} * \frac{2900}{4} * 2900$

$\delta_{svinn} = 0{,}044$ mm

Nedbøying svinn felt 4:

$\delta_{svinn} = \int_L \kappa_s * M_{virtuell}\, dx$ (Sørensen, 2013, s. 136)

$\delta_{svinn} = \frac{1}{2} * \kappa_s * \frac{L}{4} * L$

$\delta_{svinn} = \frac{1}{2} * 4{,}23 * 10^{-8} * \frac{1200}{4} * 1200$

$\delta_{svinn} = 7{,}61 * 10^{-3}$ mm

Krav til maksimum nedbøying:

$\delta_{tillatt} = \frac{L}{500}$ (Standard Norge, 2004, pkt. 7.4.1(5))

Felt 1:

$\delta_{tillatt} = \frac{L}{500} = \frac{3700}{500} = 7{,}40$ mm

Felt 2 og 3:

$\delta_{tillatt} = \frac{L}{500} = \frac{2900}{500} = 5{,}80$ mm

Felt 4:

$\delta_{tillatt} = \frac{L}{500} = \frac{1200}{500} = 2{,}40$ mm

Total nedbøying:

$\delta_{total} = \delta_{kryp} + \delta_{svinn}$ (Sørensen, 2013, s. 136)

Total nedbøying felt 1, uopprisset:

$\delta_{total} = \delta_{kryp,u} + \delta_{svinn}$

$\delta_{total} = 0{,}99 + 0{,}072$

$\delta_{total} = 1{,}062$ mm $< \ \delta_{tillatt} = 7{,}40$ mm $\Rightarrow OK$

Total nedbøying felt 2 og 3, uopprisset:

$\delta_{total} = \delta_{kryp,u} + \delta_{svinn}$

$\delta_{total} = 7{,}73 * 10^{-3} + 0{,}044$

$\delta_{total} = 0{,}052 \text{ mm} < \delta_{tillatt} = 5{,}80 \text{ mm} \Rightarrow OK$

Total nedbøying felt 4, uopprisset:

$\delta_{total} = \delta_{kryp,u} + \delta_{svinn}$

$\delta_{total} = 0{,}011 + 7{,}61 * 10^{-3}$

$\delta_{total} = 0{,}019 \text{ mm} < \delta_{tillatt} = 2{,}40 \text{ mm} \Rightarrow OK$

Total nedbøying felt 1, opprisset:

$\delta_{total} = \delta_{kryp,o} + \delta_{svinn}$

$\delta_{total} = 4{,}57 + 0{,}072$

$\delta_{total} = 4{,}64 \text{ mm} < \delta_{tillatt} = 7{,}40 \text{ mm} \Rightarrow OK$

Total nedbøying felt 2 og 3, opprisset:

$\delta_{total} = \delta_{kryp,o} + \delta_{svinn}$

$\delta_{total} = 0{,}035 + 0{,}044$

$\delta_{total} = 0{,}079 \text{ mm} > \delta_{tillatt} = 5{,}80 \text{ mm} \Rightarrow OK$

Total nedbøying felt 4, opprisset:

$$\delta_{total} = \delta_{kryp,o} + \delta_{svinn}$$

$$\delta_{total} = 0{,}053 + 7{,}61 * 10^{-3}$$

$$\delta_{total} = 0{,}061 \text{ mm} < \ \delta_{tillatt} = 2{,}40 \text{ mm} \ \Rightarrow OK$$

Riss og spenningsbegrensning:

Bruker c_{nom} og $c_{min,dur}$ for overkant bru:

$k_c = \frac{c_{nom}}{c_{min,dur}} \leq 1{,}3$ (Standard Norge, 2008, pkt. NA.7.3.1(5))

$k_c = \frac{60{,}00}{50} \leq 1{,}3$

$k_c = 1{,}20 < 1{,}3 \Rightarrow OK$

Rissviddekrav for eksponeringsklasse XD3 (overkant bru):

$w_{max} = 0{,}30 * k_c$ (Standard Norge, 2008, pkt. NA.7.3.1(5) og tabell NA.7.1N)

$w_{max} = 0{,}30 * 1{,}20$

$w_{max} = 0{,}36$ mm

Tilfredstilling av rissviddekrav:

$w_k = \max\{0{,}4, 0{,}3, 0{,}2\} \leq w_{max}$ (Standard Norge, 2004, pkt. 7.3.3, tabell 7.2N og 7.3N)

$w_k = \max\{0{,}4, 0{,}3, 0{,}2\} \leq 0{,}36$

$w_k = 0{,}3$ mm $< 0{,}36$ mm $\Rightarrow OK$

Senteravstand til strekkarmering:

$s = \frac{b - 2 * c_{nom} - 2 * \phi_{skjær} - \phi_{strekk}}{n-1}$

$s = \frac{1000 - 2 * 60{,}00 - 2 * 10 - 16}{9-1}$

$s = 105{,}50$ mm

Tillatt armeringsspenning mht. stangdiameter bestemmes av w_k og ϕ_{strekk}:

(Standard Norge, 2004, pkt. 7.3.3, tabell 7.2N)

$\sigma_{s,tillatt} = 240 \frac{\mathrm{N}}{\mathrm{mm}^2}$

Tillatt armeringsspenning mht. senteravstand bestemmes av w_k og s:

(Standard Norge, 2004, pkt. 7.3.3, tabell 7.3N)

$\sigma_{s,tillatt} = 320 \frac{\mathrm{N}}{\mathrm{mm}^2}$

Tillatt armeringsspenning $\sigma_{s,tillatt}$, er den minste av de to tillatte armeringsspenningene:

$\sigma_{s,tillatt} = 240 \frac{\mathrm{N}}{\mathrm{mm}^2}$

Tidligere beregnede verdier:

$M = 185{,}37$ kNm (Vedlegg 5, s. 9)

$E_{middel} = 15\ 133{,}96 \frac{\mathrm{N}}{\mathrm{mm}^2}$

$d = 722{,}00$ mm

$\eta = 13{,}22$

$\rho = 2{,}51 * 10^{-3}$

$\alpha = 0{,}23$

Armeringsspenning for opprisset tverrsnitt:

$I_o = I_c = \frac{1}{2} * \alpha^2 * \left(1 - \frac{\alpha}{3}\right) * b * d^3$ (Sørensen, 2013, s. 118)

$I_o = I_c = \frac{1}{2} * 0{,}23^2 * \left(1 - \frac{0{,}23}{3}\right) * 1000 * 722{,}00^3$

$I_o = 9{,}19 * 10^9$ mm^4

$\sigma_s = E_s * \frac{M*(1-\alpha)*d}{E_{middel}*I_o}$ (Sørensen, 2013, s. 150)

$\sigma_s = 2 * 10^5 * \frac{185{,}37*10^6*(1-0{,}23)*722{,}00}{15133{,}96*9{,}19*10^9}$

$\sigma_s = 148{,}19\ \frac{\mathrm{N}}{\mathrm{mm}^2}$

Krav til armeringsspenninger i opprisset tverrsnitt:

$\sigma_s \leq 0{,}8 * f_{yk}$ (Standard Norge, 2004, pkt. 7.2(5); Standard Norge, 2008, pkt. NA.7.2)

$148{,}19 \leq 0{,}8 * 500$

$148{,}19\ \frac{\mathrm{N}}{\mathrm{mm}^2} < 400{,}00\ \frac{\mathrm{N}}{\mathrm{mm}^2} \Rightarrow OK$, uakseptabel opprissing mht. utseende kan antas unngått (Sørensen, 2013, s. 155)

$\sigma_{s,tillatt} > \sigma_s$ (Sørensen, 2013, s. 152)

$200\,\frac{\mathrm{N}}{\mathrm{mm}^2} > 148{,}19\ \frac{\mathrm{N}}{\mathrm{mm}^2} \Rightarrow OK$, rissviddekravet er tilfredsstilt

Generelle krav til spenninger i betongen for å unngå riss i lengderetningen:

$\sigma_c \leq 0{,}6 * f_{ck}$ (Standard Norge, 2004, pkt. 7.2(2); Standard Norge, 2008, pkt. NA.7.2)

$1{,}74 \frac{\mathrm{N}}{\mathrm{mm}^2} \leq 0{,}6 * 55$

$1{,}74 \frac{\mathrm{N}}{\mathrm{mm}^2} < 33{,}00 \ \frac{\mathrm{N}}{\mathrm{mm}^2} \Rightarrow OK$

$\sigma_c \leq 0{,}45 * f_{ck}$ (Standard Norge, 2004, pkt. 7.2(3); Standard Norge, 2008, pkt. NA.7.2)

$1{,}74 \frac{\mathrm{N}}{\mathrm{mm}^2} \leq 0{,}45 * 55$

$1{,}74 \frac{\mathrm{N}}{\mathrm{mm}^2} < 24{,}75 \frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow \mathrm{OK},\ \text{antar derfor lineær kryptøyning}$

Betongspenninger i overkant for uopprisset tverrsnitt $\left(\boldsymbol{y = -\frac{800}{2}}\ \mathbf{mm}\right)$:

$\sigma_c = \frac{M * y}{I}$ (Bell, 2017, s.83)

<u>Felt 1:</u>

$\sigma_c^o = \frac{185{,}37 * 10^6 * \left(-\frac{800}{2}\right)}{4{,}27 * 10^{10}}$

$\sigma_c^o = -1{,}74 \ \frac{\mathrm{N}}{\mathrm{mm}^2}$

Kontroll av betongens trykkspenninger i feltet:

$\sigma_{c,tillatt} = -0{,}6 * f_{ck}$ (Standard Norge, 2004, pkt. 5.10.2.2(5))

$\sigma_{c,tillatt} = -0{,}6 * 55$

$\sigma_{c,tillatt} = -33{,}00 \ \frac{\mathrm{N}}{\mathrm{mm}^2} > \sigma_c^0 = -1{,}74 \frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$

<u>Felt 2 og 3:</u>

$\sigma_c^o = \frac{9{,}51*10^6*\left(-\frac{800}{2}\right)}{4{,}27*10^{10}}$

$\sigma_c^o = -0{,}089 \ \frac{\mathrm{N}}{\mathrm{mm}^2}$

Kontroll av betongens trykkspenninger i feltet:

$\sigma_{c,tillatt} = -0{,}6 * f_{ck}$ (Standard Norge, 2004, pkt. 5.10.2.2(5))

$\sigma_{c,tillatt} = -0{,}6 * 55$

$\sigma_{c,tillatt} = -33{,}00 \ \frac{\mathrm{N}}{\mathrm{mm}^2} > \sigma_c^0 = -0{,}089 \frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$

<u>Felt 4:</u>

$\sigma_c^o = \frac{20{,}28*10^6*\left(-\frac{800}{2}\right)}{4{,}27*10^{10}}$

$\sigma_c^o = -0{,}19 \ \frac{\mathrm{N}}{\mathrm{mm}^2}$

Kontroll av betongens trykkspenninger i feltet:

$\sigma_{c,tillatt} = -0,6 * f_{ck}$ (Standard Norge, 2004, pkt. 5.10.2.2(5))

$\sigma_{c,tillatt} = -0,6 * 55$

$\sigma_{c,tillatt} = -33,00\ \frac{\mathrm{N}}{\mathrm{mm}^2} > \sigma_c^0 = -0,19 \frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$

Betongspenninger i underkant for uopprisset tverrsnitt $\left(\boldsymbol{y = \frac{800}{2}}\ \mathbf{mm}\right)$:

$\sigma_c = \frac{M*y}{I}$ (Bell, 2017, s.83)

<u>Felt 1:</u>

$\sigma_c^u = \frac{185,37*10^6*\left(\frac{800}{2}\right)}{4,27*10^{10}}$

$\sigma_c^u = 1,74\ \frac{\mathrm{N}}{\mathrm{mm}^2}$

Kontroll av betongens strekkspenninger i feltet:

$f_{ctm} = 4,2 \frac{\mathrm{N}}{\mathrm{mm}^2}$ (Standard Norge, 2004, tabell 3.1)

$f_{ctm} = 4,2 \frac{\mathrm{N}}{\mathrm{mm}^2} > \sigma_c^u = 1,74 \frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$

Felt 2 og 3:

$$\sigma_c^u = \frac{9{,}51*10^6*\left(\frac{800}{2}\right)}{4{,}27*10^{10}}$$

$$\sigma_c^u = 0{,}089\ \frac{\mathrm{N}}{\mathrm{mm}^2}$$

Kontroll av betongens strekkspenninger i feltet:

$f_{ctm} = 4{,}2\frac{\mathrm{N}}{\mathrm{mm}^2}$ (Standard Norge, 2004, tabell 3.1)

$$f_{ctm} = 4{,}2\frac{\mathrm{N}}{\mathrm{mm}^2} > \sigma_c^u = 0{,}089\frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$$

Felt 4:

$$\sigma_c^u = \frac{20{,}28*10^6*\left(\frac{800}{2}\right)}{4{,}27*10^{10}}$$

$$\sigma_c^u = 0{,}19\ \frac{\mathrm{N}}{\mathrm{mm}^2}$$

Kontroll av betongens strekkspenninger i feltet:

$f_{ctm} = 4{,}2\frac{\mathrm{N}}{\mathrm{mm}^2}$ (Standard Norge, 2004, tabell 3.1)

$$f_{ctm} = 4{,}2\frac{\mathrm{N}}{\mathrm{mm}^2} > \sigma_c^u = 0{,}19\frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$$