VEDLEGG 10

DIMENSJONERING AV SPENNARMERING,

TVERRETNING

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

<u>Bruddgrensetilstand:</u>

Maksimalt opptredende moment og skjærkraft:

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

$M_{Ed,q} = 229{,}99$ kNm (Vedlegg 6, s. 3)

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

Spennarmering:

For å finne nødvendig mengde spennarmering tas det kun utgangspunkt i moment pga. jevnt fordelte laster, $M_{Ed,q}$.

Overslagsberegninger ble gjort for å finne omtrentlig mengde nødvendig armering:

Velger 12-taus kabler ⇒ $\phi = 90$ mm (Statens Vegvesen, 2017, s.30)

Overdekning:

Velger dimensjonerende brukstid: 100 år

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

$c_{min,dur} = 60$ mm (overkant og sidene) (Standard Norge, 2008, tabell NA.4.5N)

$c_{min,dur} = 45$ mm (underkant) (Standard Norge, 2008, tabell NA.4.5N)

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

$c_{min,b} = 1{,}5 * \varphi = 1{,}5 * 90 = 135$ 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))

$$c_{min} = max \begin{Bmatrix} c_{min,b} \\ c_{min,dur} \\ 10 \text{ mm} \end{Bmatrix} = max \begin{Bmatrix} 135 \text{ mm} \\ 60 \text{ mm} \\ 10 \text{ mm} \end{Bmatrix} = 135 \text{ mm}$$

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

$$c_{nom} = 135 \text{ mm} + 10 \text{ mm}$$

$$c_{nom} = 145{,}00 \text{ mm}$$

Krav til effektiv tverrsnittshøyde:

$d_{krav} = \sqrt{\frac{M_{Ed,q}}{0{,}269 * f_{cd} * b}}$ (Sørensen, 2013, s.284)

$$d_{krav} = \sqrt{\frac{229{,}99 * 10^6}{0{,}269 * 31{,}17 * 1000}}$$

$$d_{krav} = 165{,}62 \text{ mm}$$

Tverrsnittets nødvendige effektive høyde:

$d = h - c_{nom} - \frac{\phi_{kabel}}{2}$

$d = 800 - 145{,}00 - \frac{90}{2}$

$d = 610{,}00 \text{ mm} > d_{krav} = 165{,}62 \text{ mm} \Rightarrow OK$

Eksentrisitet:

$e = \frac{h}{2} - c_{nom} - \frac{\phi_{kabel}}{2}$

$e = \frac{800}{2} - 145{,}00 - \frac{90}{2}$

$e = 210{,}00 \text{ mm}$

Indre momentarm:

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

$z = (1 - 0{,}5 * 0{,}79 * 0{,}383) * 610{,}00$

$z = 517{,}72 \text{ mm}$

Nødvendig armeringsmengde mht. opptredende moment:

$A_{p,nødvendig} \geq \frac{M_{Ed,q}}{f_{pd} * z}$ (Sørensen, 2013, s.285)

$A_{p,nødvendig} \geq \frac{229{,}99 * 10^6}{1426{,}09 * 517{,}72}$

$A_{p,nødvendig} > 311{,}51 \text{ mm}^2$

Velger 12-taus kabler med tau som har tverrsnitt 140 mm^2.

1 stk. 12-taus kabel ⇒ $A_{p,12} = 1680{,}00 \text{ mm}^2$ (Statens Vegvesen, 2017, s.30)

Nødvendig antall kabler:

$n \geq \frac{A_{p,nødvendig}}{A_{p,12}}$ (Sørensen, 2013, s.41)

$n \geq \frac{311{,}51}{1680{,}00}$

$n \geq 0{,}19 \Longrightarrow n = 1$ stk. 12-taus kabel

Faktisk armeringsmengde:

$A_p = 1680{,}00 \text{ mm}^2$

Revidert verdi for α:

$\alpha_{rev} = \frac{f_{pd} * A_p}{\lambda * f_{cd} * b * d}$ (Sørensen, 2013, s.280)

$\alpha_{rev} = \frac{1426{,}09 * 1680{,}00}{0{,}79 * 31{,}17 * 1000 * 610{,}00}$

$\alpha_{rev} = 0{,}16$

Sjekker krav til armeringsmengde med den reviderte verdien for α:

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

$z_{rev} = (1 - 0{,}5 * 0{,}79 * 0{,}16) * 610{,}00$

$z_{rev} = 571{,}45$ mm

$A_{p,nødvendig,rev} \geq \frac{M_{Ed,q}}{f_{pd} * z_{rev}}$ (Sørensen, 2013, s.285)

$A_{p,nødvendig,rev} \geq \frac{229{,}99 * 10^6}{1426{,}09 * 571{,}45}$

$A_{p,nødvendig,rev} \geq 282{,}22\ \mathrm{mm}^2 < A_p = 1680{,}00\ \mathrm{mm}^2 \Rightarrow OK$

Største tillatte spenning i spennarmering ved oppspenning:

$\sigma_{p,max} = \min\{0{,}8 f_{pk}; 0{,}9 f_{p0,1k}\}$ (Standard Norge, 2004, pkt. 5.10.2.1(1))

$\sigma_{p,max} = \min\{0{,}8 * 1860; 0{,}9 * 1640\}$

$\sigma_{p,max} = \min\{1488{,}00\ ; 1476{,}00\} = 1476{,}00 \frac{\mathrm{N}}{\mathrm{mm}^2}$

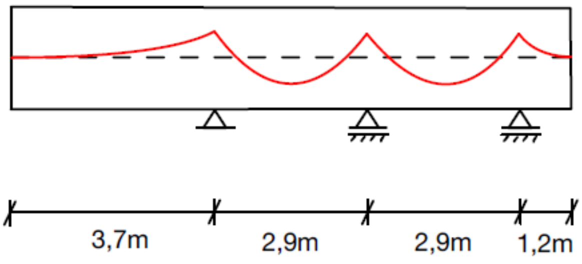
Største tillatte oppspenningskraft:

$P_{max} = A_p * \sigma_{p,max}$ (Standard Norge, 2004, pkt. 5.10.2.1(1))

$P_{max} = 1680{,}00 * 1476{,}00$

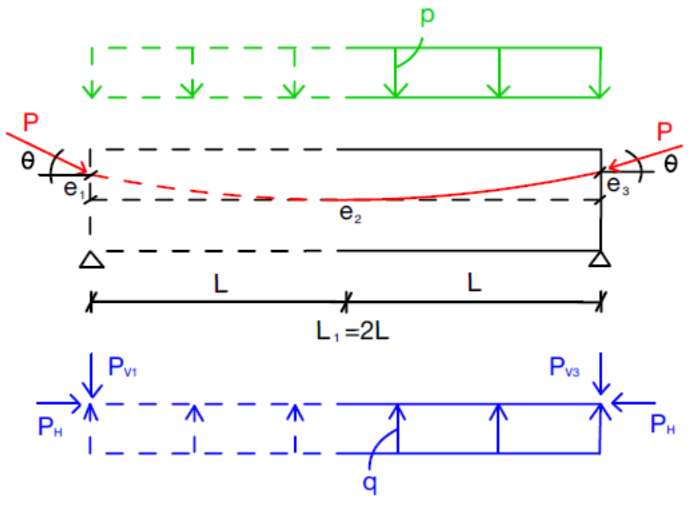
$P_{max} = 2479{,}68$ kN

Beregning av nødvendig oppspenningskraft: (Formula list, TKT4220 Concrete Structures 2, s.2)



Figur 1: Skisse av spennarmering i tverretning

Felt 1 og 4:



Figur 2: Skisse av lastbalansering for felt 1 og 4

$e_1 = e$

$e_2 = 0$

$e_3 = e$

$$e_m = \frac{e_1}{2} + e_2 + \frac{e_3}{2}$$

$$e_m = \frac{e}{2} + 0 + \frac{e}{2}$$

$$e_m = e$$

$$e = h - C_{nom} - \frac{\phi}{2} - \frac{h}{2}$$

$$e = 800 - 145{,}00 - \frac{90}{2} - \frac{800}{2}$$

$$e = 210{,}00 \text{ mm}$$

$$p = q = \frac{8*P*e_m}{L_1^2}$$

$$p = \frac{8*P*e}{(2L)^2}$$

$$p = \frac{2*P*e}{L^2}$$

Felt 1:

$p = maksimal\ jevnt\ fordelt\ last\ som\ forekommer$ på $spennet$

$p = 26{,}1 + 7{,}5$ (Vedlegg 3, s. 9)

$$p = 33{,}6\,\frac{\text{kN}}{\text{m}}$$

$$p = \frac{2*P*e}{L^2} \Longrightarrow P = \frac{p*L^2}{2*e}$$

$P = \frac{p*L^2}{2*e}$

$P = \frac{33,6*3700^2}{2*210,00} * 10^{-3}$

$P_{nødvendig} = 1095{,}20 \text{ kN} < P_{max} = 2479{,}68 \text{ kN} \Longrightarrow OK$

Felt 4:

$p = maksimal\ jevnt\ fordelt\ last\ som\ forekommer\ \text{på}\ spennet$

$p = 26{,}1 + 8{,}1$ (Vedlegg 3, s. 9)

$p = 34{,}2\,\frac{\text{kN}}{\text{m}}$

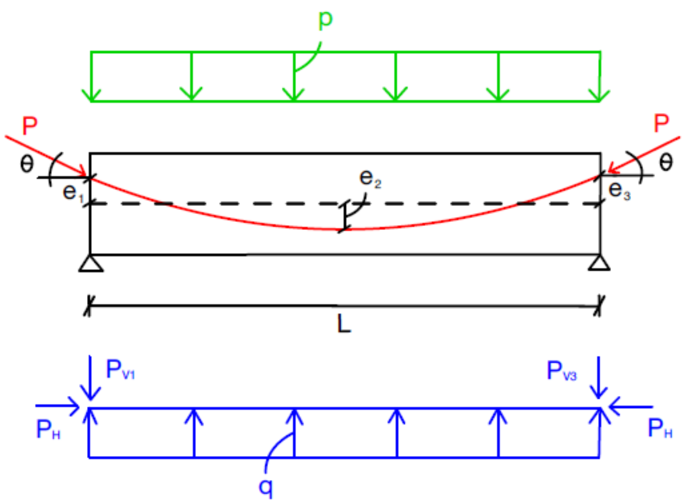
$p = \frac{2*P*e}{L^2} \Longrightarrow P = \frac{p*L^2}{2*e}$

$P = \frac{p*L^2}{2*e}$

$P = \frac{34,2*1200^2}{2*210,00} * 10^{-3}$

$P_{nødvendig} = 117{,}26 \text{ kN} < P_{max} = 2479{,}68 \text{ kN} \Longrightarrow OK$

Felt 2 og 3:



Figur 3: Skisse av lastbalansering for felt 2 og 3

$$e_1 = e$$

$$e_2 = e$$

$$e_3 = e$$

$$e_m = \frac{e_1}{2} + e_2 + \frac{e_3}{2}$$

$$e_m = \frac{e}{2} + e + \frac{e}{2}$$

$$e_m = 2 * e$$

$$e = h - C_{nom} - \frac{\phi}{2} - \frac{h}{2}$$

$$e = 800 - 145{,}00 - \frac{90}{2} - \frac{800}{2}$$

$$e = 210{,}00 \text{ mm}$$

$p = q = \frac{8*P*e_m}{L^2}$

$p = \frac{8*P*2*e}{L^2}$

$p = \frac{16*P*e}{L^2}$

$p = maksimal\ jevnt\ fordelt\ last\ som\ forekommer$ på $spennet$

$p = 26{,}1 + 8{,}1$ (Vedlegg 3, s. 9)

$p = 34{,}2\,\frac{\text{kN}}{\text{m}}$

$p = \frac{16*P*e}{L^2} \Longrightarrow\ P = \frac{p*L^2}{16*e}$

$P = \frac{p*L^2}{16*e}$

$P = \frac{34{,}2*2900^2}{16*210{,}00} * 10^{-3}$

$P_{nødvendig} = 85{,}60\text{ kN} < P_{max} = 2479{,}68\text{ kN} \Longrightarrow OK$

Strekkarmering:

Sjekker om spennarmeringen har tilstrekkelig kapasitet til å tåle maksimalt opptredende moment M_{Ed}, med både jevnt fordelte laster og punktlaster, eller om det er behov for strekkarmering i tillegg til spennarmeringen:

$A_{p,nødvendig} \geq \frac{M_{Ed}}{f_{pd}*z}$ (Sørensen, 2013, s.285)

$A_{p,nødvendig} \geq \frac{454,65*10^6}{1426,09*571,45}$

$A_{p,nødvendig} > 557,89 \text{ mm}^2 < A_p = 1680,00 \text{ mm}^2 \Rightarrow Ikke\ behov\ for\ strekkarmering$

Trykkarmering:

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

$M_{Rd} = 0{,}250 * 31{,}17 * 1000 * 610{,}00^2$

$M_{Rd} = 2899{,}59 \text{ kNm} > M_{Ed} = 454{,}65 \text{ kNm} \Rightarrow \text{ikke behov for trykkarmering}$ (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))

$k = 1 + \sqrt{\frac{200}{610,00}} = 1,57 < 2,0 \Rightarrow OK$

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

$\rho_L = \frac{1680,00}{1000*610,00} = 2,75 * 10^{-3} < 0,02 \Rightarrow OK$

$k_1 = 0,15\ ved\ trykk$ (Standard Norge, 2008, pkt. NA6.2.2(1))

Forenkler og setter $tap = 0$

$N_{Ed} = -P * \gamma_p * (1 - tap)$ (Løsningsforslag øving 5, TKT4220 Concrete Structures, s.2)

$N_{Ed} = -(-1095,20) * 0,9 * (1 - 0)$

$N_{Ed} = 985,68$ kN

$\sigma_{cp} = \frac{N_{Ed}}{A_c} < 0,2 f_{cd}$ (Standard Norge, 2004, pkt. 6.2.2(1))

$\sigma_{cp} = \frac{985,68}{1000*800} < 0,2 * 31,17$

$\sigma_{cp} = 1,23 * 10^{-3} \frac{\mathrm{N}}{\mathrm{mm}^2} < 6,23 \frac{\mathrm{N}}{\mathrm{mm}^2} \Longrightarrow OK$

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

$V_{Rd,c} = \left[0{,}12 * 1{,}57 * (100 * 2{,}75 * 10^{-3} * 55)^{\frac{1}{3}} + 0{,}15 * 1{,}23 * 10^{-3}\right] * 1000 * 610{,}00$

$V_{Rd,c} = 284{,}32$ kN

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

$V_{Rd,c,min} = 0{,}035 * 1{,}57^{\frac{3}{2}} * 55^{\frac{1}{2}} * 1000 * 610{,}00$

$V_{Rd,c,min} = 311{,}48$ kN

Krav:

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

$284{,}32 \text{ kN} < 311{,}48 \text{ kN} \Rightarrow V_{Rd,c} = 311{,}48 \text{ kN}$

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

$311{,}48 \text{ kN} < 485{,}34 \text{ kN} \Rightarrow$ 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)

$\frac{A_{s,w}}{s} \geq \frac{485{,}34 * 10^3}{434{,}78 * 571{,}45 * 1}$

$\frac{A_{s,w}}{s} \geq 1{,}95 \frac{\text{mm}^2}{\text{mm}}$

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:

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

$1{,}95\,\frac{\mathrm{mm}^2}{\mathrm{mm}} > 1{,}48\,\frac{\mathrm{mm}^2}{\mathrm{mm}} \Rightarrow OK$

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))

$s = \frac{2*\pi*\left(\frac{10}{2}\right)^2}{485{,}34*10^3} * 434{,}78 * 571{,}45 * 1$

$s = 80{,}41\ \mathrm{mm} \Rightarrow 80\ \mathrm{mm}$

Krav til minimum senteravstand:

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

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

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

Krav til maksimum senteravstand:

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

$s_{L,max} = 0{,}6 * 571{,}45$

$s_{L,max} = 342{,}87\ \mathrm{mm}$

Krav til senteravstand:

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

$25{,}00 \text{ mm} < 80{,}00 \text{ mm} < 342{,}87 \text{ mm} \Rightarrow OK$

Skjærtrykkapasitet:

$\alpha_{cw} = \left(1 + \frac{\sigma_{cp}}{f_{cd}}\right) \; for \; 0 < \sigma_{cp} \leq 0{,}25 * f_{cd}$ (Standard Norge, 2008, pkt. NA.6.2.3(3))

$\alpha_{cw} = \left(1 + \frac{1{,}23*10^{-3}}{31{,}17}\right)$

$\alpha_{cw} = 1{,}00$

$v_1 = 0{,}6$ gjelder for $f_{ck} \leq 60 \, \frac{\text{N}}{\text{mm}^2}$ (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))

$V_{Rd,max} = \frac{1*1000*571{,}45*0{,}6*31{,}17}{1+1}$

$V_{Rd,max} = 5343{,}63 \text{ kN}$

Krav:

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

$5343{,}63 \text{ kN} > 485{,}34 \text{ kN} \Rightarrow OK$

<u>Bruksgrensetilstand:</u>

Maksimale spenninger pga. kryp (kun forspenning):

$\eta = \frac{E_p}{E_{cm}}$ (Sørensen, 2013, s. 252)

$\eta = \frac{195\ 000}{38\ 000}$

$\eta = 5{,}13$

$A_t = A_c + (\eta - 1) * A_p$ (Sørensen, 2013, s. 252)

$A_t = 1000 * 800 + (5{,}13 - 1) * 1680{,}00$

$A_t = 806\ 938{,}40$ mm^2

$y_t = \frac{(\eta-1)*A_p*e}{A_t}$ (Sørensen, 2013, s. 252)

$y_t = \frac{(5{,}13-1)*1680{,}00*210{,}00}{806\ 938{,}40}$

$y_t = 1{,}81$ mm

$I_t = \frac{1}{12} * b * h^3 + b * h * y_t^2 + (\eta - 1) * A_p * (e - y_t)^2$ (Sørensen, 2013, s. 252)

$I_t = \frac{1}{12} * 1000 * 800^3 + 1000 * 800 * 1{,}81^2 + (5{,}13 - 1) * 1680{,}00 * (210{,}00 - 1{,}81)^2$

$I_t = 4{,}30 * 10^{10}$ mm^4

$N = -P_0$ (Sørensen, 2013, s.252)

$N = -1095{,}20$ kN

$M_t = -P_0 * (e - y_t)$ (Sørensen, 2013, s.253)

$M_t = -1095{,}20 * 10^3 * (210{,}00 - 1{,}81)$

$M_t = -228{,}01$ kNm

Betongspenninger i underkant av tverrsnitt $\left(y = \frac{800}{2}\ \mathrm{mm}\right)$:

$\sigma_c^u = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^u = -\frac{1095{,}20*10^3}{806\,938{,}40} - \frac{228{,}01*10^6*\left(\frac{800}{2}-1{,}81\right)}{4{,}30*10^{10}}$

$\sigma_c^u = -3{,}47\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Betongspenninger i overkant av tverrsnitt $\left(y = -\frac{800}{2}\ \mathrm{mm}\right)$:

$\sigma_c^o = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^o = -\frac{1095{,}20*10^3}{806\,938{,}40} - \frac{228{,}01*10^6*\left(-\frac{800}{2}-1{,}81\right)}{4{,}30*10^{10}}$

$\sigma_c^o = 0{,}77\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (strekk)$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210 mm):

$\sigma_c^t = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^t = -\frac{1095{,}20*10^3}{806\,938{,}40} - \frac{228{,}01*10^6*(210-1{,}81)}{4{,}30*10^{10}}$

$\sigma_c^t = -2{,}46\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Kontroll av trykkspenninger:

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

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

$\sigma_{c,tillatt} = -33{,}00 \frac{\mathrm{N}}{\mathrm{mm^2}} > \sigma_c^u = -3{,}47 \frac{\mathrm{N}}{\mathrm{mm^2}} \Longrightarrow OK$

Kontroll av strekkspenninger:

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

$f_{ctm} = 4{,}2 \frac{\mathrm{N}}{\mathrm{mm^2}} > \sigma_c^o = 0{,}77 \frac{\mathrm{N}}{\mathrm{mm^2}} \Longrightarrow OK$

Spenninger pga. kryp (forspenning og egenlast):

Beregnede verdier, likt som for kun forspenning:

$\eta = 5{,}13$

$A_t = 806\ 938{,}40 \text{ mm}^2$

$y_t = 1{,}81 \text{ mm}$

$I_t = 4{,}30 * 10^{10} \text{ mm}^4$

$N = -1095{,}20 \text{ kN}$

<u>Felt 1:</u>

$g = 21{,}75 \frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s. 1)

$R = 0{,}61 \text{ kN}$ (Vedlegg 5, s. 1)

$M_{g+R} = \frac{1}{2} * g * L^2 + R * L$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$M_{g+R} = \frac{1}{2} * 21{,}75 * 3700^2 + 0{,}61 * 10^3 * 3700$

$M_{g+R} = 171{,}45 \text{ kNm}$

$M_t = -P_0 * (e - y_t) + M_{g+R}$ (Sørensen, 2013, s.253)

$M_t = -1095{,}20 * 10^3 * (210{,}00 - 1{,}81) + 171{,}45 * 10^6$

$M_t = -56{,}56 \text{ kNm}$

Betongspenninger i underkant av tverrsnitt $\left(y = \frac{800}{2}\text{ mm}\right)$:

$$\sigma_c^u = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$$ (Sørensen, 2013, s.253)

$$\sigma_c^u = -\frac{1095,20*10^3}{806\,938,40} - \frac{56,56*10^6*\left(\frac{800}{2}-1,81\right)}{4,30*10^{10}}$$

$$\sigma_c^u = -1,88\,\frac{\text{N}}{\text{mm}^2}\ (trykk)$$

Betongspenninger i overkant av tverrsnitt $\left(y = -\frac{800}{2}\text{ mm}\right)$:

$$\sigma_c^o = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$$ (Sørensen, 2013, s.253)

$$\sigma_c^o = -\frac{1095,20*10^3}{806\,938,40} - \frac{56,56*10^6*\left(-\frac{800}{2}-1,81\right)}{4,30*10^{10}}$$

$$\sigma_c^o = -0,82\,\frac{\text{N}}{\text{mm}^2}\ (trykk)$$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210,00 mm):

$$\sigma_c^t = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$$ (Sørensen, 2013, s.253)

$$\sigma_c^t = -\frac{1095,20*10^3}{806\,938,40} - \frac{56,56*10^6*(210,00-1,81)}{4,30*10^{10}}$$

$$\sigma_c^t = -1,63\,\frac{\text{N}}{\text{mm}^2}\ (trykk)$$

Felt 2 og 3:

$g = 21{,}75 \frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s. 3)

$M_g = \frac{g * L^2}{24}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$M_g = \frac{21{,}75 * 2900^2}{24}$

$M_g = 7{,}62$ kNm

$M_t = -P_0 * (e - y_t) + M_g$ (Sørensen, 2013, s.253)

$M_t = -1095{,}20 * 10^3 * (210{,}00 - 1{,}81) + 7{,}62 * 10^6$

$M_t = -220{,}39$ kNm

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

$\sigma_c^u = \frac{N}{A_t} + \frac{M_t * (y - y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^u = -\frac{1095{,}20 * 10^3}{806\,938{,}40} - \frac{220{,}39 * 10^6 * \left(\frac{800}{2} - 1{,}81\right)}{4{,}30 * 10^{10}}$

$\sigma_c^u = -3{,}40 \frac{\text{N}}{\text{mm}^2}$ $(trykk)$

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

$\sigma_c^o = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^o = -\frac{1095,20*10^3}{806\,938,40} - \frac{220,39*10^6*\left(-\frac{800}{2}-1,81\right)}{4,30*10^{10}}$

$\sigma_c^o = 0,70\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (strekk)$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210,00 mm):

$\sigma_c^t = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^t = -\frac{1095,20*10^3}{806\,938,40} - \frac{220,39*10^6*(210,00-1,81)}{4,30*10^{10}}$

$\sigma_c^t = -2,42\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

<u>Felt 4:</u>

$g = 21,75\,\frac{\mathrm{kN}}{\mathrm{m}}$ (Vedlegg 5, s. 5)

$R = 0,61$ kN (Vedlegg 5, s. 5)

$M_{g+R} = \frac{1}{2} * g * L^2 + R * L$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$M_{g+R} = \frac{1}{2} * 21,75 * 1200^2 + 0,61 * 10^3 * 1200$

$M_{g+R} = 16,39$ kNm

$M_t = -P_0 * (e - y_t) + M_{g+R}$ (Sørensen, 2013, s.253)

$M_t = -1095{,}20 * 10^3 * (210 - 1{,}81) + 16{,}39 * 10^6$

$M_t = -211{,}62$ kNm

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

$\sigma_c^u = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^u = -\frac{1095{,}20*10^3}{806\,938{,}40} - \frac{211{,}62*10^6*\left(\frac{800}{2}-1{,}81\right)}{4{,}30*10^{10}}$

$\sigma_c^u = -3{,}32\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

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

$\sigma_c^o = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^o = -\frac{1095{,}20*10^3}{806\,938{,}40} - \frac{211{,}62*10^6*\left(-\frac{800}{2}-1{,}81\right)}{4{,}30*10^{10}}$

$\sigma_c^o = 0{,}62\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (strekk)$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210 mm):

$\sigma_c^t = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^t = -\frac{1095{,}20*10^3}{806\,938{,}40} - \frac{211{,}62*10^6*(210{,}00-1{,}81)}{4{,}30*10^{10}}$

$\sigma_c^t = -2{,}38\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Spenninger pga. kryp (forspenning, egenlast og trafikklast):

$\eta = \frac{E_p}{E_{middel}}$ (Sørensen, 2013, s.252)

$\eta = \frac{195\ 000}{15\ 133{,}96}$

$\eta = 12{,}88$

$A_t = A_c + (\eta - 1) * A_p$ (Sørensen, 2013, s.252)

$A_t = 1000 * 800 + (12{,}88 - 1) * 1680{,}00$

$A_t = 819\ 958{,}40\ \text{mm}^2$

$y_t = \frac{(\eta-1)*A_p*e}{A_t}$ (Sørensen, 2013, s.252)

$y_t = \frac{(12{,}88-1)*1680{,}00*210{,}00}{819\ 958{,}40}$

$y_t = 5{,}11\ \text{mm}$

$I_t = \frac{1}{12} * b * h^3 + b * h * y_t^2 + (\eta - 1) * A_p * (e - y_t)^2$ (Sørensen, 2013, s.252)

$I_t = \frac{1}{12} * 1000 * 800^3 + 1000 * 800 * 5{,}11^2 + (12{,}88 - 1) * 1680{,}00 * (210{,}00 - 5{,}11)^2$

$I_t = 4{,}35 * 10^{10}\ \text{mm}^4$

$N = -P_0$ (Sørensen, 2013, s.252)

$N = -1095{,}20\ \text{kN}$

Felt 1:

$g = 21{,}75\,\frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s.1)

$p = 5{,}00\,\frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s.1)

$R = 0{,}61$ kN (Vedlegg 5, s.1)

$M_{g+p+R} = \frac{1}{2} * (g + p) * L^2 + R * L$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$M_{g+p+R} = \frac{1}{2} * (21{,}75 + 5{,}00) * 3700^2 + 0{,}61 * 10^3 * 3700$

$M_{g+p+R} = 185{,}36$ kNm

$M_t = -P_0 * (e - y_t) + M_{g+p+R}$ (Sørensen, 2013, s. 253)

$M_t = -1095{,}20 * 10^3 * (210{,}00 - 31{,}91) + 185{,}36 * 10^6$

$M_t = -42{,}65$ kNm

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

$\sigma_c^u = \frac{N}{A_t} + \frac{M_t * (y - y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^u = -\frac{1095{,}20 * 10^3}{819\,958{,}40} - \frac{42{,}65 * 10^6 * \left(\frac{800}{2} - 5{,}11\right)}{4{,}35 * 10^{10}}$

$\sigma_c^u = -1{,}72\ \frac{\text{N}}{\text{mm}^2}\ (trykk)$

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

$\sigma_c^o = \frac{N}{A_t} + \frac{M_t * (y - y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^o = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{42{,}65*10^6*\left(-\frac{800}{2}-5{,}11\right)}{4{,}35*10^{10}}$

$\sigma_c^o = -0{,}94\ \frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210,00 mm):

$\sigma_c^t = \frac{N}{A_t} + \frac{M_t * (y - y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^t = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{42{,}65*10^6*(210{,}00-5{,}11)}{4{,}35*10^{10}}$

$\sigma_c^t = -1{,}54\ \frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Spenningsendring:

$\varepsilon_{ck}^t = \Delta\varepsilon_{pk} = \frac{\sigma_c^t(korttid)}{E_{cm}}$ (Sørensen, 2013, s.259)

$\Delta\varepsilon_{pk} = -\frac{1{,}63}{38\,000}$

$\Delta\varepsilon_{pk} = -4{,}29 * 10^{-5}$

$\varepsilon_{cL}^t = \Delta\varepsilon_{pL} = \frac{\sigma_c^t(langtid)}{E_{middel}}$ (Sørensen, 2013, s.259)

$\Delta\varepsilon_{pL} = -\frac{1{,}54}{15\,133{,}96}$

$\Delta\varepsilon_{pL} = -1{,}02 * 10^{-4}$

$\Delta\sigma_{pk} = \Delta\varepsilon_{pk} * E_p$ (Sørensen, 2013, s.259)

$\Delta\sigma_{pk} = -4{,}29 * 10^{-5} * 195\,000$

$\Delta\sigma_{pk} = -8{,}37\,\frac{\mathrm{N}}{\mathrm{mm}^2}$

$\Delta\sigma_{pL} = \Delta\varepsilon_{pL} * E_p$ (Sørensen, 2013, s.259)

$\Delta\sigma_{pL} = -1{,}02 * 10^{-4} * 195\,000$

$\Delta\sigma_{pL} = -19{,}89\,\frac{\mathrm{N}}{\mathrm{mm}^2}$

$\Delta\sigma_{p,kryp} = \Delta\sigma_{pL} - \Delta\sigma_{pk}$ (Sørensen, 2013, s.259)

$\Delta\sigma_{p,kryp} = -19{,}89 - (-8{,}37)$

$\Delta\sigma_{p,kryp} = -11{,}52\,\frac{\mathrm{N}}{\mathrm{mm}^2}$

Prosentvis reduksjon av kraft i spennarmering pga. kryp:

$\frac{|\Delta\sigma_{p,kryp}|}{\sigma_{p,max}} * 100\%$ (Sørensen, 2013, s.259)

$\frac{11{,}52}{1476{,}00} * 100\% = 0{,}78\%$

Felt 2 og 3:

$g = 21{,}75\,\frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s.3)

$p = 5{,}4\,\frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s.3)

$M_{g+p} = \frac{(g+p)*L^2}{24}$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$M_{g+p} = \frac{(21{,}75+5{,}4)*2900^2}{24}$

$M_{g+p} = 9{,}51$ kNm

$M_t = -P_0 * (e - y_t) + M_{g+p}$ (Sørensen, 2013, s.253)

$M_t = -1095{,}20 * 10^3 * (210{,}00 - 31{,}91) + 9{,}51 * 10^6$

$M_t = -218{,}50$ kNm

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

$\sigma_c^u = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^u = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{218{,}50*10^6*\left(\frac{800}{2}-5{,}11\right)}{4{,}35*10^{10}}$

$\sigma_c^u = -3{,}32\,\frac{\text{N}}{\text{mm}^2}\ (trykk)$

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

$\sigma_c^o = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^o = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{218{,}50*10^6*\left(-\frac{800}{2}-5{,}11\right)}{4{,}35*10^{10}}$

$\sigma_c^o = 0{,}70\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (strekk)$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210,00 mm):

$\sigma_c^t = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^t = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{218{,}50*10^6*(210{,}00-5{,}11)}{4{,}35*10^{10}}$

$\sigma_c^t = -2{,}36\,\frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Spenningsendring:

$\varepsilon_{ck}^t = \Delta\varepsilon_{pk} = \frac{\sigma_c^t(korttid)}{E_{cm}}$ (Sørensen, 2013, s.259)

$\Delta\varepsilon_{pk} = -\frac{2{,}42}{38\,000}$

$\Delta\varepsilon_{pk} = -6{,}37 * 10^{-5}$

$\varepsilon_{cL}^t = \Delta\varepsilon_{pL} = \frac{\sigma_c^t(langtid)}{E_{middel}}$ (Sørensen, 2013, s.259)

$\Delta\varepsilon_{pL} = -\frac{2{,}36}{15\,133{,}96}$

$\Delta\varepsilon_{pL} = -1{,}56 * 10^{-4}$

$\Delta\sigma_{pk} = \Delta\varepsilon_{pk} * E_p$ (Sørensen, 2013, s.259)

$\Delta\sigma_{pk} = -6{,}37 * 10^{-5} * 195\ 000$

$\Delta\sigma_{pk} = -12{,}42 \frac{\text{N}}{\text{mm}^2}$

$\Delta\sigma_{pL} = \Delta\varepsilon_{pL} * E_p$ (Sørensen, 2013, s.259)

$\Delta\sigma_{pL} = -1{,}56 * 10^{-4} * 195\ 000$

$\Delta\sigma_{pL} = -30{,}42 \frac{\text{N}}{\text{mm}^2}$

$\Delta\sigma_{p,kryp} = \Delta\sigma_{pL} - \Delta\sigma_{pk}$ (Sørensen, 2013, s.259)

$\Delta\sigma_{p,kryp} = -30{,}42 - (-12{,}42)$

$\Delta\sigma_{p,kryp} = -18{,}00 \frac{\text{N}}{\text{mm}^2}$

Prosentvis reduksjon av kraft i spennarmering pga. kryp:

$\frac{|\Delta\sigma_{p,kryp}|}{\sigma_{p,max}} * 100\%$ (Sørensen, 2013, s.259)

$\frac{18{,}00}{1476{,}00} * 100\% = 1{,}22\%$

Felt 4:

$g = 21{,}75\,\frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s. 5)

$p = 5{,}4\,\frac{\text{kN}}{\text{m}}$ (Vedlegg 5, s. 5)

$R = 0{,}61$ kN (Vedlegg 5, s. 5)

$M_{g+p+R} = \frac{1}{2} * (g + p) * L^2 + R * L$ (Aalberg, Clausen og Larsen, 2003, tabell 3.2)

$M_{g+p+R} = \frac{1}{2} * (21{,}75 + 5{,}4) * 1200^2 + 0{,}61 * 10^3 * 1200$

$M_{g+p+R} = 20{,}28$ kNm

$M_t = -P_0 * (e - y_t) + M_{g+p+R}$ (Sørensen, 2013, s.253)

$M_t = -1095{,}20 * 10^3 * (210{,}00 - 31{,}91) + 20{,}28 * 10^6$

$M_t = -207{,}73$ kNm

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

$\sigma_c^u = \frac{N}{A_t} + \frac{M_t * (y - y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^u = -\frac{1095{,}20 * 10^3}{819\,958{,}40} - \frac{207{,}73 * 10^6 * \left(\frac{800}{2} - 5{,}11\right)}{4{,}35 * 10^{10}}$

$\sigma_c^u = -3{,}22\ \frac{\text{N}}{\text{mm}^2}\ (trykk)$

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

$\sigma_c^o = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^o = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{207{,}73*10^6*\left(-\frac{800}{2}-5{,}11\right)}{4{,}35*10^{10}}$

$\sigma_c^o = 0{,}60\ \frac{\mathrm{N}}{\mathrm{mm}^2}\ (strekk)$

Betongspenninger ved spennarmeringen i tverrsnittet (y = e = 210,00 mm):

$\sigma_c^t = \frac{N}{A_t} + \frac{M_t*(y-y_t)}{I_t}$ (Sørensen, 2013, s.253)

$\sigma_c^t = -\frac{1095{,}20*10^3}{819\,958{,}40} - \frac{207{,}73*10^6*(210{,}00-5{,}11)}{4{,}35*10^{10}}$

$\sigma_c^t = -2{,}31\ \frac{\mathrm{N}}{\mathrm{mm}^2}\ (trykk)$

Spenningsendring:

$\varepsilon_{ck}^t = \Delta\varepsilon_{pk} = \frac{\sigma_c^t(korttid)}{E_{cm}}$ (Sørensen, 2013, s.259)

$\Delta\varepsilon_{pk} = -\frac{2{,}38}{38\,000}$

$\Delta\varepsilon_{pk} = -6{,}26 * 10^{-5}$

$\varepsilon_{cL}^t = \Delta\varepsilon_{pL} = \frac{\sigma_c^t(langtid)}{E_{middel}}$ (Sørensen, 2013, s.259)

$\Delta\varepsilon_{pL} = -\frac{2{,}31}{15\,133{,}96}$

$\Delta\varepsilon_{pL} = -1{,}53 * 10^{-4}$

$\Delta\sigma_{pk} = \Delta\varepsilon_{pk} * E_p$ (Sørensen, 2013, s.259)

$\Delta\sigma_{pk} = -6{,}26 * 10^{-5} * 195\ 000$

$\Delta\sigma_{pk} = -12{,}21 \frac{\mathrm{N}}{\mathrm{mm}^2}$

$\Delta\sigma_{pL} = \Delta\varepsilon_{pL} * E_p$ (Sørensen, 2013, s.259)

$\Delta\sigma_{pL} = -1{,}53 * 10^{-4} * 195\ 000$

$\Delta\sigma_{pL} = -29{,}84 \frac{\mathrm{N}}{\mathrm{mm}^2}$

$\Delta\sigma_{p,kryp} = \Delta\sigma_{pL} - \Delta\sigma_{pk}$ (Sørensen, 2013, s.259)

$\Delta\sigma_{p,kryp} = -29{,}84 - (-12{,}21)$

$\Delta\sigma_{p,kryp} = -17{,}63 \frac{\mathrm{N}}{\mathrm{mm}^2}$

Prosentvis reduksjon av kraft i spennarmering pga. kryp:

$\frac{|\Delta\sigma_{p,kryp}|}{\sigma_{p,max}} * 100\%$ (Sørensen, 2013, s.259)

$\frac{17{,}63}{1476{,}00} * 100\% = 1{,}19\%$

Spenningsendring pga. svinn:

Tidligere beregnede verdier:

$A_t = 819\,958{,}40$ mm^2

$A_p = 1680{,}00$ mm^2

$y_t = 5{,}11$ mm

$I_t = 4{,}35 * 10^{10}$ mm^4

$e = 210{,}00$ mm

$\varepsilon_{cs} = -2{,}55 * 10^{-4}$ (Vedlegg 8, s. 19)

$E_{middel} = 15\,133{,}96 \frac{\text{N}}{\text{mm}^2}$ (Vedlegg 8, s. 14)

$N_s = |\varepsilon_{sc}| * E_p * A_p$ (Sørensen, 2013, s.260)

$N_s = 2{,}55 * 10^{-4} * 195\,000 * 1680{,}00$

$N_s = 83{,}54$ kN

$\Delta\varepsilon_{p,svinn} = \varepsilon_{cs} + \frac{N_s}{E_{middel} * A_t} + \frac{N_s * (e - y_t)^2}{E_{middel} * I_t}$ (Sørensen, 2013, s.260)

$\Delta\varepsilon_{p,svinn} = -2{,}55 * 10^{-4} + \frac{83{,}54 * 10^3}{15\,133{,}96 * 819\,958{,}40} + \frac{83{,}54 * 10^3 * (210{,}00 - 5{,}11)^2}{15\,133{,}96 * 4{,}35 * 10^{10}}$

$\Delta\varepsilon_{p,svinn} = -2{,}43 * 10^{-4}$

Spenningsendring i spennarmeringen pga. svinn:

$\Delta\sigma_{p,svinn} = \Delta\varepsilon_{p,svinn} * E_p$ (Sørensen, 2013, s.261)

$\Delta\sigma_{p,svinn} = -2{,}43 * 10^{-4} * 195\,000$

$\Delta\sigma_{p,svinn} = -47{,}39\,\frac{\mathrm{N}}{\mathrm{mm}^2}$

Prosentvis reduksjon av kraft i spennarmering pga. svinn:

$\frac{|\Delta\sigma_{p,svinn}|}{\sigma_{p,max}} * 100\%$ (Sørensen, 2013, s.261)

$\frac{47{,}39}{1476{,}00} * 100\% = 3{,}21\%$

Spenningsendring pga. relaksasjon:

$\rho_{1000} = 2{,}5\%$ (Standard Norge, 2004, pkt. 3.3.2(6))

$\sigma_{pi} = \sigma_{pm0}$ (Standard Norge, 2004, pkt. 3.3.2(7))

$\sigma_{pm0} = \min\{0{,}75 f_{pk}; 0{,}85 f_{p0,1k}\}$ (Standard Norge, 2004, pkt. 5.10.3(2))

$\sigma_{pm0} = \min\{0{,}75 * 1860; 0{,}85 * 1640\}$

$\sigma_{pm0} = \min\{1395{,}00; 1394{,}00\}$

$\sigma_{pm0} = 1394{,}00 \frac{\text{N}}{\text{mm}^2}$

$\mu = \frac{\sigma_{pi}}{f_{pk}}$ (Sørensen, 2013, s.263)

$\mu = \frac{1394{,}00}{1860}$

$\mu = 0{,}75$

$\frac{\Delta\sigma_{pr}}{\sigma_{pi}} = 0{,}66 * \rho_{1000} * e^{9{,}1\mu} \left(\frac{t}{1000}\right)^{0{,}75(1-\mu)} * 10^{-5}$ (Standard Norge, 2004, pkt. 3.3.2(7))

Omformulert:

$$\Delta\sigma_{pr} = \left(0{,}66 * \rho_{1000} * e^{9{,}1\mu} \left(\frac{t}{1000}\right)^{0{,}75(1-\mu)} * 10^{-5}\right) * \sigma_{pi}$$

$$\Delta\sigma_{pr} = \left(0{,}66 * 2{,}5 * e^{9{,}1*0{,}75} * \left(\frac{500\,000}{1000}\right)^{0{,}75*(1-0{,}75)} * 10^{-5}\right) * 1394{,}00$$

$$\Delta\sigma_{pr} = 67{,}90 \frac{\text{N}}{\text{mm}^2}$$

Prosentvis reduksjon av kraft i spennarmeringen pga. relaksasjon:

$\frac{|\Delta\sigma_{pr}|}{\sigma_{p,max}} * 100\%$ (Sørensen, 2013, s.264)

$\frac{67,90}{1476,00} * 100\% = 4,60\%$

Total prosentvis reduksjon av kraft i spennarmeringen:

Felt 1:

$$0{,}78\% + 3{,}21\% + 4{,}60\% = 8{,}59\%$$

Felt 2 og 3:

$$1{,}22\% + 3{,}21\% + 4{,}60\% = 9{,}03\%$$

Felt 4:

$$1{,}19\% + 3{,}21\% + 4{,}60\% = 9{,}00\%$$

Nedbøying:

Krav til maksimum nedbøying:

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

<u>Felt 1:</u>

$\delta_{tillatt} = \frac{3700}{500}$

$\delta_{tillatt} = 7{,}40$ mm

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

$\delta_{tillatt} = \frac{2900}{500}$

$\delta_{tillatt} = 5{,}80$ mm

<u>Felt 4:</u>

$\delta_{tillatt} = \frac{1200}{500}$

$\delta_{tillatt} = 2{,}40$ mm

Oppbøying av bjelke:

$\delta_b = \frac{P*e}{EI} * \frac{L^2}{12}$ (Sørensen, 2013, s.226)

<u>Felt 1:</u>

$$\delta_{b,start} = \frac{1095{,}20*10^3*210{,}00}{15\ 133{,}96*\frac{1}{12}*1000*800^3} * \frac{3700^2}{12}$$

$\delta_{b,start} = 0{,}41$ mm

$$\delta_{b,langtid} = \frac{1095{,}20*10^3*(100\%-8{,}59\%)*210{,}00}{15\ 133{,}96*\frac{1}{12}*1000*800^3} * \frac{3700^2}{12}$$

$\delta_{b,langtid} = 0{,}37$ mm

Nedbøying pga. kryp, svinn og relaksasjon:

$\delta_{total} = \delta_{b,start} - \delta_{b,langtid}$

$\delta_{total} = 0{,}41 - 0{,}37$

$\delta_{total} = 0{,}040$ mm $< \delta_{tillatt} = 7{,}40$ mm $\Rightarrow OK$

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

$$\delta_{b,start} = \frac{1095{,}20 * 10^3 * 210{,}00}{15\,133{,}96 * \frac{1}{12} * 1000 * 800^3} * \frac{2900^2}{12}$$

$$\delta_{b,start} = 0{,}25 \text{ mm}$$

$$\delta_{b,langtid} = \frac{1095{,}20 * 10^3 * (100\% - 9{,}03\%) * 210{,}00}{15\,133{,}96 * \frac{1}{12} * 1000 * 800^3} * \frac{2900^2}{12}$$

$$\delta_{b,langtid} = 0{,}23 \text{ mm}$$

Nedbøying pga. kryp, svinn og relaksasjon:

$$\delta_{total} = \delta_{b,start} - \delta_{b,langtid}$$

$$\delta_{total} = 0{,}25 - 0{,}23$$

$$\delta_{total} = 0{,}020 \text{ mm} < \delta_{tillatt} = 5{,}80 \text{ mm } \Rightarrow OK$$

Felt 4:

$$\delta_{b,start} = \frac{1095,20 * 10^3 * 210,00}{15\ 133,96 * \frac{1}{12} * 1000 * 800^3} * \frac{1200^2}{12}$$

$\delta_{b,start} = 0{,}043$ mm

$$\delta_{b,langtid} = \frac{1095,20 * 10^3 * (100\% - 9,00\%) * 210,00}{15\ 133,96 * \frac{1}{12} * 1000 * 800^3} * \frac{1200^2}{12}$$

$\delta_{b,langtid} = 0{,}039$ mm

Nedbøying pga. kryp, svinn og relaksasjon:

$\delta_{total} = \delta_{b,start} - \delta_{b,langtid}$

$\delta_{total} = 0{,}043 - 0{,}039$

$\delta_{total} = 0{,}0040$ mm $< \delta_{tillatt} = 2{,}40$ mm $\Rightarrow OK$