Betongegnekaper:

$f_{ck} := 30\ MPa$ $f_{cd} := 17\ MPa$ $f_{ctm} := 2.9\ MPa$

$f_{cm} := 38\ MPa$ $E_{cm} := 33\ GPa$

Stålegnekaper:

$f_{yk} := 500\ MPa$ $f_{yd} := 434\ MPa$ $\gamma_s := 1.15$

$E_p := 195\ GPa$ $E_s := 200\ GPa$

$\phi_{slakk} := 16\ mm$ $\phi_{spenn} := 12.9\ mm$

Geometri:

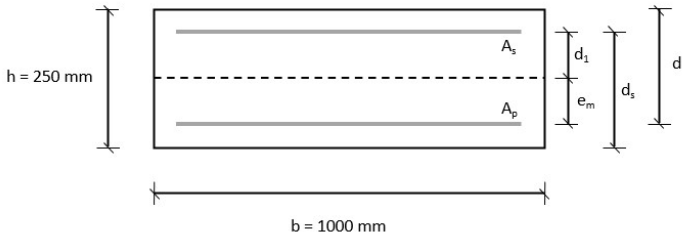
$b := 1000\ mm$ $h := 250\ mm$ $L := 7.2\ m$

$c_{nom} := 35\ mm$

$$d_1 := \frac{h}{2} - c_{nom} - \frac{\phi_{slakk}}{2} = 82\ mm$$

$$d_s := h - c_{nom} - \frac{\phi_{slakk}}{2} = 207\ mm$$

$$d := h - c_{nom} - \frac{\phi_{spenn}}{2} = 208.55\ mm$$



Spennarmering:

$cc := 160\ mm$ $n := \frac{b}{cc} = 6.25$

$$A_{p.kabel} := \pi \cdot \left(\frac{\phi_{spenn}}{2}\right)^2 = 131\ mm^2 \qquad A_p := A_{p.kabel} \cdot 6.25 = 817\ mm^2$$

$f_{pk} := 1700\ MPa$ $f_{p0.1k} := 1550\ MPa$

$$\sigma_p := min\left(0.8 \cdot f_{pk}, 0.9 \cdot f_{p0.1k}\right) = 1360\ MPa$$ (EC2, 5.10.2.1(1))

$$\varepsilon_{p0} := \frac{\sigma_p}{E_p} = 6.97 \cdot 10^{-3}$$

$$f_{pd} := \frac{f_{p0.1k}}{\gamma_s} = \left(1.348 \cdot 10^3\right)\ MPa$$ (EC2, Figur 3.10)

$$P := A_p \cdot \sigma_p = 1111\ kN$$ (EC2, 5.10.2.1(1))

Laster:

$\gamma_g := 1.2$ $\gamma_q := 1.5$

$g_{k.dekke} := 6.25\ \frac{kN}{m}$ $g_{d.dekke} := g_{k.dekke} \cdot \gamma_g = 7.5\ \frac{kN}{m}$

$q_{k.dekke} := 2\ \frac{kN}{m}$ $q_{d.dekke} := q_{k.dekke} \cdot \gamma_q = 3\ \frac{kN}{m}$

$$M_{Ed} := \frac{\left(g_{d.dekke} + q_{d.dekke}\right) \cdot L^2}{8} = 68\ kN \cdot m$$

Strekkarmering:

$$A_{s.min} := 0.26 \cdot \frac{f_{ctm}}{f_{yk}} \cdot b \cdot d_s = 312\ mm^2$$ (EC2, 9.2.1.1(1))

$$A_s := \frac{M_{Ed}}{0.835 \cdot d_s \cdot f_{yd}} = 907\ mm^2$$ (Sørensen, (4.26))

$$A'_s := 5 \cdot \pi \cdot \left(\frac{\varnothing_{slakk}}{2}\right)^2 = 1005\ mm^2$$ 5ø16

E-middel:

$RH := 40$

$\alpha_1 := \left(\frac{35}{38}\right)^{0.7} = 944.059 \cdot 10^{-3}$ $\alpha_2 := \left(\frac{35}{38}\right)^{0.2} = 983.687 \cdot 10^{-3}$ (EC2, (B,8c))

$h_0 := \frac{2 \cdot h \cdot b}{2 \cdot h + 2 \cdot b} = 200\ mm$ (EC2, (B.6))

$\beta(f_{cm}) := \frac{16.8}{\sqrt{38}} = 2.725$ (EC2, (B.4))

$\varphi_{RH} := \left(1 + \frac{1 - \frac{RH}{100}}{0.1 \cdot \sqrt[3]{200}} \cdot \alpha_1\right) \cdot \alpha_2 = 1.936$ (EC2, (B.3b))

$\beta_{3døgn} := \frac{1}{0.1 + 3^{0.2}} = 743.091 \cdot 10^{-3}$ $\beta_{28døgn} := \frac{1}{0.1 + 28^{0.2}} = 488.45 \cdot 10^{-3}$ (EC2, (B.5))

$\varphi_3 := \varphi_{RH} \cdot \beta(f_{cm}) \cdot \beta_{3døgn} = 3.922$ $\varphi_{28} := \varphi_{RH} \cdot \beta(f_{cm}) \cdot \beta_{28døgn} = 2.578$ (EC2, (B.1))

$E_{cl.3} := \frac{E_{cm}}{1 + \varphi_3} = \left(6.705 \cdot 10^3\right) \frac{N}{mm^2}$ (Sørensen, (5.24))

$E_{cl.28} := \frac{E_{cm}}{1 + \varphi_{28}} = \left(9.224 \cdot 10^3\right) \frac{N}{mm^2}$

$M_g := \frac{g_{k.dekke} \cdot L^2}{8} = 40.5\ kN \cdot m$

$M_q := \frac{q_{k.dekke} \cdot L^2}{8} = 12.96\ kN \cdot m$

$e_m := \frac{\left(g_{d.dekke} + q_{d.dekke}\right) \cdot L^2}{8 \cdot P} = 61.2\ mm$ (Sørensen, (4.10a))

$M_p := -P \cdot e_m = -68.04\ kN \cdot m$

$E_{middel} := \frac{M_g + M_q + |M_p|}{\frac{M_g}{E_{cl.3}} + \frac{M_q}{E_{cl.28}} + \frac{|M_p|}{E_{cl.3}}} = \left(6.906 \cdot 10^3\right) \frac{N}{mm^2}$ (Sørensen, (5.25))

Kryp:

$A_c := b \cdot h = 250000\ mm^2$

$\eta := \frac{E_p}{E_{middel}} = 28.236$ (Sørensen, (6.6))

$A_t := A_c + (\eta - 1) \cdot A_p = 272247.741\ mm^2$ (Sørensen, (6.6))

$y_t := \frac{(\eta - 1) \cdot A_p \cdot e_m}{A_t} = 5.005\ mm$ (Sørensen, (6.7))

$I_t := \frac{b \cdot h^3}{12} + b \cdot h \cdot y_t^2 + (\eta - 1) \cdot A_p \cdot (e_m - y_t)^2 = (1.379 \cdot 10^9)\ mm^4$ (Sørensen, (6.8))

$N := P = 1111\ kN$ (Sørensen, (6.9))

$y := \frac{h}{2} = 125\ mm$

$\sigma_{c.u} := \frac{-P}{A_t} - \frac{P \cdot (e_m - y_t) \cdot (y - y_t)}{I_t} = -9.518\ \frac{N}{mm^2}$ (Sørensen, (6.12))

$\sigma_{c.o} := \frac{-P}{A_t} - \frac{P \cdot (e_m - y_t) \cdot (-y - y_t)}{I_t} = 1.811\ \frac{N}{mm^2}$

$\sigma_{c.t} := \frac{-P}{A_t} - \frac{P \cdot (e_m - y_t)^2}{I_t} = -6.629\ \frac{N}{mm^2}$

Kort tid: $\Delta\varepsilon_{pk} := \frac{\sigma_{c.t}}{E_{cm}} = -2.009 \cdot 10^{-4}$

$\Delta\sigma_{pk} := \Delta\varepsilon_{pk} \cdot E_p = -39.2\ \frac{N}{mm^2}$

Lang tid: $\Delta\varepsilon_{pl} := \frac{\sigma_{c.t}}{E_{middel}} = -9.599 \cdot 10^{-4}$

$\Delta\sigma_{pl} := \Delta\varepsilon_{pl} \cdot E_p = -187.2\ \frac{N}{mm^2}$

$\Delta\sigma_{p.kryp} := \Delta\sigma_{pl} - \Delta\sigma_{pk} = -148\ \frac{N}{mm^2}$

Spenningstap i prosent: $\frac{148}{1360} = 10.9\%$

Relaksjon:

$\sigma_{pm0} := min\left(0.75 \cdot f_{pk}, 0.85 \cdot f_{p0.1k}\right) = 1275 \ \frac{N}{mm^2}$ (EC2, 5.10.2.3(2))

$\sigma_{pi} := \sigma_{pm0} \qquad \rho_{1000} := 2.5 \qquad t := 500000$

$\mu := \frac{\sigma_{pi}}{f_{pk}} = 750 \cdot 10^{-3}$

$\Delta\sigma_{pr} := \sigma_{pi} \cdot 0.66 \cdot \rho_{1000} \cdot e^{9.1 \cdot \mu} \cdot \left(\frac{t}{1000}\right)^{0.75 \cdot (1-\mu)} \cdot 10^{-5} = 62 \ \frac{N}{mm^2}$ (EC2, 3.3.2(7))

Spenningstap i prosent: $\frac{62}{1360} = 4.6\%$

Svinn:

$K_h := 0.85$ (EC2, Tabell 3.3)

$\varepsilon_{cd.0} := 0.52 \cdot 10^{-3}$ (EC2, Tabell 3.2)

$\varepsilon_{cd} := K_h \cdot \varepsilon_{cd.0} = 442 \cdot 10^{-6}$ (EC2, 3.1.4(6))

$\varepsilon_{ca} := 2.5 \ (30 - 10) \cdot 10^{-6} = 50 \cdot 10^{-6}$ (EC2, 3.1.4(6))

$\varepsilon_{cs} := \varepsilon_{cd} + \varepsilon_{ca} = 492 \cdot 10^{-6}$ (EC2, 3.1.4(6))

$N_s := \varepsilon_{cs} \cdot E_p \cdot A_p = 78.37 \ kN$

$\Delta\varepsilon_{p.svinn} := -\varepsilon_{cs} + \frac{N_s}{E_{middel} \cdot A_t} + \frac{N_s \cdot \left(e_m - y_t\right)^2}{E_{middel} \cdot I_t} = -4.243 \cdot 10^{-4}$ (Sørensen, (6.16))

$\Delta\sigma_{p.svinn} := \Delta\varepsilon_{p.svinn} \cdot E_p = -82.7 \ \frac{N}{mm^2}$ (Sørensen, (6.17))

Spenningstap i prosent: $\frac{82.7}{1360} = 6\%$

Låstap:

$\Delta L_{Lås} := 5 \ mm$

$\Delta\varepsilon_{lås} := \frac{\Delta L_{Lås}}{L} = 6.944 \cdot 10^{-4}$

Total tøyningstap:

$\Delta\varepsilon_{tap} := \left|\Delta\varepsilon_{pl}\right| + \left|\Delta\varepsilon_{p.svinn}\right| + \left|\Delta\varepsilon_{lås}\right| = 2.079 \cdot 10^{-3}$

Momentkapasitet:

$\varepsilon_{cu} := 3.5 \cdot 10^{-3}$

$\varepsilon'_{p0} := \varepsilon_{p0} - \Delta\varepsilon_{tap} = 4.896 \cdot 10^{-3}$

$$\alpha_b := \frac{\varepsilon_{cu}}{\frac{f_{pd}}{E_p} - \varepsilon'_{p0} + \varepsilon_{cu}} = 634.494 \cdot 10^{-3}$$ (Sørensen, (7.7))

$$A_{pb} := 0.8 \cdot \frac{f_{cd}}{f_{pd}} \cdot \alpha_b \cdot b \cdot d = \left(1.335 \cdot 10^3\right)\ mm^2$$ (Sørensen, (7.8))

$A_{pb} > A_p$ Gir underarmert tversnitt

$$\alpha := \frac{f_{pd} \cdot A_p}{0.8\ f_{cd} \cdot b \cdot d} = 388.181 \cdot 10^{-3}$$ (Sørensen, (7.9))

$$M_{Rd} := 0.8\ \left(1 - 0.4\ \alpha\right) \cdot f_{cd} \cdot \alpha \cdot b \cdot d^2 = 194\ kN \cdot m$$ (Sørensen, (7.5))

$$M_{Ed} := \frac{\left(g_{d.dekke} + q_{d.dekke}\right) \cdot L^2}{8} = 68\ kN \cdot m$$

$M_{Rd} > M_{Ed}$ gir tilstrekkelig kapasitet

Kontroll av oppspenningstilstanden:

$\beta_{cc} := e^{0.25 \cdot \left(1 - \left(\frac{28}{3}\right)^{\frac{1}{2}}\right)}$ $\quad f_{cm.3} := \beta_{cc} \cdot f_{cm} = 23\ MPa$ (EC2, 3.1.2(6))

$f_{ck.3} := f_{cm.3} - 8\ MPa = 15\ MPa$ $\quad f_{cd.3} := 0.85\ \frac{f_{ck.3}}{1.5} = 8\ MPa$ (EC2, 3.1.2(5))

1) Rent trykk:

$\varepsilon_{c1} := 2.2 \cdot 10^{-3}$ $\quad \varepsilon_s := \varepsilon_{c1}$ $\quad \varepsilon_p := \varepsilon_{c1}$

$T_c := f_{cd.3} \cdot b \cdot h = 2087\ kN$

$T_p := \varepsilon_p \cdot E_p \cdot A_p = 350\ kN$

$T_s := \varepsilon_s \cdot E_s \cdot A_s = 399\ kN$

$N_1 := T_c + T_p + T_s = 2837\ kN$

$M_1 := T_p \cdot e_m - T_s \cdot d_1 = -11.263\ kN \cdot m$

2) Balansepunkt:

$\varepsilon_c := \varepsilon_{cu} = 3.5 \cdot 10^{-3}$ $\quad \varepsilon_{yd} := \frac{f_{yd}}{E_s} = 2.17 \cdot 10^{-3}$ $\quad \varepsilon_s := \varepsilon_{yd} = 2.17 \cdot 10^{-3}$

$\alpha := \frac{\varepsilon_c}{\varepsilon_s + \varepsilon_c} = 0.617$

$T_c := 0.8 \cdot \alpha \cdot d \cdot b \cdot f_{cd.3} = 860\ kN$

$\Delta\varepsilon_p := \frac{\varepsilon_c}{\alpha \cdot d} \cdot (\alpha \cdot d - (h - d)) = 2.373 \cdot 10^{-3}$

$T_p := \Delta\varepsilon_p \cdot E_p \cdot A_p = 378\ kN$

$S := f_{yd} \cdot A_s = 394\ kN$

$N_2 := T_c + T_p - S = 844\ kN$

$M_2 := T_c \cdot (0.5 \cdot h - 0.4 \cdot \alpha \cdot d) + T_p \cdot e_m + S \cdot d_1 = 119\ kN \cdot m$

3) Trykkbrudd i betong og dobbel flytetøyning i armering

$\varepsilon_c := \varepsilon_{cu} = 3.5 \cdot 10^{-3}$ $\varepsilon_{yk} := \frac{f_{yk}}{E_s} = 2.5 \cdot 10^{-3}$ $\varepsilon_s := 2 \cdot \varepsilon_{yk} = 5 \cdot 10^{-3}$

$\alpha := \frac{\varepsilon_c}{\varepsilon_s + \varepsilon_c} = 0.412$

$T_c := 0.8 \cdot \alpha \cdot d \cdot b \cdot f_{cd.3} = 574$ **kN**

$\Delta\varepsilon_p := \frac{\varepsilon_c}{\alpha \cdot d} \cdot (\alpha \cdot d - (h - d)) = 1.811 \cdot 10^{-3}$

$T_p := \Delta\varepsilon_p \cdot E_p \cdot A_p = 288$ **kN**

$S := f_{yd} \cdot A_s = 394$ **kN**

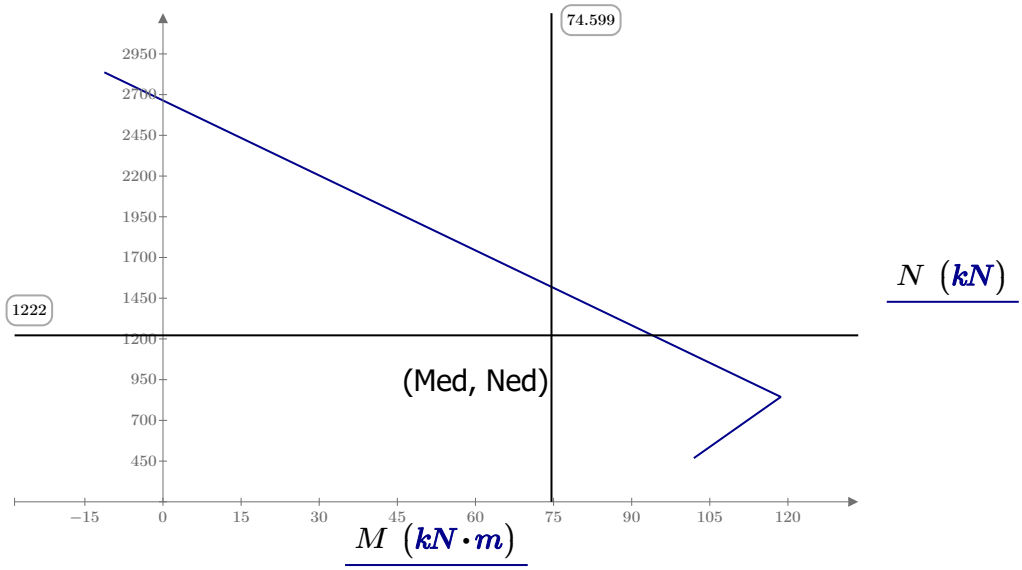
$N_3 := T_c + T_p - S = 468$ **kN**

$M_3 := T_c \cdot (0.5 \cdot h - 0.4 \cdot \alpha \cdot d) + T_p \cdot e_m + S \cdot d_1 = 102$ **kN·m**

$N := \begin{bmatrix} N_1 \\ N_2 \\ N_3 \end{bmatrix} = \begin{bmatrix} 2837 \\ 844 \\ 468 \end{bmatrix}$ **kN** $M := \begin{bmatrix} M_1 \\ M_2 \\ M_3 \end{bmatrix} = \begin{bmatrix} -11 \\ 119 \\ 102 \end{bmatrix}$ **kN·m**

$N_{Ed} := 1.1 \cdot P = 1222$ **kN**

$M_{Ed} := N_{Ed} \cdot e_m = 75$ **kN·m**



Skjærkapasitet:

$$V_{Ed} := \frac{\left(g_{d.dekke} + q_{d.dekke}\right) \cdot L}{2} = 37.8\ \boldsymbol{kN}$$

$$N_{Ed} := 0.9 \cdot P = 1000\ \boldsymbol{kN}$$

$$\sigma_{cp} := min\left(\frac{N_{Ed}}{A_c}, 0.2 \cdot f_{cd}\right) = 3.4\ \frac{\boldsymbol{N}}{\boldsymbol{mm}^2}$$ (EC2, 6.2.2(1))

$$C_{Rd.c} := \frac{0.18}{1.5} = 0.12$$ (EC2, NA6.2.2(1))

$$K := 1 + \sqrt{\frac{200\ \boldsymbol{mm}}{d}} = 1.979$$ (EC2, 6.2.2(1))

$$\rho_l := \frac{A_p}{h \cdot d} = 0.016$$ (EC2, 6.2.2(1))

$$V_{Rd.c} = \left(C_{Rd.c} \cdot K \cdot \left(100 \cdot \rho_l \cdot f_{ck}\right)^{\frac{1}{3}} + 0.15\ \sigma_{cp}\right) \cdot h \cdot d$$ (EC2, 6.2.2(1))

$$V_{Rd.c} := 40.1\ \boldsymbol{kN}$$

$V_{Rd.c} > V_{Ed}$ Tilstrekkelig kapasitet - ikke behov for skjærarmering

$$V_{Rd.max} := 0.5 \cdot h \cdot d \cdot 0.6 \cdot \left(1 - \frac{30}{250}\right) \cdot f_{cd} = 234\ \boldsymbol{kN}$$ (EC2, 6.2.2(3))

$V_{Rd.max} > V_{Ed}$ Tilstrekkelig skjærtrykkkapasitet

Minimum skjærarmering:

$$S_{L.max} := 0.6\ h = 150\ \boldsymbol{mm}$$ (EC2, NA.9.2.2(6))

$$\rho_{w.min} := 0.1 \cdot \frac{\sqrt{30}}{500} \cdot 1000 \cdot \boldsymbol{mm} = 1.095\ \boldsymbol{mm}$$ (EC2, NA.9.2.2(5))

$$A_{s.w.min} := \rho_{w.min} \cdot S_{L.max} = 164\ \boldsymbol{mm}^2$$ (EC2, 9.2.2(5))

$$n := \frac{A_{s.w.min}}{\pi \cdot \left(\frac{8\ \boldsymbol{mm}}{2}\right)^2} = 3.269 \qquad S := \frac{b}{n} = 305.906\ \boldsymbol{mm}$$

Bruker Sl.max: ø8c150

Nedbøying:

$$\eta := \frac{E_s}{E_{middel}} = 28.96$$

$$\rho := \frac{A_s}{b \cdot d_s} = 4.382 \cdot 10^{-3}$$

$$\alpha := \sqrt{(\eta \cdot \rho)^2 + 2 \cdot \eta \cdot \rho} - \eta \cdot \rho = 392.615 \cdot 10^{-3}$$ (Sørensen, (5.5))

$$I_c := 0.5 \cdot \alpha^2 \cdot \left(1 - \frac{\alpha}{3}\right) \cdot b \cdot {d_s}^3 = \left(5.942 \cdot 10^8\right)\ mm^4$$ (Sørensen, (5.9))

$$EI := E_{middel} \cdot I_c = \left(4.103 \cdot 10^{12}\right)\ N \cdot mm^2$$ (Sørensen, (5.10))

Tap spennkraft: $4.6\% + 6\% + 10.9\% = 21.5\%$

$$P_{nedbøying} := P \cdot (1 - 21.5\%) = 872\ kN$$

$$p := \frac{8\ P_{nedbøying} \cdot e_m}{L^2} = 8.243\ \frac{kN}{m}$$

$$\delta_{ytre} := \frac{5}{384} \cdot \frac{\left(g_{k.dekke} + q_{k.dekke}\right) \cdot L^4}{EI} = 70.354\ mm$$

$$\delta_P := \frac{5}{384} \cdot \frac{p \cdot L^4}{EI} = 70.29\ mm$$

$$\delta_{tot} := \delta_{ytre} - \delta_P = 0.064\ mm$$

$$\delta_{max} := \frac{L}{250} = 28.8\ mm$$

$\delta_{tot} < \delta_{max}$ Ok nedbøying