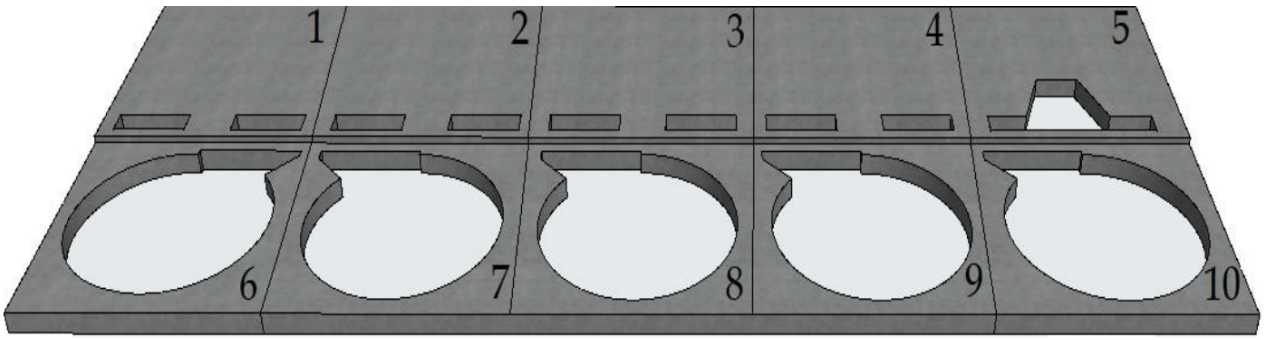
Vedlegg

Vedleggsliste

Vedlegg A : Artikkel

NTNU
Fakultet for ingeniørvitenskap
Institutt for konstruksjonsteknikk

Publisert: 22. mai 2023



Skisse av betongdekket som blir dimensjonert i oppgaven (Privat, 2023)

Integritetskontroll av betongdekke

Av Håkon Bendik Pedersen og Vegard Mortensen Eide

To studenter fra NTNU har skrevet bacheloroppgave hvor det er gjort nye beregninger av det snart 70 år gamle betongdekket til Yara i Glomfjord, og sammenlignet mot dagens krav i Eurocode 2.

Syrebelastet miljø

Området betongdekket befinner seg i er påvirket av et aggressivt syremiljø. Fabrikken produserer blant annet salpetersyre opp til 60% konsentrasjon, noe betongdekket bærer synlig preg av.

Utforming og beregningsgrunnlag

Det armerte betongdekket er satt opp i et statisk system hvor platene er fast innspente. Dette tillater studentene å beregne dekket både som enveisplate og som toveisplate

Kapasitet

Beregningen beviser at dimensjoneringen tilfredsstiller de fleste kravene i Eurocode 2, og at alle snittene har tilstrekkelig kapasitet.

Befaring

Studentene var på befaring av fabrikken i februar. Dette ga et godt bilde og grunnlag for oppstarten av oppgaven, sier studentene. På befaringen ble det blant annet oppdaget større mengder med synlig eksponert og korrodert armering på undersiden av dekket

Undersiden av dekket bærer preg av eksponert og korrodert armering (Privat, 2023)

Redusert Armeringstverrsnitt

Observasjonene på befaring gjorde at studentene har beregnet et av snittene med lavere armerings-tverrsnitt enn det som opprinnelig er. Resultatet viser at også her tilfredsstiller det snart 70 år gamle dekket dagens krav i Eurocoden.

Studentene konkluderer med at betongdekket tilfredsstiller kravene, bortsett fra rissviddekontrollen. Her er dekkets verdier for lave, noe som skyldes den lave overdekningen på 10 mm.

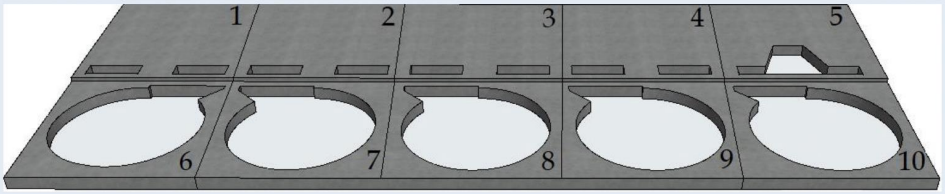
Videre konkluderes det med at dekkets skader skyldes syreangrep fra lekkasjer og damp fra utstyret i fabrikken.

Vedlegg B: Plakat

NTNU

Institutt for konstruksjonsteknikk

Prosjektnr 2023-33



Håkon Bendik Pedersen, Vegard Mortensen Eide

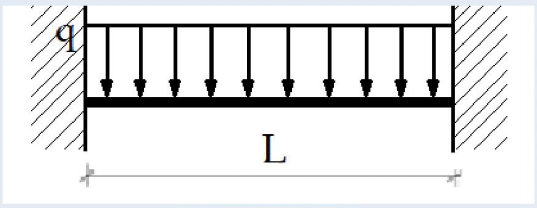
Intern veileder: Arne Mathias Selberg
Ekstern kontakt: Helge Hamnevoll (Yara)

Integritetskontroll av betongdekke

Integrity control of floor divider in concrete

Prosjektbeskrivelse

Formålet med oppgaven er å teste og gjøre nye beregninger på et betongdekke som er fra 1954. For å kunne konkludere om kapasiteten er tilstrekkelig eller ikke.



Illustrasjon av statisk modell

Fotografi av målt overdekning

Analyseområder

- **Overdekning**
- **Kloridinnhold**
- **Karbonatiseringsdybde**
- **Nedbøyning**
- **Riss**
- **Syreskader**

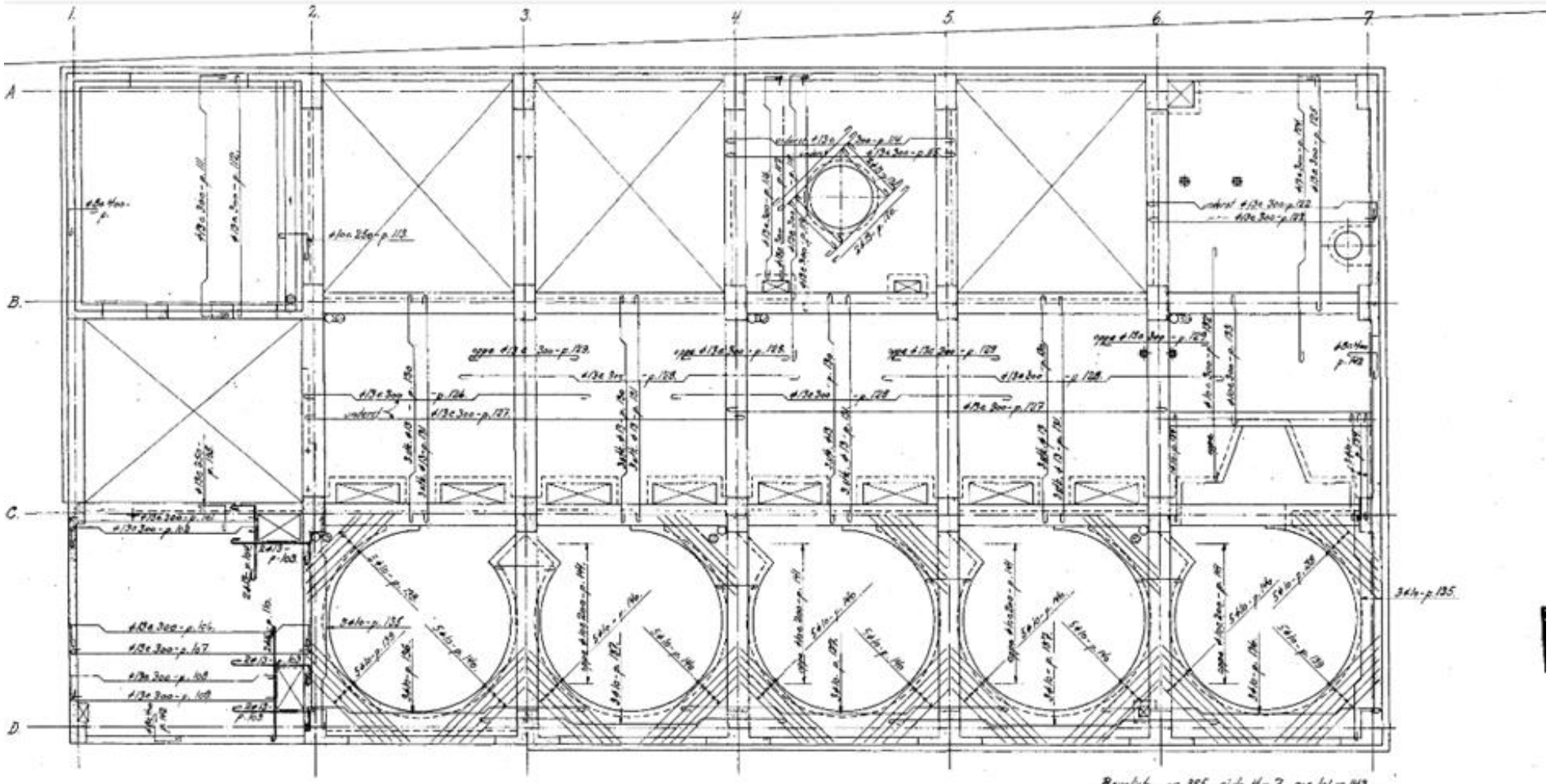
Fotografering av skadet betong

Konklusjon

Oppgaven har konkludert med tilstrekkelig kapasitet for betongdekket, men kravet til rissvidde blir ikke innfridd ved de fleste anledningene. I tillegg til dette er det blitt konstantert at skadene på betongen skyldes det syrlige miljøet og lekkasjer fra anlegget

Vedlegg C:Tegninger og skisser

Vedlegg C.1 : Armeringstegning



Bøyelista nr 385, side 4 - 7, pos. 141 - 143.
For mål, dragearmering m.v. henvises til tegn. nr. 1F. 31158.
Hvor annet ikke er angitt legges Ø 13 ekstra rundt alle utsparinger
Fordelingsjern i alle armeringsplater Ø 10 c 250.
I topp av alle spylekanaler legges 1 stk. Ø 10 gjennomgående.

Antall	Gjenstand	No.	Materiale	Tegn. nr.	Vekt	Anmerkning

NORSK HYDRO-ELEKTRISK KVÆLSTOFAKTIESELSKAB

Gulv på kote 119,20 - Armering

Sak 1152-36

Gruppe 7F.315B:36

Målestokk: 1:50

Tegn. L.Lu. 19.5.37

Ryss

Godkj.

38 - 122

Erstatning for:

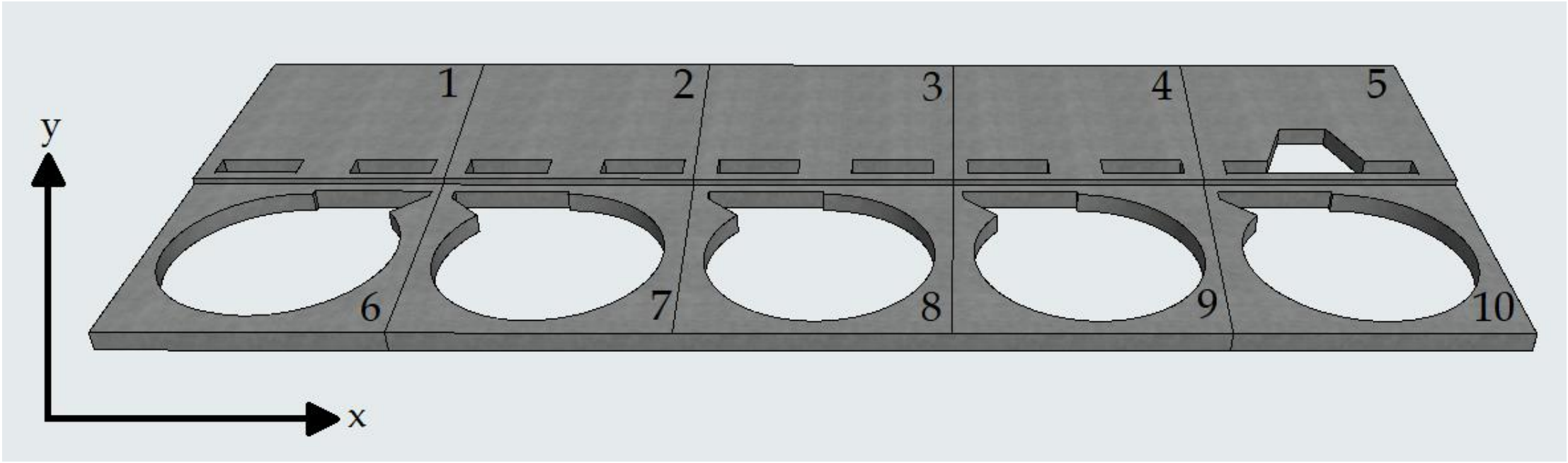
1. F. 31344 A

Erstatter evt.:

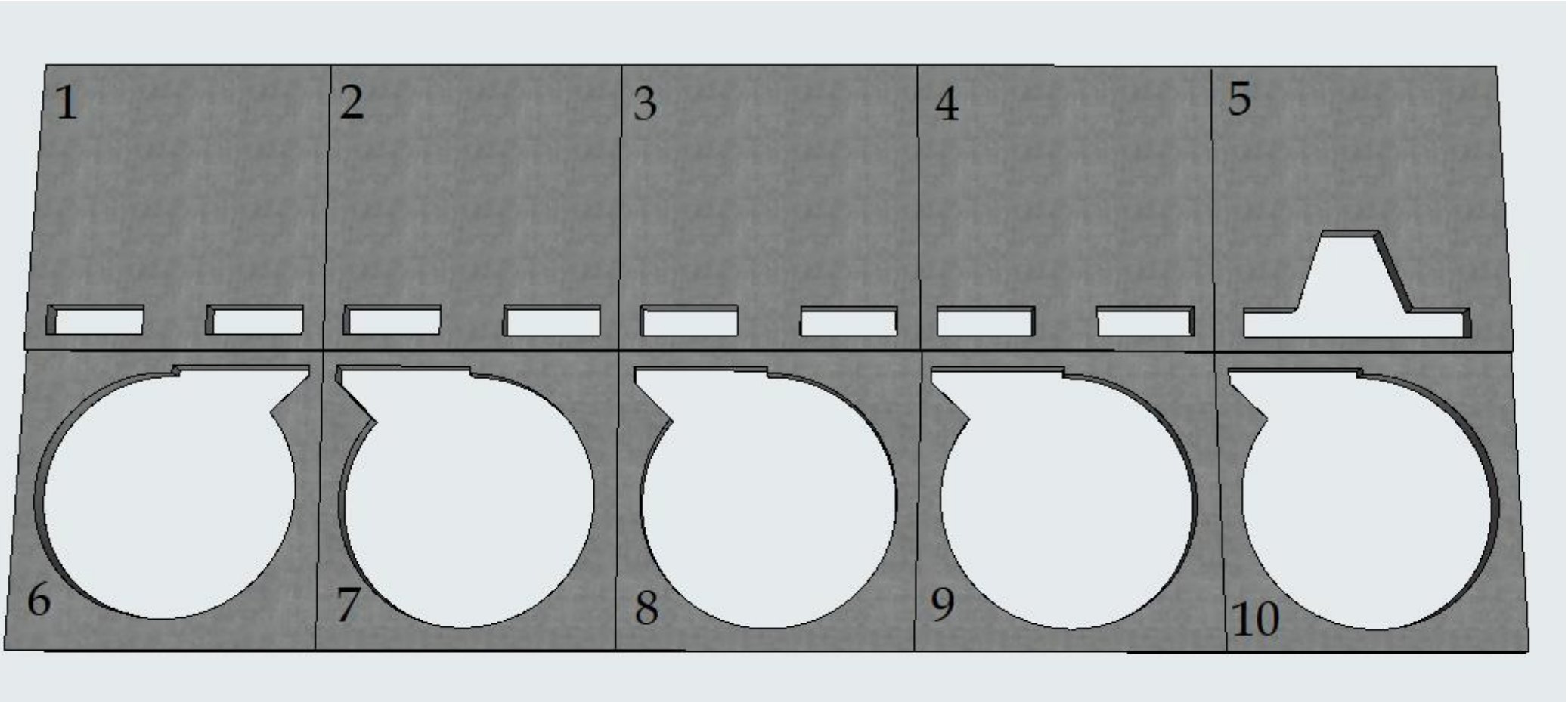
Anmerkninger

Tegningen må ikke kopieres, vises eller meddeles 3dje person eller på noen måte anvendes uten våre interesser. Kfr. lover av 22/8 1903 og 7/7 1922. Alle rettigheter i henhold til lov av 6/5 1930 tilkommer oss. TEGNINGEN SKAL RETTER BRUK STRAKS RETURNERES

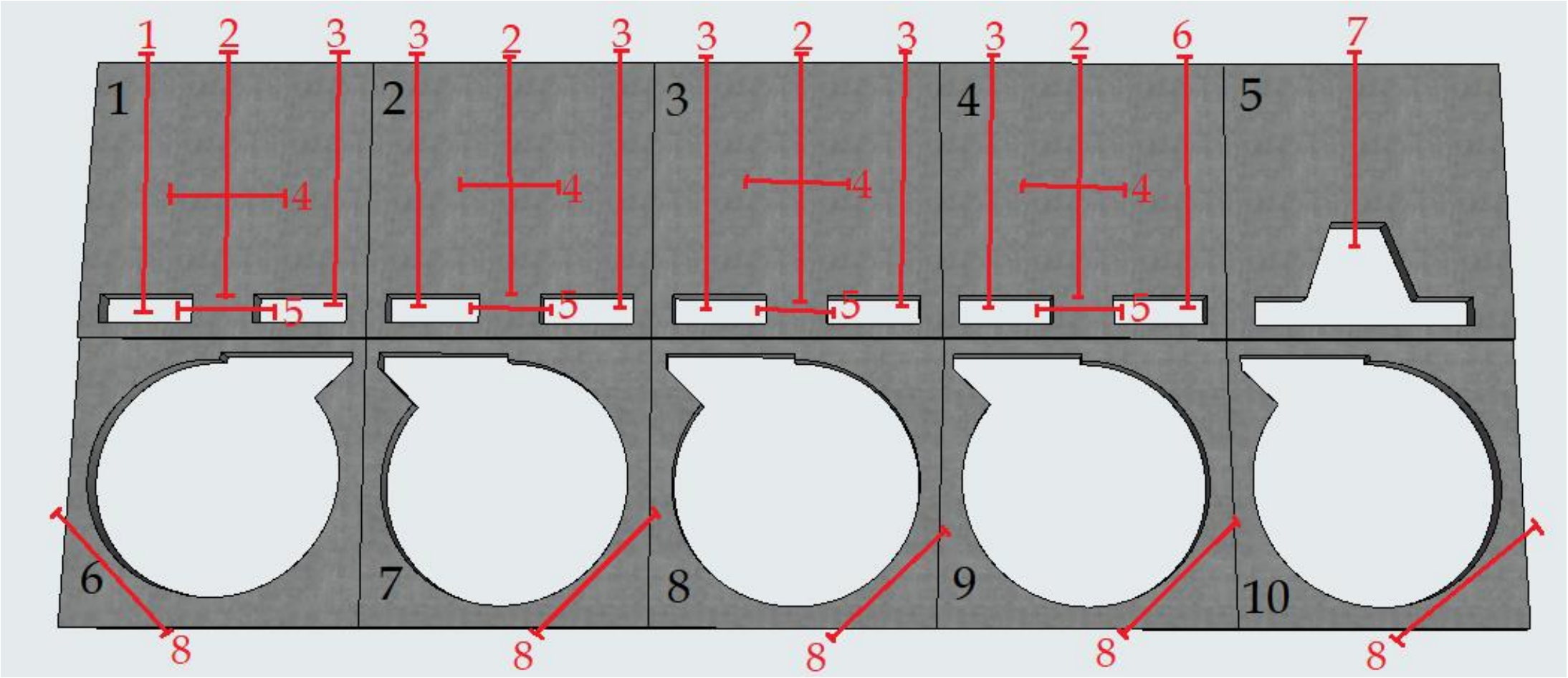
Vedlegg C.2: Plate inndeling (sett fra siden)


1
2
3
4
5
6
7
8
9
10
y
x

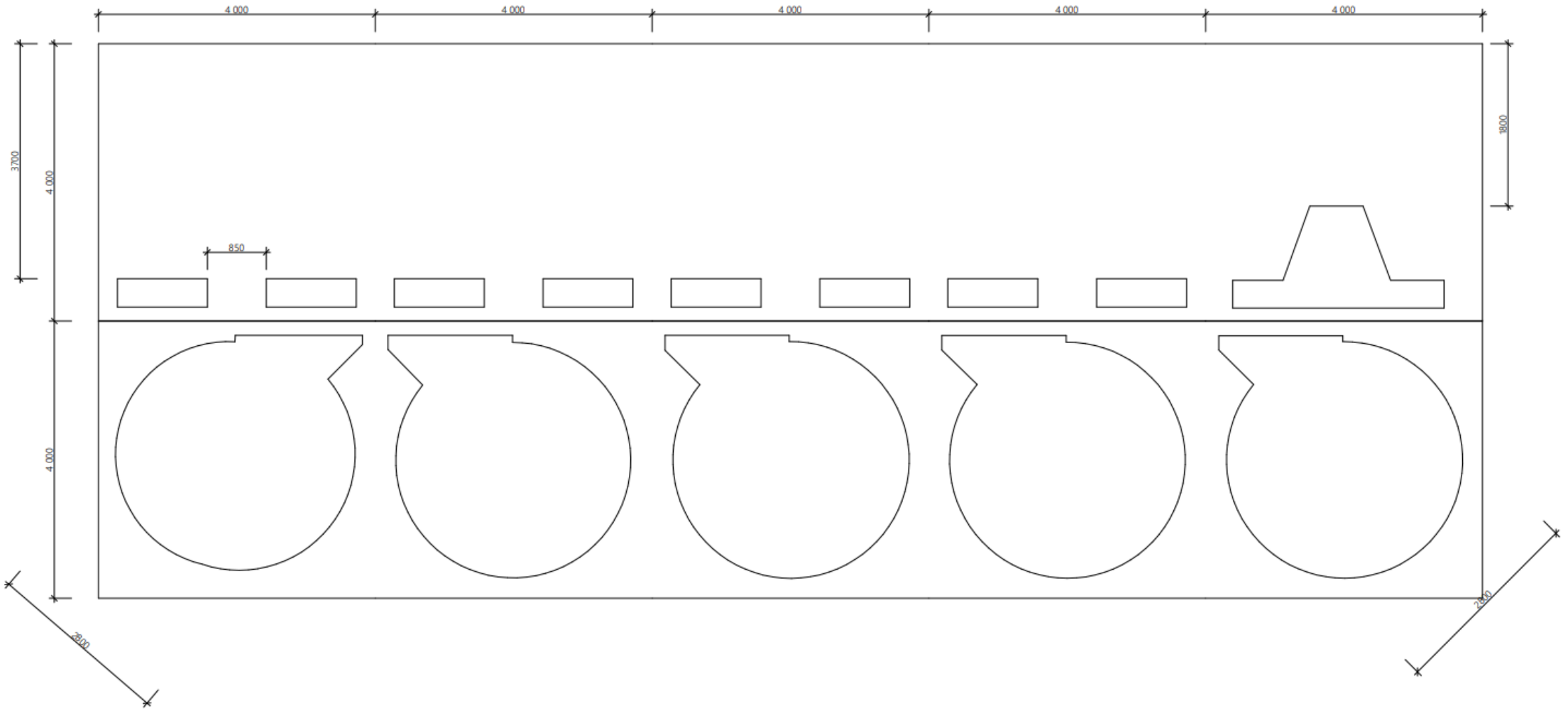
Vedlegg C.3: Plate inndeling (sett ovenfra)


1
2
3
4
5
6
7
8
9
10

Vedlegg C.4: plassering av snitt


1 2 3
3 2 3
3 2 3
3 2 6
7
1
2
3
4
5
4
5
6
7
8
9
10
8

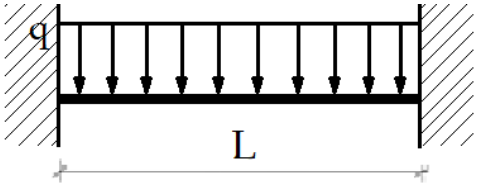
Vedlegg C.5: Plantegning dekke

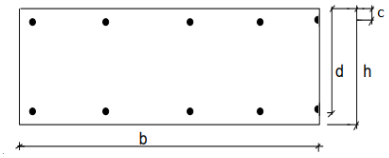

4 000
4 000
4 000
4 000
4 000
3700
4 000
1800
850
4 000
2800
2800

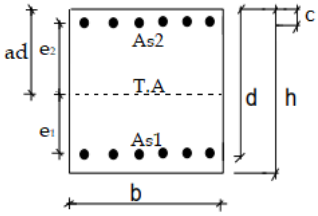
Vedlegg D:Beregninger

Vedlegg D.1: Snitt 1

Snitt 1:







Sikkerhets faktor

$\gamma_c = 1.5$ EC2-Tabell 2.1N

$\gamma_s = 1.15$ EC2-Tabell 2.1N

$\alpha_{cc} = 0.85$ EC2- NA.3.1.6(1)

$\gamma_G = 1.2$ EC - Tabell NA.A1.2(A)

$\gamma_Q = 1.5$ EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

$h = 300\ mm$

$b = 1000\ mm$

$d = 300 - 10 - \frac{13}{2} = 283.5\ mm$

c = $10 + \frac{13}{2}$ = 16.5mm

$h` = h - 2 * c$ = 267

$L = 4000\ mm$

$e = \frac{h}{2} - (h - d) = 133.5\ mm$

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$ EC2-Tabell 3.1

$f_{ctm} = 2.2\ N/mm^2$ EC2-Tabell 3.1

$E_{cm} = 30000\ N/mm^2$ EC2-Tabell 3.1

Standard armering

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\, f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\mathrm{fck(3)}}{\gamma c} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\mathrm{fctm}}{\mathrm{fyk}}\, b_t\, d;\ 0.0013\, b_t\, d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 283.5\ ;\ 0.0013 * 1000 * 283.5\} = 405.4\ mm^2$

Antall jern $= \frac{28\ jern}{3.7m} = 7.5$

$A_s = \pi(\frac{13}{2})^2 * 7.5 = 995.5\ mm^2$

$A_{s1} = A_s/2 = 497.75\ mm^2$

$A_{s2} = A_s/2 = 497.75\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st}$ = ikke gjeldende

$\Delta c_{dur,add}$ = ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000\ N = 3390\ kN$
$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117.45\ N = 173\ kN$
$S_2 = S_1$

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 173 + 173 =$ **3736 kN**
Momentlikevekt : $M_1 =$ **0**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter
$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 16.5*0.0035/300 = 0{,}00019 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00019 = 38\ N/mm^2$

$T_c = f_{cd} * b * 0.8h = 11.3*1000*0.8*300 = 2712000\ N = 2712\ kN$

$S_1 = \sigma_{sd} * A_{s1} = 38 * 497.75 = 11647\ N = 18.9\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 497.75 = 173117\ N = 173\ kN$

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712+18.9+173 =$ **2903.9 kN**

Momentlikevekt: $M_2 = T_c * (0.5h-0{,}4h)+S_2*h`/2 - S_1*h`/2 =$

$2712*(0.5*0.300-0.4*0.300)+173*0.267/2 - 18.9*0.267/2 =$ **102 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d = 0.668 * 283.5 = 189.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{189.4-16.5}{189.4} * 0.0035 = 0.0032$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 189.4 = 1712176\ N = 1712\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117\ N = 173\ kN$

$S_2 = S_1$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1712 + 173 - 173 =$ **1712 kN**

Momentlikevekt : $M_3 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h` =$

$1712 * (0.5*300 - 0.4 * 189.4) + 173 * 267 =$ **173 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d = 0.467 * 283.5 = 132.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{132.4-16.5}{132.4} * 0.0035 = 0.003$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 132.4 = 1196896\ N = 1196.9\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117\ N = 173\ kN$

$S_2 = S_1$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1196.9 + 173 - 173 =$ **1196.9 kN**

Momentlikevekt : $M_4 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h` =$

$1196.9 * (0.5*300 - 0.4 * 132.4) + 173 * 267 =$ **160 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d = 0.189 * 283.5 = 53.6\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{53.6-16.5}{53.6} * 0.0035 = 0.0024$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 53.6 = 484544\ N = 485\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117\ N = 173\ kN$

$S_2 = S_1$

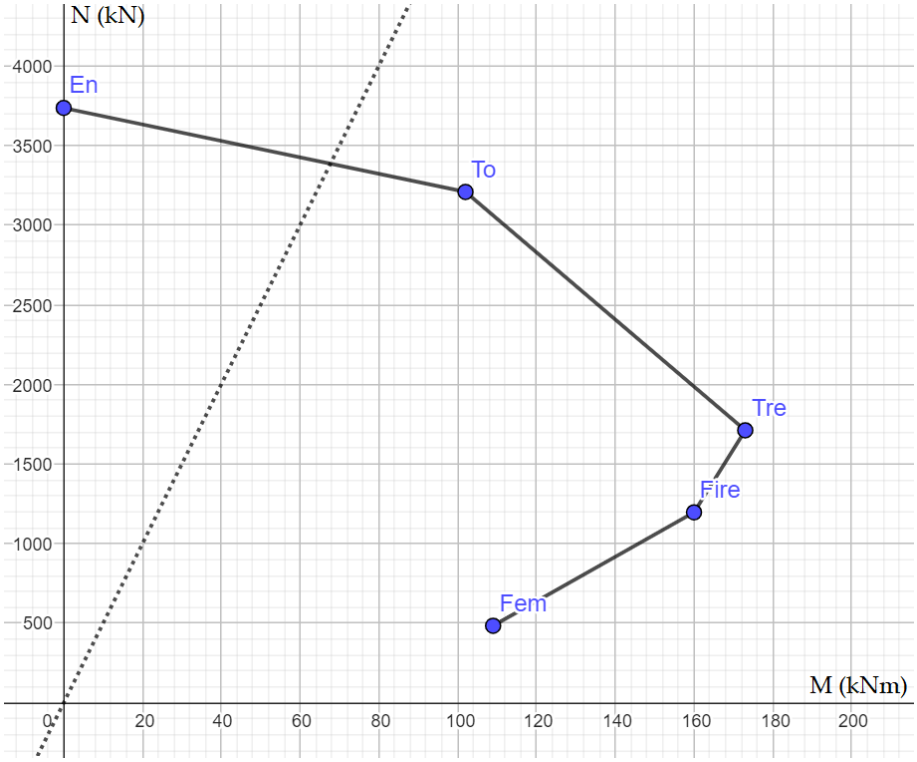
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 485 + 173 - 173 =$ **485 kN**

Momentlikevekt : $M_5 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h`/2 + S_2 * h`/2 =$

$485 * (0.5*300 - 0.4 * 53.6) + 173 * 267/2 + 173 * 267/2 =$ **109 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{283.5}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{497.75}{1000*283.5} = 0.00176$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.00176 * 20)^{\frac{1}{3}} * 1000 * 283.5 = 79350.9$ N = **79.3 kN**

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

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2}$ =79.3 → p = **20.4kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*283.5*0.552*11.3 = 884179.8$ N = **884 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2}$ =884 → p = **288 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 283.5 * 0.668 = 4922\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 995.5}{0.8 * 1.0 * 11.3 * 1000 * 283.5} = 0.135$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.135}{0.135} * 0.0035 = 0.0224$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.135 * (1-0.5 * 0{,}8 * 0.135) * 11.3 * 1000 * 283.5^2$

$= 92789634\ Nmm =$ **92.7 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{12} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 4^2}{12} =$ **27 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 4^2}{12} = 92.7 \rightarrow p =$ **40 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 995.5) + 347.8 * 995.5 = 3724985.75\ N =$ **3724 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{995.5}{1000*283.5} = 0.0035$

$\eta\rho = 6.667 * 0.0035 = 0.023$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.023^2 + 2 * 0.023} - 0.023 = 0.19$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 995.5 * (1-0.19) * (1-\frac{0.19}{3}) * 283.5^2 = 6.07*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*6.07*10^7 = 1.21 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*4000^4}{384*1.21*10^{13}}$ = **0.83 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

φ_3 =1.33 * 3.17 * 0.74 = 3.12

φ_{28} =1.33 * 3.17 * 0.49 = 2.07

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3)$ =4.96 * 1 = 3.12

$\varphi(\infty, 28)$ = 4.71 * 1 = 2.07

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{12} = \frac{(9)*4^2}{12} = 12$ kNm

$M_2 = \frac{q*L^2}{12} = \frac{(11.25)*4^2}{12} = 15$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_c 2}} = \frac{12+15}{\frac{12}{7282}+\frac{15}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_s}{b*d} = \frac{995.5}{1000*283.5} = 0.0035$

$\eta\rho = 23.6 * 0.0035 = 0.083$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.083^2 + 2 * 0.083} - 0.083 = 0.33$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.33^2*(1-\frac{0.33}{3})*1000*283.5^3 = 1.10 * 10^9 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*1.10*10^9 = 9.3 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*4000^4}{384*9.3*10^{12}} =$ **1.45 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*f_{cm}}{f_{cm0}})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{h}{2} = \frac{300}{2} = 150$

$e = d - \alpha d = 283.5 - 150 = 133.5$

$I = \frac{b*h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000*300^3}{12} + 1000 * 300 * \left(150 - \frac{300}{2}\right)^2 + 23.6 * 995.5 * 133.5^2 = 26.69 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{995.5*133.5}{26.69*10^8} = 2.56 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{2.56*10^{-7}*4000^2}{8} =$ **0.51mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 1.45 + 0.51 =$ **1.96 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > 1.93 \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5*1.2+1.5*q)*4000^4}{384*9.3*10^{12}} + 0.51 \rightarrow q = 138$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25*4^2}{12} = 27$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{27*10^6*(1-0.33)*283.5}{9.3*10^{12}} = 110MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h-\alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-283.5); (\frac{300-0.33*283.5}{3}); \frac{300}{2}\} = 41.25$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{995.5}{1000*41.25} = 0.024$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta\rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{110 - 0.4 * \frac{2.2}{0.024} * (1 + 6.667 * 0.024)}{200000} = 3.37 * 10^{-4} \geq 0.6 * \frac{110}{200000} = 3.3 * 10^{-4}$

$C_{nom} = 10mm$

$5*(c_{nom} + \frac{\phi}{2}) = 5*(10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3*(h - \alpha d) = 1.3*(300 - 0.33*283.5) = 268.4$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 268.4 * 3.37*10^{-4} =$ **0.09** Sørensen (5.58)

$w_k > w_{max} = 0.05$ (Rissviddekrav ikke oppfylt)

Max nyttelast:

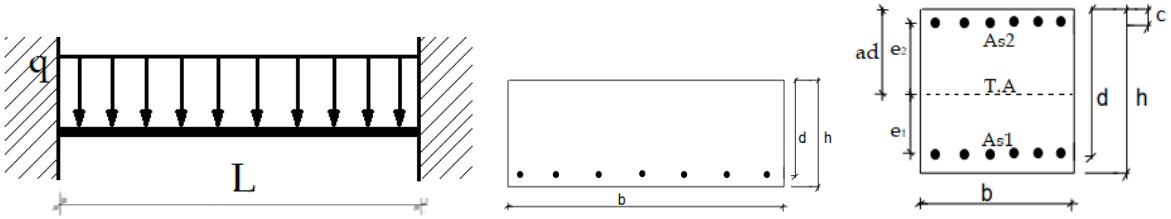
$$268.4* \frac{\sigma_s - 0.4*\frac{2.2}{0.024}*(1+6.667*0.024)}{200000} = 0.05 \rightarrow \sigma_s = 79.7$$

$$200000 * \frac{M*10^6*(1-0.33)*283.5}{9.3*10^{12}} = 79.7 \rightarrow M = 19.5$$

$$\frac{(1.2*7.5+1.5*q)*4^2}{12} = 19.5 \rightarrow q = 3.7$$

Vedlegg D.2: Snitt 2

Snitt 2:



Sikkerhets faktor

$\gamma_c = 1.5$ EC2-Tabell 2.1N

$\gamma_s = 1.15$ EC2-Tabell 2.1N

$\alpha_{cc} = 0.85$ EC2- NA.3.1.6(1)

$\gamma_G = 1.2$ EC - Tabell NA.A1.2(A)

$\gamma_Q = 1.5$ EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

h = 300 mm

b = 1000 mm

$d = 300 - 10 - \frac{13}{2} = 283.5\ mm$

$c = 10 + \frac{13}{2} = 16.5$mm

$h` = h - 2 * c = 267$

L = 4000 mm

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$ EC2-Tabell 3.1

$f_{ctm} = 2.2\ N/mm^2$ EC2-Tabell 3.1

$E_{cm} = 30000\ N/mm^2$ EC2-Tabell 3.1

Standard armering:

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\ f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\text{fck(3)}}{\gamma c} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\text{fctm}}{\text{fyk}}\ b_t\ d;\ 0.0013\ b_t\ d\} =$

$\max\{0.26\frac{2.2}{400}*1000*283.5\ ;\ 0.0013*1000*283.5\} = 405.4\ mm^2$

Antall jern $= \frac{28\ jern}{3.7m} = 7.5$

$A_s = \pi(\frac{13}{2})^2 * 7.5 = 995.5\ mm^2$

$A_{s1} = A_s = 995.5\ mm^2$

$A_{s2} = 0 = 0\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st}$ = ikke gjeldende

$\Delta c_{dur,add}$ = ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

$\eta = \frac{E_s}{E_{c,middel}} = \frac{200000}{8483} = 23.6$ (se langtidsnedbøyning)
$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 995.5 * 283.5}{300000 + 23.6 * 995.5} = 160$
e = d-αd = 283.5-160 =123.5

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000$ N = 3390 kN
$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 995.5 = 346235$ N = 346 kN
$S_2 = 0$

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 346 =$ **3736 kN**
Momentlikevekt : $M_1 = T_c * (\alpha d - 0.5h) - S_1 * e$
3390*(160-150)- 346* 123.5 = **-8.8**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter
$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 16.5 * 0.0035/300 = 0{,}00019 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00019 = 38$ N/mm²

$T_c = f_{cd} * b * 0.8h = 11.3 * 1000 * 0.8 * 300 = 2712000$ N = 2712 kN

$S_1 = \sigma_{sd} * A_{s1} = 38 * 995.5 = 37829$ N = 38 kN

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0$ N = 0 kN

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712 + 38 =$ **2750 kN**

Momentlikevekt: $M_2 = T_c * (\alpha d - 0{,}4h) + S_2 * e_2 - S_1 * e_1 =$

2712*(160-0.4*300)– 38*123.5 = **104 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d_2 = 0.668 * 283.5 = 189.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{189.4-16.5}{189.4} * 0.0035 = 0.0032$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 189.4 = 1712176\ N = 1712\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 995.5 = 346234.9\ N = 346\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1712 - 346 =$ **1366 kN**

Momentlikevekt : $M_3 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$1712 * (160 - 0.4 * 189.4) + 346 * 123.5 =$ **187 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d_2 = 0.467 * 283.5 = 132.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{132.4-16.5}{132.4} * 0.0035 = 0.003$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 132.4 = 1196896\ N = 1196.9\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 995.5 = 346234.9\ N = 346\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1196.9 - 346 =$ **850.9 kN**

Momentlikevekt : $M_4 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e + S_2 * h`/2 =$

$1196.9* (160 - 0.4 * 132.4) + 346 * 123.5 =$ **171 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d_2 = 0.189 * 283.5 = 53.6\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{53.6-16.5}{53.6} * 0.0035 = 0.0024$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 53.6 = 484544\ N = 485\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 995.5 = 346234.9\ N = 346\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

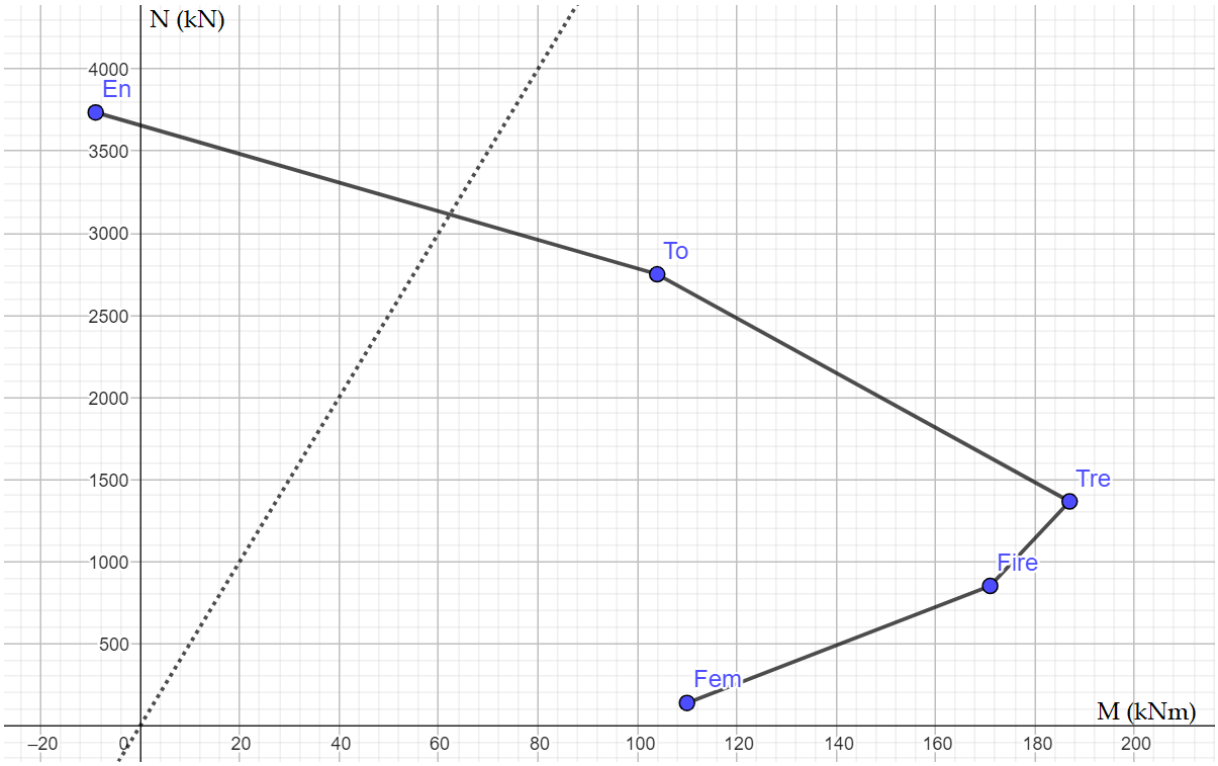
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 484 + 0 - 346 =$ **138 kN**

Momentlikevekt : $M_5 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$485 * (160 - 0.4 * 53.6) + 346 * 123.5 =$ **110 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{283.5}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{995.5}{1000*283.5} = 0.0035$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.0035 * 20)^{\frac{1}{3}} * 1000 * 283.5 = 79350.9$ N = **99.8 kN**

$V_{Rd,c} > V_{Ed}$ **(ok)**

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2}$ =99.8 → p = **27kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*283.5*0.552*11.3 = 884179.8$ N = **884 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2}$ =884 → p = **288 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 283.5 * 0.668 = 4922\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 995.5}{0.8 * 1.0 * 11.3 * 1000 * 283.5} = 0.135$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.135}{0.135} * 0.0035 = 0.0224$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.135 * (1-0.5 * 0{,}8 * 0.135) * 11.3 * 1000 * 283.5^2$

$= 92789634\ Nmm =$ **92.7 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{24} = \frac{(1.2*7.5+1.5*7.5)*4^2}{24} =$ **13.5 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4^2}{24} = 92.7 \rightarrow p =$ **86.7 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 995.5) + 347.8 * 995.5 = 3724985.75\ N =$ **3725 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{995.5}{1000*283.5} = 0.0035$

$\eta\rho = 6.667 * 0.0035 = 0.023$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.023^2 + 2 * 0.023} - 0.023 = 0.19$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 995.5 * (1-0.19) * (1-\frac{0.19}{3}) * 283.5^2 = 6.07*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*6.07*10^7 = 1.21 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*4000^4}{384*1.21*10^{13}}$ = **0.83 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231$mm

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

$\varphi_3 = 1.33 * 3.17 * 0.74 = 3.12$

$\varphi_{28} = 1.33 * 3.17 * 0.49 = 2.07$

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3) = 4.96 * 1 = 3.12$

$\varphi(\infty, 28) = 4.71 * 1 = 2.07$

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{24} = \frac{(9)*4^2}{24} = 6$ kNm

$M_2 = \frac{q*L^2}{24} = \frac{(11.25)*4^2}{24} = 7.5$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_c 2}} = \frac{6+7.5}{\frac{6}{7282}+\frac{7.5}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_s}{b*d} = \frac{995.5}{1000*283.5} = 0.0035$

$\eta\rho = 23.6 * 0.0035 = 0.083$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.083^2 + 2 * 0.083} - 0.083 = 0.33$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.33^2*(1-\frac{0.33}{3})*1000*283.5^3 = 1.10 * 10^9 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*1.10*10^9 = 9.3 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{20.25*4000^4}{384*9.3*10^{12}} =$ **1.45 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*f_{cm}}{f_{cm0}})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \rightarrow \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 995.5 * 283.5}{300000 + 23.6 * 995.5} = 160$

$e = d - \alpha d = 283.5 - 160 = 123.5$

$I = \frac{b * h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000 * 300^3}{12} + 1000 * 300 * \left(160 - \frac{300}{2}\right)^2 + 23.6 * 995.5 * 123.5^2 = 26.38 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{995.5 * 123.5}{26.38 * 10^8} = 2.40 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{2.40 * 10^{-7} * 4000^2}{8} =$ **0.48mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 1.45 + 0.48 =$ **1.93 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > 1.93 \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5 * 1.2 + 1.5 * q) * 4000^4}{384 * 9.3 * 10^{12}} + 0.48 \rightarrow q = 138$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25 * 4^2}{24} = 13.5$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{13.5 * 10^6 * (1 - 0.33) * 283.5}{9.3 * 10^{12}} = 55MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h - \alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-283.5); (\frac{300 - 0.33 * 283.5}{3}); \frac{300}{2}\} = 41.25$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{995.5}{1000 * 41.25} = 0.024$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta \rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{55 - 0.4 * \frac{2.2}{0.024} * (1 + 6.667 * 0.024)}{200000} = 6.23 * 10^{-5} \geq 0.6 * \frac{55}{200000} = 1.65 * 10^{-4}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{ø}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.33 * 283.5) = 268.5$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 268.4 * 1.65 * 10^{-4} =$ **0.044** Sørensen (5.58)

$w_k < w_{max} = 0.05$ (Rissviddekrav oppfylt)

Max nyttelast:

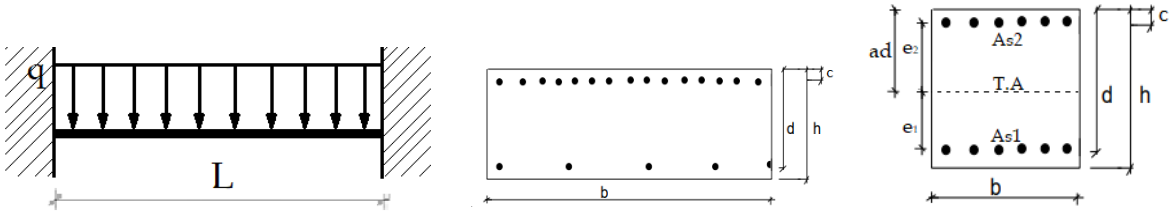
$$0.6 * \frac{\sigma_s}{200000} * 268.5 = 0.05 \rightarrow \sigma_s = 62$$

$$200000 * \frac{M*10^6*(1-0.33)*283.5}{9.3*10^{12}} = 62 \rightarrow M = 15.1$$

$$\frac{(1.2*7.5+1.5*q)*4^2}{24} = 15.1 \rightarrow q = 9.1$$

Vedlegg D.3: Snitt 3

Snitt 3:



Sikkerhets faktor

$\gamma_c = 1.5$ EC2-Tabell 2.1N
$\gamma_s = 1.15$ EC2-Tabell 2.1N
$\alpha_{cc} = 0.85$ EC2- NA.3.1.6(1)
$\gamma_G = 1.2$ EC - Tabell NA.A1.2(A)
$\gamma_Q = 1.5$ EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)
$g_1 = 0$
g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m
$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

$h = 300\ mm$
$b = 1000\ mm$
$d = 300 - 10 - \frac{13}{2} = 283.5\ mm$
c = $10 + \frac{13}{2}$ = 16.5mm
$h` = h - 2 * c$ = 267
$L = 4000\ mm$

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$ EC2-Tabell 3.1
$f_{ctm} = 2.2\ N/mm^2$ EC2-Tabell 3.1
$E_{cm} = 30000\ N/mm^2$ EC2-Tabell 3.1

Standard armering:

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\ f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\text{fck(3)}}{\gamma c} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\text{fctm}}{\text{fyk}}\ b_t\ d;\ 0.0013\ b_t\ d\} =$

$\max\{0.26\frac{2.2}{400}$ *1000*283.5 ; 0.0013*1000*283.5$\} = 405.4\ mm^2$

Antall jern $= \frac{56\ jern}{3.7m} = 15$

$A_s = \pi(\frac{13}{2})^2 * 15 = 1991\ mm^2$

$A_{s1} = A_s * 25\% = 497.75\ mm^2$

$A_{s2} = A_s * 75\% = 1493.25\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st}$ = ikke gjeldende

$\Delta c_{dur,add}$ = ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * (1493.25 - 497.75) * 283.5}{300000 + 23.6 * (1493.25 - 497.75)} = 160 \rightarrow 140$

e_2 = d-αd = 283.5-160 =123.5 (avstand A_{s2} til T.A)

e_1 = h`-e_2 = 267-123.5 = 143.5 (avstand A_{s1} til T.A)

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h$ = 11.3 * 1000 * 300 = 3390000 N = 3390 kN

$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1}$ = 347.8 * 497.75 =173117.45 N = 173 kN

$S_2 = \frac{f_{yk}}{\gamma_s} * A_{s2} = f_{yd} * A_{s2}$ = 347.8 * 1493.25 = 519352.35 N = 519 kN

Aksiell likevekt: $N_1 = T_c + S_1 + S_2$ =3390 + 173 + 519 = **4082 kN**

Momentlikevekt : $M_1 = T_c * (\alpha d - 0.5h) + S_2 * e_2 - S_1 * e_1$

= 3390*(140-300/2)+519*123.5 -173*143.5 =**5.4**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 16.5 * 0.0035/300 = 0{,}00019 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00019 = 38$ N/mm^2

$T_c = f_{cd} * b * 0.8 * h = 11.3 * 1000 * 0.8 * 300 = 2712000$ N = 2712 kN

$S_1 = \sigma_{sd} * A_{s1}$ = 38 * 497.75 =18914.5 N = 19 kN

$S_2 = f_{yd} * A_{s2}$ = 347.8 * 1493.25 = 519352 N = 519 kN

Aksiell likevekt: $N_2 = T_c + S_1 + S_2$ =2712+19+519 = **3250 kN**

Momentlikevekt: $M_2 = T_c * (\alpha d - 0{,}4h) + S_2 * e_2 - S_1 * e_1$ =

3250*(140-0.4*300)+519*123.5 – 19*143.5 = **126 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d_2 = 0.668 * 283.5 = 189.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{189.4-16.5}{189.4} * 0.0035 = 0.0032$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 189.4 = 1712176\ N = 1712\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117.45\ N = 173\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 1493.25 = 519352.35\ N = 519\ kN$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1712 + 519 - 173 =$ **2058 kN**

Momentlikevekt : $M_3 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e_1 + S_2 * e_2 =$

$1712 * (140 - 0.4 * 189.4) + 173 * 143.5 + 519 * 123.5 =$ **199 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d_2 = 0.467 * 283.5 = 132.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{132.4-16.5}{132.4} * 0.0035 = 0.003$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 132.4 = 1196896\ N = 1196.9\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117.45\ N = 173\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 1493.25 = 519352.35\ N = 519\ kN$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1196.9 + 519 - 173 =$ **1543 kN**

Momentlikevekt : $M_4 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e_1 + S_2 * e_2 =$

$1196.9* (140 - 0.4 * 132.4) + 173 * 143.5+519*123.5 =$ **193 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d_2 = 0.189 * 283.5 = 53.6\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{53.6-16.5}{53.6} * 0.0035 = 0.0024$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 53.6 = 484544\ N = 485\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 497.75 = 173117.45\ N = 173\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 1493.25 = 519352.35\ N = 519\ kN$

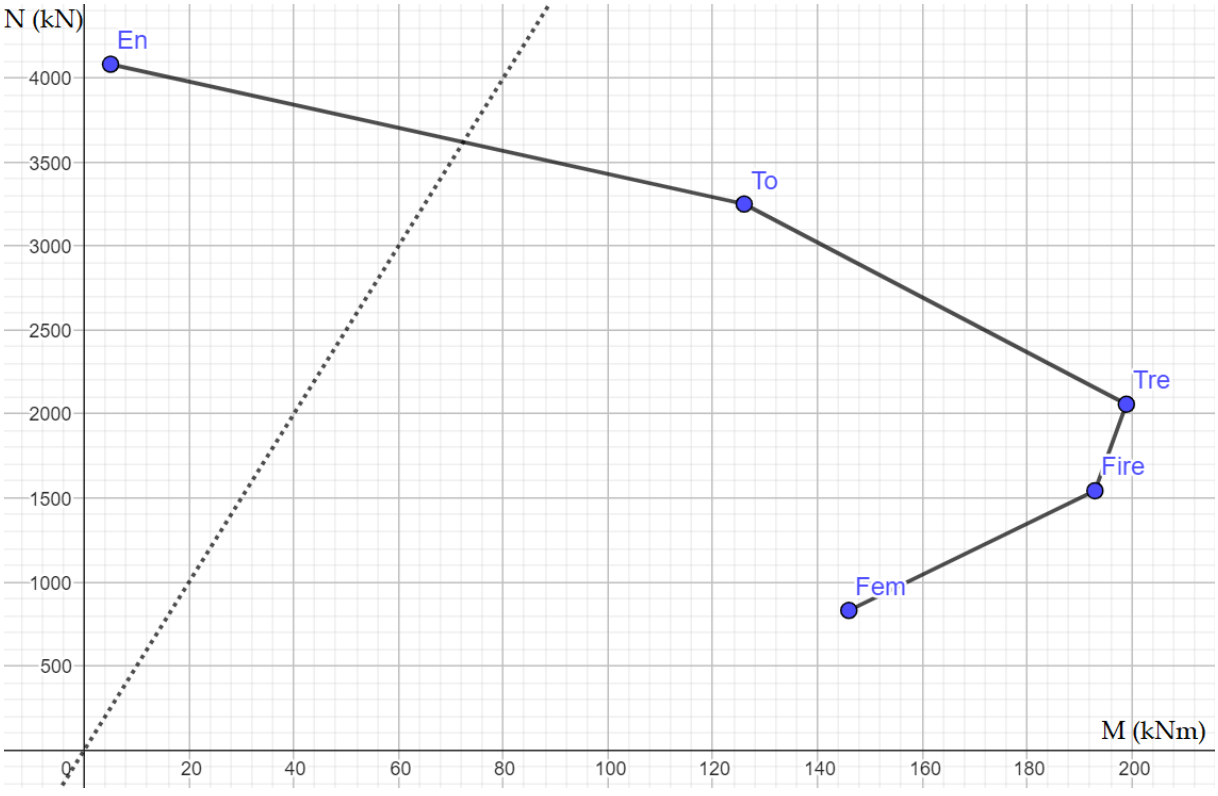
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 484 + 519 - 173 =$ **830 kN**

Momentlikevekt : $M_5 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * h`/2 + S_2 * h`/2 =$

$485 * (140 - 0.4 * 53.6) + 173 * 143.5 + 519 * 123.5 =$ **146 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{283.5}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{497.75}{1000*283.5} = 0.00176$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.00176 * 20)^{\frac{1}{3}} * 1000 * 283.5 = 79350.9$ N = **79.3 kN**

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

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2} = 79.3 \rightarrow$ p = **20.4kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*283.5*0.552*11.3 = 884179.8$ N = **884 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2} = 884 \rightarrow$ p = **288 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 283.5 * 0.668 = 4922\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 1991}{0.8 * 1.0 * 11.3 * 1000 * 283.5} = 0.270$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.27}{0.27} * 0.0035 = 0.0095$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.27 * (1-0.5 * 0{,}8 * 0.27) * 11.3 * 1000 * 283.5^2$

$= 174985948.3\ Nmm =$ **175 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{12} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 4^2}{12} =$ **27 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 4^2}{12} = 175 \rightarrow$ p = **81.5 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 1991) + 347.8 * 1991 = 4059971.5\ N =$ **4060 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{1991}{1000*283.5} = 0.007$

$\eta\rho = 6.667 * 0.007 = 0.047$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.047^2 + 2 * 0.047} - 0.047 = 0.26$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 1991 * (1-0.26) * (1-\frac{0.26}{3}) * 283.5^2 = 10.8*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*10.8*10^7 = 2.16 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q * L^4}{EI} = \frac{15*4000^4}{384*2.16*10^{13}} =$ **0.46 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1*\sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1*\sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+t_0{}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

φ_3 =1.33 * 3.17 * 0.74 = 3.12

φ_{28} =1.33 * 3.17 * 0.49 = 2.07

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3)$ =4.96 * 1 = 3.12

$\varphi(\infty, 28)$ = 4.71 * 1 = 2.07

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{12} = \frac{(9)*4^2}{12} = 12$ kNm

$M_2 = \frac{q*L^2}{12} = \frac{(11.25)*4^2}{12} = 15$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_c 2}} = \frac{12+15}{\frac{12}{7282}+\frac{15}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_s}{b*d} = \frac{1995}{1000*283.5} = 0.007$

$\eta\rho = 23.6 * 0.007 = 0.165$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.165^2 + 2*0.165} - 0.165 = 0.43$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.43^2*(1-\frac{0.43}{3})*1000*283.5^3 = 1.80 * 10^9 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*1.80*10^9 = 1.5 * 10^{13}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*4000^4}{384*1.5*10^{13}}$ = **0.9 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*f_{cm}}{f_{cm0}})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * (1493.25 - 497.75) * 283.5}{300000 + 23.6 * (1493.25 - 497.75)} = 160 \rightarrow 140$

$e_2 = d - \alpha d = 283.5 - 160 = 123.5$ (avstand A_{s2} til T.A)

$e_1 = h` - e_2 = 267 - 123.5 = 143.5$ (avstand A_{s1} til T.A)

$I = \frac{b * h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000 * 300^3}{12} + 1000 * 300 * \left(140 - \frac{300}{2}\right)^2 + 23.6 * 1493.25 * 123.5^2 + 23.6 * 497.75 * 143.5^2$

$= 30.6 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{1493.25 * 123.5 + 497.75 * 143.5}{30.6 * 10^8} = 4.3 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{4.3 * 10^{-7} * 4000^2}{8} =$ **0.86mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 0.9 + 0.86 =$ **1.76 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5 * 1.2 + 1.5 * q) * 4000^4}{384 * 1.5 * 10^{13}} + 0.86 \rightarrow q = 221$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25 * 4^2}{12} = 27$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{27 * 10^6 * (1 - 0.43) * 283.5}{1.5 * 10^{13}} = 58MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h - \alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-283.5); (\frac{300 - 0.33 * 283.5}{3}); \frac{300}{2}\} = 41.25$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{1991}{1000 * 41.25} = 0.048$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta \rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{58 - 0.4 * \frac{2.2}{0.048} * (1 + 6.667 * 0.048)}{200000} = 1.69 * 10^{-4} \geq 0.6 * \frac{58}{200000} = 1.74 * 10^{-4}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{\phi}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.43 * 283.5) = 231.5$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 231.5 * 1.74 * 10^{-4} =$ **0.04** Sørensen (5.58)

$w_k < w_{max} = 0.05$ (Rissviddekrav oppfylt)

Max Nyttelast :

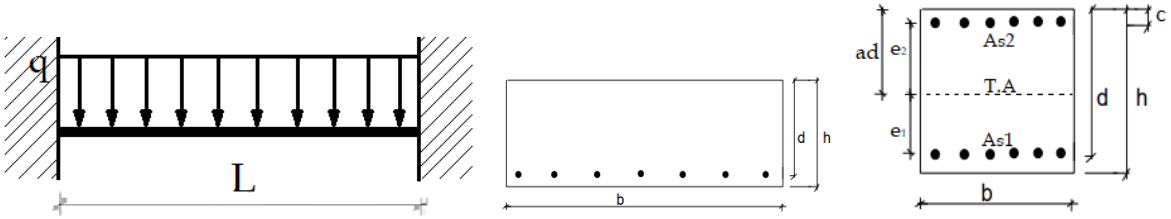
$0.6 * \frac{\sigma_s}{200000} * 231.5 = 0.05 \rightarrow \sigma_s = 71.9$

$200000 * \frac{M*10^6*(1-0.43)*283.5}{1.5*10^{13}} = 71.9 \rightarrow M = 33.3$

$\frac{(1.2*7.5+1.5*q)*4^2}{12} = 33.3 \rightarrow q = 10$

Vedlegg D.4: Snitt 4

Snitt 4:



Sikkerhets faktor

$\gamma_c = 1.5$ EC2-Tabell 2.1N

$\gamma_s = 1.15$ EC2-Tabell 2.1N

$\alpha_{cc} = 0.85$ EC2- NA.3.1.6(1)

$\gamma_G = 1.2$ EC - Tabell NA.A1.2(A)

$\gamma_Q = 1.5$ EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

h = 300 mm

b = 1000 mm

$d = 300 - 10 - 13 - \frac{13}{2} = 270.5\ mm$

$c = 10 + 13 + \frac{13}{2} = 29.5$mm

$h` = h - 2 * c = 241$

L = 4000 mm

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$ EC2-Tabell 3.1

$f_{ctm} = 2.2\ N/mm^2$ EC2-Tabell 3.1

$E_{cm} = 30000\ N/mm^2$ EC2-Tabell 3.1

Standard armering:

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\ f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\text{fck(3)}}{\gamma c} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\text{fctm}}{\text{fyk}}\ b_t\ d;\ 0.0013\ b_t\ d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 270.5\ ;\ 0.0013 * 1000 * 270.5\} = 386.8\ mm^2$

Antall jern $= \frac{6\ jern}{0.85m} = 7$

$A_s = \pi(\frac{13}{2})^2 * 7 = 929\ mm^2$

$A_{s1} = A_s = 929\ mm^2$

$A_{s2} = 0 = 0\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st} =$ ikke gjeldende

$\Delta c_{dur,add} =$ ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

$\eta = \frac{E_s}{E_{c,middel}} = \frac{200000}{8483} = 23.6$ (se langtidsnedbøyning)

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 929 * 270.5}{300000 + 23.6 * 929} = 158$

$e = d - \alpha d = 270.5 - 158 = 112.5$

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000\ N = 3390\ kN$

$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 929 = 323106\ N = 323\ kN$

$S_2 = 0$

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 323 =$ **3713 kN**

Momentlikevekt : $M_1 = T_c * (\alpha d - 0.5h) - S_1 * e$

$3390*(158-150) - 323*112.5 =$ **-92**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 16.5*0.0035/300 = 0{,}00034 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00034 = 68\ N/mm^2$

$T_c = f_{cd} * b * 0.8 * h = 11.3*1000*0.8*300 = 2712000\ N = 2712\ kN$

$S_1 = \sigma_{sd} * A_{s1} = 68 * 929 = 63172\ N = 63\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712+63 =$ **2775 kN**

Momentlikevekt: $M_2 = T_c * (\alpha d - 0{,}4h) + S_1 * e =$

$2712*(158-0.4*300) - 63*112.5 =$ **96 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d_2 = 0.668 * 270.5 = 180.7\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{180.7-29.5}{180.7} * 0.0035 = 0.003$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 180.7 = 1633528\ N = 1634\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 929 = 323106.2\ N = 323\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1634 - 323 =$ **1311 kN**

Momentlikevekt : $M_3 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$1712 * (158 - 0.4 * 180.7) + 323 * 112{,}5 =$ **183 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d_2 = 0.467 * 270.5 = 126.3\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{126.3-29.5}{126.3} * 0.0035 = 0.0027$(flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 126.3 = 1141752\ N = 1142\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 929 = 323106.2\ N = 323\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1142 - 323 =$ **819 kN**

Momentlikevekt : $M_4 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$1142* (158 - 0.4 * 126.3) + 323 *112.5 =$ **159 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d_2 = 0.189 * 270.5 = 51\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{51-29.5}{51} * 0.0035 = 0.0015$ (flyter)

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}0015 = 300\ N/mm^2$

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3*1000*0.8*51 = 461040\ N = 461\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 929 = 323106.2\ N = 323\ kN$

$S_2 = \sigma_{sd} * A_{s2} = 300 * 0 = 0\ N = 0\ kN$

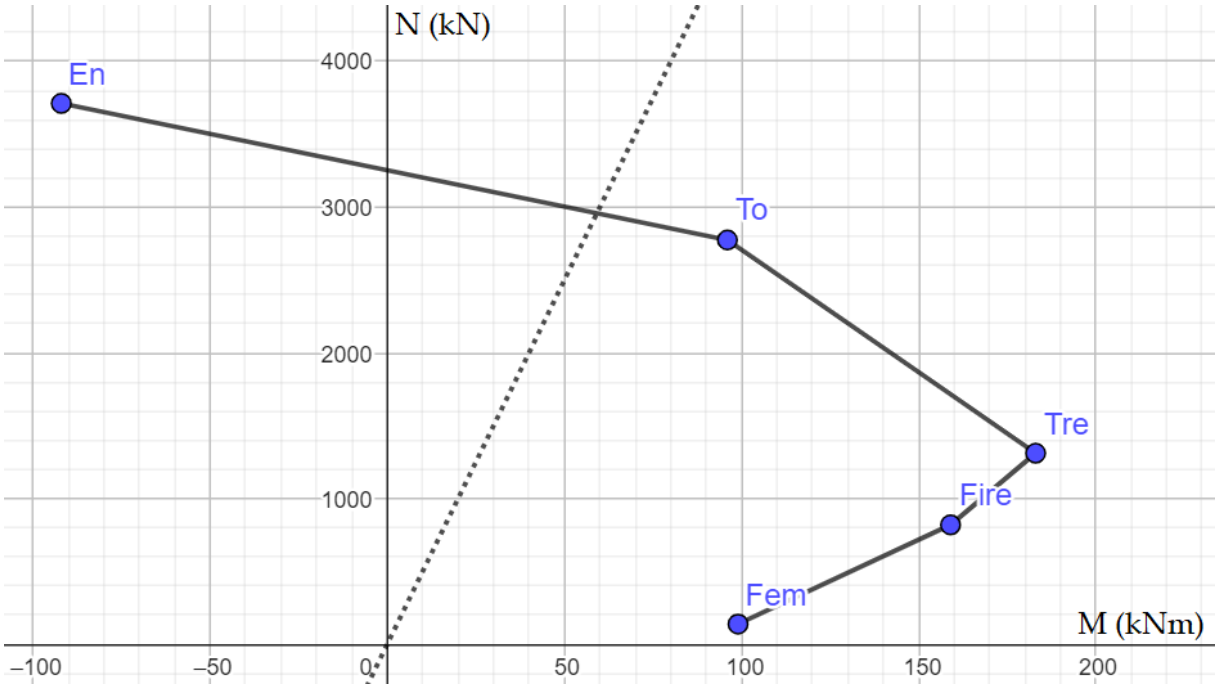
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 461 + 0 - 323 =$ **138 kN**

Momentlikevekt : $M_5 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$461 * (158 - 0.4 * 53.6) + 323 * 112.5 =$ **99 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{270.5}} = 1.86$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{929}{1000*270.5} = 0.0034$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.86 * (100 * 0.0034 * 20)^{\frac{1}{3}} * 1000 * 270.5 = 95319.8$ N = **95.3 kN**

$V_{Rd,c} > V_{Ed}$ **(ok)**

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2}$ =95.3 → p = **25.7 kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*270.5*0.552*11.3 = 843635.4$ N = **843 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2}$ =843 → p = **275 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b*d*\alpha_b = 0.8*1.0* \frac{11.3}{347.8} * 1000*270.5*0.668 = 4697\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda*\eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda*\eta * f_{cd} * b * d} = \frac{347.8*929}{0.8*1.0*11.3*1000*270.5} = 0.132$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.132}{0.132} * 0.0035 = 0.023$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5* \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8*1.0*0.132*(1-0.5*0{,}8*0.132) * 11.3*1000*270.5^2$

$= 82702490.9\ Nmm =$ **82.7 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5\cdot p]*L^2}{24} = \frac{(1.2*7.5+1.5*7.5)*4^2}{24} =$ **13.5 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4^2}{24} = 82.7 \rightarrow p =$ **76.7 kN/m**

Aksialkraftkapasitet:

$A_c = b*h = 1000*300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000- 929) + 347.8 * 929 = 3702608.5\ N =$ **3703 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{929}{1000*270.5} = 0.0034$

$\eta\rho = 6.667 * 0.0034 = 0.023$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.023^2 + 2 * 0.023} - 0.023 = 0.21$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 929 * (1-0.21) * (1-\frac{0.21}{3}) * 270.5^2 = 4.99*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*4.99*10^7 = 9.98 * 10^{12}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*4000^4}{384*9.98*10^{12}}$ = **1.00 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

$\varphi_3 = 1.33 * 3.17 * 0.74 = 3.12$

$\varphi_{28} = 1.33 * 3.17 * 0.49 = 2.07$

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3) = 4.96 * 1 = 3.12$

$\varphi(\infty, 28) = 4.71 * 1 = 2.07$

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{24} = \frac{(9)*4^2}{24} = 6$ kNm

$M_2 = \frac{q*L^2}{24} = \frac{(11.25)*4^2}{24} = 7.5$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_c 2}} = \frac{6+7.5}{\frac{6}{7282}+\frac{7.5}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_S}{b*d} = \frac{929}{1000*270.5} = 0.0034$

$\eta\rho = 23.6 * 0.0034 = 0.08$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.08^2 + 2*0.08} - 0.08 = 0.33$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.33^2*(1-\frac{0.33}{3})*1000*270.5^3 = 9.59 * 10^8 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*9.59 * 10^8 = 8.1 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{20.25*4000^4}{384*8.1*10^{12}} =$ **1.67 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*fcm}{fcm0})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 929 * 270.5}{300000 + 23.6 * 929} = 158$

$e = d - \alpha d = 270.5 - 158 = 112.5$

$I = \frac{b * h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000 * 300^3}{12} + 1000 * 300 * \left(158 - \frac{300}{2}\right)^2 + 23.6 * 929 * 112.5^2 = 25.5 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{929 * 112.5}{25.5 * 10^8} = 2.1 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{2.1 * 10^{-7} * 4000^2}{8} =$ **0.42mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 1.67 + 0.42 =$ **2.09 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5 * 1.2 + 1.5 * q) * 4000^4}{384 * 8.1 * 10^{12}} + 0.42 \rightarrow q = 120$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25 * 4^2}{24} = 13.5$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{13.5 * 10^6 * (1 - 0.33) * 270.5}{8.1 * 10^{12}} = 60MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h - \alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-270.5); (\frac{300 - 0.33 * 270.5}{3}); \frac{300}{2}\} = 70.25$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{929}{1000 * 70.25} = 0.013$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta \rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{60 - 0.4 * \frac{2.2}{0.013} * (1 + 6.667 * 0.013)}{200000} = 6.78 * 10^{-5} \geq 0.6 * \frac{60}{200000} = 1.8 * 10^{-4}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{\phi}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.33 * 270.5) = 274$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 274 * 1.8 * 10^{-4} =$ **0.049** Sørensen (5.58)

$w_k < w_{max} = 0.05$ (Rissviddekrav oppfylt)

Max nyttelast:

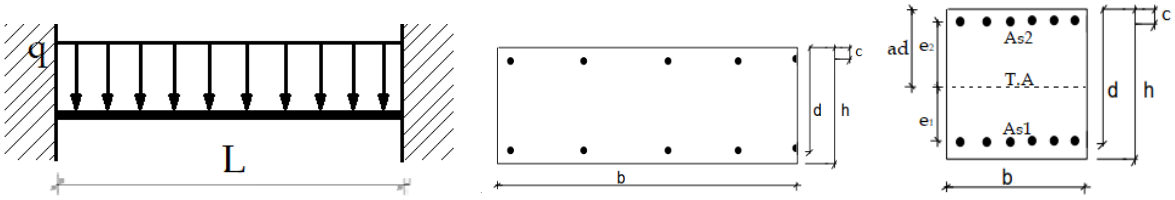
$0.6 * \frac{\sigma_s}{200000} * 274 = 0.05 \rightarrow \sigma_s = 60.8$

$200000 * \frac{M*10^6*(1-0.33)*270.5}{8.1*10^{12}} = 60.8 \rightarrow M = 13.5$

$\frac{20.25*4^2}{24} = 13.5 \text{ kNm} \rightarrow 7.5$

Vedlegg D.5: Snitt 5

Snitt 5:



Sikkerhets faktor

$\gamma_c = 1.5$	EC2-Tabell 2.1N
$\gamma_s = 1.15$	EC2-Tabell 2.1N
$\alpha_{cc} = 0.85$	EC2- NA.3.1.6(1)
$\gamma_G = 1.2$	EC - Tabell NA.A1.2(A)
$\gamma_Q = 1.5$	EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

h = 300 mm

b = 1000 mm

$d = 300 - 10 - 13 - \frac{13}{2} = 270.5\ mm$

c = 10 + 13 + $\frac{13}{2}$ = 29.5mm

$h` = h - 2 * c$ = 241

L = 4000 mm

e = h`/2 = 241/2 =120.5

αd = h/2 = 300/2 = 150

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$	EC2-Tabell 3.1
$f_{ctm} = 2.2\ N/mm^2$	EC2-Tabell 3.1
$E_{cm} = 30000\ N/mm^2$	EC2-Tabell 3.1

Standard armering

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\, f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\mathrm{fck(3)}}{\gamma \mathrm{c}} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\mathrm{fctm}}{\mathrm{fyk}}\, b_t\, d;\ 0.0013\, b_t\, d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 270.5\ ;\ 0.0013 * 1000 * 270.5\} = 386.8\ mm^2$

Antall jern $= \frac{6\ jern}{0{,}85m} = 7$

$A_s = \pi(\frac{13}{2})^2 * 7 = 929\ mm^2$

$A_{s1} = A_s/2 = 464.5\ mm^2$

$A_{s2} = A_s/2 = 464.5\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st}$ = ikke gjeldende

$\Delta c_{dur,add}$ = ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000\ N = 3390\ kN$
$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 464.5 = 161553.1\ N = 162\ kN$
$S_2 = S_1$

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 162 + 162 =$ **3714 kN**
Momentlikevekt : $M_1 =$ **0**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter
$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 29.5*0.0035/300 = 0{,}00034 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00034 = 68\ N/mm^2$

$T_c = f_{cd} * b * 0.8 * h = 11.3*1000*0.8*300 = 2712000\ N = 2712\ kN$

$S_1 = \sigma_{sd} * A_{s1} = 68 * 464.5 = 17651\ N = 31.6\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 464.5 = 161553.1\ N = 162\ kN$

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712+31.6+173 =$ **2916.6 kN**

Momentlikevekt: $M_2 = T_c * (0.5h-0{,}4h) + S_2 * h`/2 - S_1 * h`/2 =$

$2712*(0.5*0.300-0.4*0.300)+162*0.241/2 - 31.6*0.241/2 =$ **104.7 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d = 0.668 * 270.5 = 180.7\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{180.7-29.5}{180.7} * 0.0035 = 0.0029$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 180.7 = 1633528\ N = 1634\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 464.5 = 161553.1\ N = 162\ kN$

$S_2 = S_1$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1634 + 162 - 162 =$ **1634 kN**

Momentlikevekt : $M_3 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h` =$

$1634 * (0.5*300 - 0.4 * 180.7) + 162 * 241 =$ **166 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d = 0.467 * 270.5 = 126.3\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{126.3-29.5}{126.3} * 0.0035 = 0.0027$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 126.3 = 1196896\ N = 1142\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 464.5 = 161553.1\ N = 162\ kN$

$S_2 = S_1$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1142 + 162 - 162 =$ **1142 kN**

Momentlikevekt : $M_4 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h` =$

$1142 * (0.5*300 - 0.4 * 126.3) + 162 * 241 =$ **152.6 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d = 0.189 * 270.5 = 51.1\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{51.1-29.5}{51.1} * 0.0035 = 0.0015$ (flyter ikke)

$\sigma_{sd} = E_s * \varepsilon_{s2} = 200000 * 0{,}0015 = 300\ N/mm^2$

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 51.1 = 461944\ N = 462\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 464.5 = 161553.1\ N = 162\ kN$

$S_2 = \sigma_{sd} * A_{s2} = 300 * 464.5 = 139350\ N = 139\ kN$

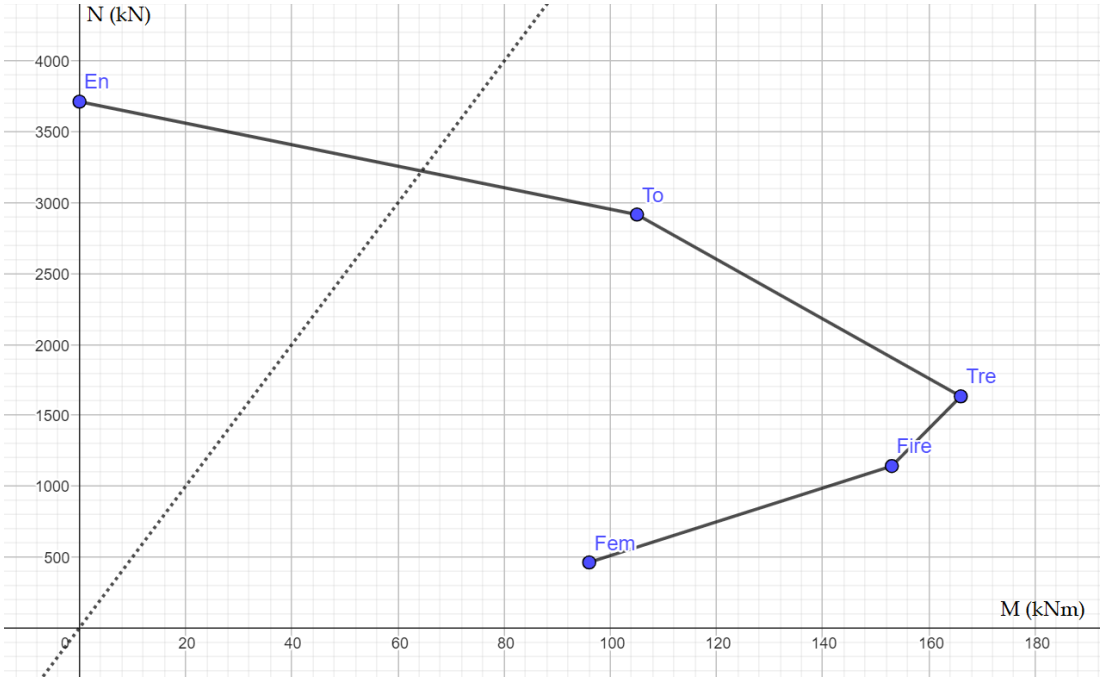
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 462 + 162 - 162 =$ **462 kN**

Momentlikevekt : $M_5 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h`/2 + S_2 * h`/2 =$

$462 * (0.5*300 - 0.4 * 51.1) + 162 * 241/2 + 139 * 241/2 =$ **96 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{270.5}} = 1.86$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{464.5}{1000*270.5} = 0.0017$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.86 * (100 * 0.0017 * 20)^{\frac{1}{3}} * 1000 * 270.5 = 75655.4$ N = **75.7 kN**

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

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2}$ =75.7 → p = **19.2kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*270.5*0.552*11.3 = 843935.4$ N = **844 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2}$ =844 → p = **275 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 270.5 * 0.668 = 4696.6\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 929}{0.8 * 1.0 * 11.3 * 1000 * 270.5} = 0.132$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.132}{0.132} * 0.0035 = 0.0230$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.132 * (1-0.5 * 0{,}8 * 0.132) * 11.3 * 1000 * 270.5^2$

$= 82702490.9$ Nmm = **82.7 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{12} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 4^2}{12}$ = **27 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 4^2}{12} = 82.7 \rightarrow$ p = **35.3 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 929) + 347.8 * 929 = 3702608.5\ N = \mathbf{3703\ kN}$

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{929}{1000*270.5} = 0.0034$

$\eta\rho = 6.667 * 0.0034 = 0.023$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.023^2 + 2 * 0.023} - 0.023 = 0.19$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 929 * (1-0.19) * (1-\frac{0.19}{3}) * 270.5^2 = 5.16*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*5.16*10^7 = 1.03 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*4000^4}{384*1.03*10^{13}}$ = **0.97 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

$\varphi_3 = 1.33 * 3.17 * 0.74 = 3.12$

$\varphi_{28} = 1.33 * 3.17 * 0.49 = 2.07$

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3) = 4.96 * 1 = 3.12$

$\varphi(\infty, 28) = 4.71 * 1 = 2.07$

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{12} = \frac{(9)*4^2}{12} = 12$ kNm

$M_2 = \frac{q*L^2}{12} = \frac{(11.25)*4^2}{12} = 15$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_{c2}}} = \frac{12+15}{\frac{12}{7282}+\frac{15}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_S}{b*d} = \frac{929}{1000*270.5} = 0.0034$

$\eta\rho = 23.6 * 0.0034 = 0.080$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.08^2 + 2*0.08} - 0.08 = 0.33$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.33^2*(1-\frac{0.33}{3})*1000*270.5^3 = 0.96 * 10^9 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*0.96*10^9 = 8.1 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*4000^4}{384*8.1*10^{12}} =$ **1.67 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*fcm}{fcm0})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{h}{2} = \frac{300}{2} = 150$

$e = d - \alpha d = 270.5 - 150 = 120.5$

$I = \frac{b*h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000*300^3}{12} + 1000 * 300 * \left(150 - \frac{300}{2}\right)^2 + 23.6 * 929 * 120.5^2 = 25.68 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{929*120.5}{25.68*10^8} = 2.24 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{2.24*10^{-7}*4000^2}{8} =$ **0.45mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 1.67 + 0.45 =$ **2.01 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5*1.2+1.5*q)*4000^4}{384*8.1*10^{12}} + 0.45 \rightarrow q = 119.9$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25*4^2}{12} = 27$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{27*10^6*(1-0.33)*270.5}{8.1*10^{12}} = 121MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h-\alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-270.5); (\frac{300-0.33*270.5}{3}); \frac{300}{2}\} = 70.25$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{929}{1000*70.25} = 0.013$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta\rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{121 - 0.4 * \frac{2.2}{0.013} * (1 + 6.667 * 0.013)}{200000} = 2.37 * 10^{-4} \geq 0.6 * \frac{121}{200000} = 3.63 * 10^{-4}$

$C_{nom} = 10mm$

$5*(c_{nom} + \frac{\phi}{2}) = 5*(10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3*(h - \alpha d) = 1.3*(300 - 0.33*270.5) = 274$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 274 * 3.63*10^{-4} =$ **0.10** Sørensen (5.58)

$w_k > w_{max} = 0.05$ (Rissviddekrav ikke oppfylt)

Max nyttelast :

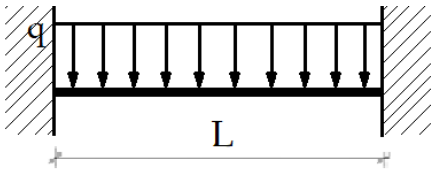
$0.6 * \frac{\sigma_s}{200000} * 275 = 0.05 \rightarrow \sigma_s = 60.6$

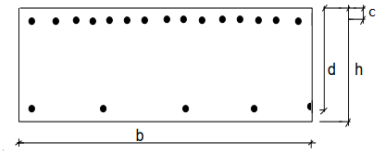
$200000 * \frac{M*10^6*(1-0.33)*270.5}{8.1*10^{12}} = 60.6 \rightarrow M = 13.5$

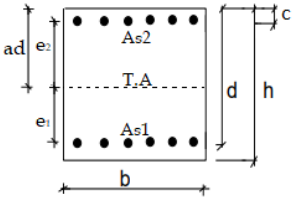
$\frac{(1.2*7.5+1.5*q)*4^2}{12} = 13.5 \rightarrow q = 0.75$

Vedlegg D.6: Snitt 6

Snitt 6:







Sikkerhets faktor

$\gamma_c = 1.5$ EC2-Tabell 2.1N

$\gamma_s = 1.15$ EC2-Tabell 2.1N

$\alpha_{cc} = 0.85$ EC2- NA.3.1.6(1)

$\gamma_G = 1.2$ EC - Tabell NA.A1.2(A)

$\gamma_Q = 1.5$ EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

h = 300 mm

b = 1000 mm

$d = 300 - 10 - \frac{13}{2} = 283.5\ mm$

c = $10 + \frac{13}{2}$ = 16.5mm

$h` = h - 2 * c$ = 267

L = 4000 mm

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$ EC2-Tabell 3.1

$f_{ctm} = 2.2\ N/mm^2$ EC2-Tabell 3.1

$E_{cm} = 30000\ N/mm^2$ EC2-Tabell 3.1

Standard armering:

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\, f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\mathrm{fck(3)}}{\mathrm{\gamma c}} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\mathrm{fctm}}{\mathrm{fyk}}\, b_t\, d;\ 0.0013\, b_t\, d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 283.5\ ;\ 0.0013 * 1000 * 283.5\} = 405.4\ mm^2$

Antall jern $= \frac{42\ jern}{3.7m} = 11.35$

$A_s = \pi(\frac{13}{2})^2 * 11.35 = 1506\ mm^2$

$A_{s1} = \mathrm{A_s} * \frac{1}{3} = 502\ mm^2$

$A_{s2} = \mathrm{A_s} * \frac{2}{3} = 1004\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st} =$ ikke gjeldende

$\Delta c_{dur,add} =$ ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

$\eta = \frac{E_s}{E_{c,middel}} = \frac{200000}{8483} = 23.6$ (fra Langtidsnedbøynig)

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * (1004 - 502) * 283.5}{300000 + 23.6 * (1004 - 502)} = 155 \rightarrow 145$

e_2 = d-αd = 283.5-155 =128.5 (avstand A_{s2} til T.A)

e_1 = h`-e_2 = 267-128.5 = 138.5 (avstand A_{s1} til T.A)

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000$ N = 3390 kN

$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 502 = 175$ kN

$S_2 = \frac{f_{yk}}{\gamma_s} * A_{s2} = f_{yd} * A_{s2} = 347.8 * 1004 = 349$ kN

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 175 + 349 =$ **3914 kN**

Momentlikevekt : $M_1 = T_c * (\alpha d - 0.5h) + S_2 * e_2 - S_1 * e_1$

$= 3390 * (145 - 300/2) + 349 * 128.5 - 175 * 138.5 =$ **37 kNm**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 16.5 * 0.0035/300 = 0{,}00019 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00019 = 38$ N/mm²

$T_c = f_{cd} * b * 0.8h = 11.3 * 1000 * 0.8 * 300 = 271200$ N = 2712 kN

$S_1 = \sigma_{sd} * A_{s1} = 38 * 502 = 18914.5$ N = 19 kN

$S_2 = f_{yd} * A_{s2} = 347.8 * 1493.25 = 519352$ N = 349 kN

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712 + 19 + 349 =$ **3080 kN**

Momentlikevekt: $M_2 = T_c * (\alpha d - 0{,}4h) + S_2 * e_2 - S_1 * e_1 =$

$2712 * (145 - 0.4 * 300) + 349 * 128.5 - 19 * 138.5 =$ **110 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d_2 = 0.668 * 283.5 = 189.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{189.4-16.5}{189.4} * 0.0035 = 0.0032$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 189.4 = 1712176\ N = 1712\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 502 = 174596\ N = 175\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 1004 = 349191.2\ N = 349\ kN$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1712 + 349 - 175 =$ **1886 kN**

Momentlikevekt : $M_3 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e_1 + S_2 * e_2 =$

$1712 * (145 - 0.4 * 189.4) + 175 * 138.5 + 349 * 128.5 =$ **188 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d_2 = 0.467 * 283.5 = 132.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{132.4-16.5}{132.4} * 0.0035 = 0.003$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 132.4 = 1196896\ N = 1196.9\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 502 = 174596\ N = 175\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 1004 = 349191.2\ N = 349\ kN$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1196.9 + 349 - 175 =$ **1371 kN**

Momentlikevekt : $M_4 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e_1 + S_2 * e_2 =$

$1196.9* (145 - 0.4 * 132.4) + 175 * 138.5+349*128.5 =$ **179 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d_2 = 0.189 * 283.5 = 53.6\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{53.6-16.5}{53.6} * 0.0035 = 0.0024$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 53.6 = 484544\ N = 485\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 502 = 174596\ N = 175\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 1004 = 349191.2\ N = 349\ kN$

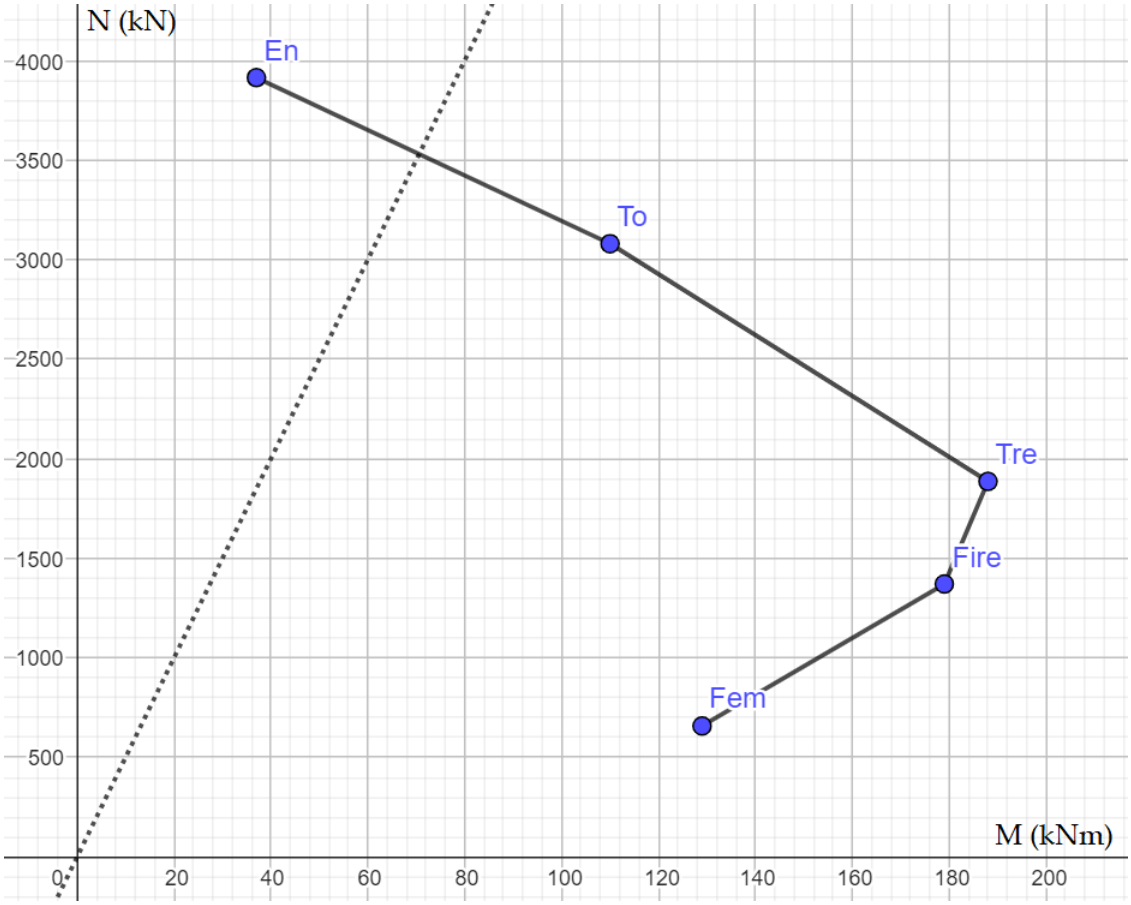
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 484 + 349 - 175 =$ **658 kN**

Momentlikevekt : $M_5 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e_1 + S_2 * e_2 =$

$485 * (145 - 0.4 * 53.6) + 175 * 138.5 + 349 * 128.5 =$ **129 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{283.5}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{502}{1000*283.5} = 0.00177$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.00177 * 20)^{\frac{1}{3}} * 1000 * 283.5 = 79500.9$ N = **79.5 kN**

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

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2} = 79.5 \rightarrow$ p = **20.5kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*283.5*0.552*11.3 = 884179.8$ N = **884 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2} = 884 \rightarrow$ p = **288 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 283.5 * 0.668 = 4922\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 1509}{0.8 * 1.0 * 11.3 * 1000 * 283.5} = 0.205$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.205}{0.205} * 0.0035 = 0.014$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.205 * (1-0.5 * 0{,}8 * 0.205) * 11.3 * 1000 * 283.5^2$

$= 136732293.7\ Nmm =$ **136.7 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{12} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 4^2}{12} =$ **27 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 4^2}{12} = 136.7 \rightarrow$ p = **62 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 1506) + 347.8 * 1506 = 4059971.5\ N =$ **3898 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{1506}{1000*283.5} = 0.005$

$\eta\rho = 6.667 * 0.005 = 0.033$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.033^2 + 2 * 0.033} - 0.033 = 0.23$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 1506 * (1-0.23) * (1-\frac{0.23}{3}) * 283.5^2 = 8.6*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*8.6*10^7 = 1.72 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*4000^4}{384*1.72*10^{13}}$ = **0.58 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

φ_3 =1.33 * 3.17 * 0.74 = 3.12

φ_{28} =1.33 * 3.17 * 0.49 = 2.07

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3)$ =4.96 * 1 = 3.12

$\varphi(\infty, 28)$ = 4.71 * 1 = 2.07

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{12} = \frac{(9)*4^2}{12} = 12$ kNm

$M_2 = \frac{q*L^2}{12} = \frac{(11.25)*4^2}{12} = 15$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_c 2}} = \frac{12+15}{\frac{12}{7282}+\frac{15}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_s}{b*d} = \frac{1506}{1000*283.5} = 0.005$

$\eta\rho = 23.6 * 0.005 = 0.118$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.118^2 + 2 * 0.118} - 0.118 = 0.38$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.38^2*(1-\frac{0.38}{3})*1000*283.5^3 = 1.44 * 10^9 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*1.44*10^9 = 1.2 * 10^{13}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*4000^4}{384*1.2*10^{13}} =$ **1.13 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*f_{cm}}{f_{cm0}})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * (1004 - 502) * 283.5}{300000 + 23.6 * (1004 - 502)} = 155 \rightarrow 145$

$e_2 = d - \alpha d = 283.5 - 155 = 128.5$ (avstand A_{s2} til T.A)

$e_1 = h` - e_2 = 267 - 128.5 = 138.5$ (avstand A_{s1} til T.A)

$I = \frac{b * h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000 * 300^3}{12} + 1000 * 300 * \left(145 - \frac{300}{2}\right)^2 + 23.6 * 1004 * 128.5^2 + 23.6 * 502 * 138.5^2$

$= 28.7 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{1004 * 128.5 + 502 * 138.5}{28.7 * 10^8} = 3.56 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{3.56 * 10^{-7} * 4000^2}{8} =$ **0.71mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 1.13 + 0.71 =$ **1.84 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5 * 1.2 + 1.5 * q) * 4000^4}{384 * 1.2 * 10^{13}} + 0.71 \rightarrow q = 177$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25 * 4^2}{12} = 27$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{27 * 10^6 * (1 - 0.38) * 283.5}{1.2 * 10^{13}} = 79MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h - \alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-283.5); (\frac{300 - 0.38 * 283.5}{3}); \frac{300}{2}\} = 41.25$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{1506}{1000 * 41.25} = 0.037$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta \rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{79 - 0.4 * \frac{2.2}{0.037} * (1 + 6.667 * 0.037)}{200000} = 2.46 * 10^{-4} \geq 0.6 * \frac{79}{200000} = 2.37 * 10^{-4}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{\phi}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.38 * 283.5) = 250$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 250 * 2.46 * 10^{-4} = 0.06$ Sørensen (5.58)

$w_k > w_{max} = 0.05$ (Rissviddekrav ikke oppfylt)

Max nyttelast:

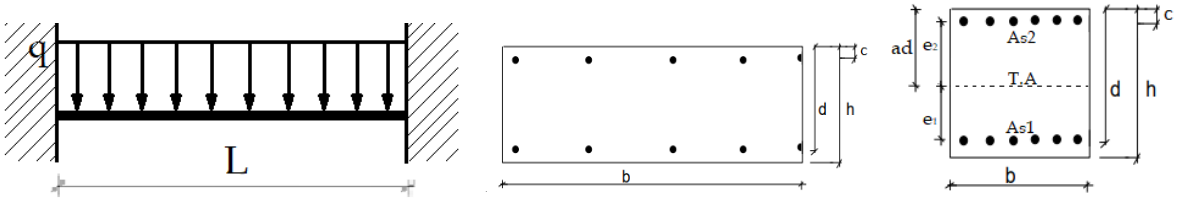
$$\frac{Mpa - 0.4 * \frac{2.2}{0.037} * (1 + 6.667 * 0.037)}{200000} * 250 = 0.05 \rightarrow Mpa = 69.6$$

$$200000 * \frac{M*10^6*(1-0.38)*283.5}{1.2*10^{13}} = 69.6 \rightarrow \text{M} = 23.7$$

$$\frac{(1.2*7.5+q*1.5)*4^2}{12} = 23.7 \rightarrow \text{q} = 5.8$$

Vedlegg D.7: Snitt 7

Snitt 7:



Sikkerhets faktor

$\gamma_c = 1.5$	EC2-Tabell 2.1N
$\gamma_s = 1.15$	EC2-Tabell 2.1N
$\alpha_{cc} = 0.85$	EC2- NA.3.1.6(1)
$\gamma_G = 1.2$	EC - Tabell NA.A1.2(A)
$\gamma_Q = 1.5$	EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

h = 300 mm

b = 1000 mm

$d = 300 - 10 - \frac{10}{2} = 285\ mm$

c = $10 + \frac{10}{2}$ = 15mm

$h` = h - 2 * c$ = 270

L = 1800 mm

$e = \frac{h}{2} - (h - d) = 135\ mm$

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$	EC2-Tabell 3.1
$f_{ctm} = 2.2\ N/mm^2$	EC2-Tabell 3.1
$E_{cm} = 30000\ N/mm^2$	EC2-Tabell 3.1

Standard armering

$f_{yk} = 400\ N/mm^2$	V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\, f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\mathrm{fck(3)}}{\gamma c} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\mathrm{fctm}}{\mathrm{fyk}}\, b_t\, d;\ 0.0013\, b_t\, d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 285\ ;\ 0.0013 * 1000 * 285\} = 407.6\ mm^2$

Antall jern $= \frac{30\ jern}{4m} = 7.5$

$A_s = \pi(\frac{10}{2})^2 * 7.5 = 589\ mm^2$

$A_{s1} = A_s/2 = 294.5\ mm^2$

$A_{s2} = A_s/2 = 294.5\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st} =$ ikke gjeldende

$\Delta c_{dur,add} =$ ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000\ N = 3390\ kN$
$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 294.5 = 102427.1\ N = 102\ kN$
$S_2 = S_1$

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 102 + 102 =$ **3594 kN**
Momentlikevekt : $M_1 =$ **0**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter
$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 15*0.0035/300 = 0{,}00018 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00018 = 36\ N/mm^2$

$T_c = f_{cd} * b * 0.8 * h = 11.3*1000*0.8*300 = 2712000\ N = 2712\ kN$

$S_1 = \sigma_{sd} * A_{s1} = 36 * 294.5 = 10602\ N = 10.6\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 294.5 = 102427.1\ N = 102\ kN$

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712+10.6+102 =$ **2824.6 kN**

Momentlikevekt: $M_2 = T_c * (0.5h-0{,}4h) + S_2 * h`/2 - S_1 * h`/2 =$

$2712*(0.5*0.300-0.4*0.300)+102*0.270/2 - 10.6*0.270/2 =$ **94 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d = 0.668 * 285 = 190.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{190.4-15}{190.4} * 0.0035 = 0.0032$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 190.4 = 1721216\ N = 1721\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 294.5 = 102427.1\ N = 102\ kN$

$S_2 = S_1$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1721 + 102 - 102 =$ **1721 kN**

Momentlikevekt : $M_3 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h` =$

$1721* (0.5*300 - 0.4 * 190.4) + 102 * 270 =$ **155 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d = 0.467 * 285 = 133\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{133-15}{133} * 0.0035 = 0.0031$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 133 = 1202320\ N = 1020\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 294.5 = 102427.1\ N = 102\ kN$

$S_2 = S_1$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1020 + 102 - 102 =$ **1020 kN**

Momentlikevekt : $M_4 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h` =$

$1020 * (0.5*300 - 0.4 * 133) + 102 * 270 =$ **126 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d = 0.189 * 285 = 53.9\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{53.9-15}{53.9} * 0.0035 = 0.0025$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d = 11.3 * 1000 * 0.8 * 53.9 = 487256\ N = 487\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 294.5 = 102427.1\ N = 102\ kN$

$S_2 = S_1$

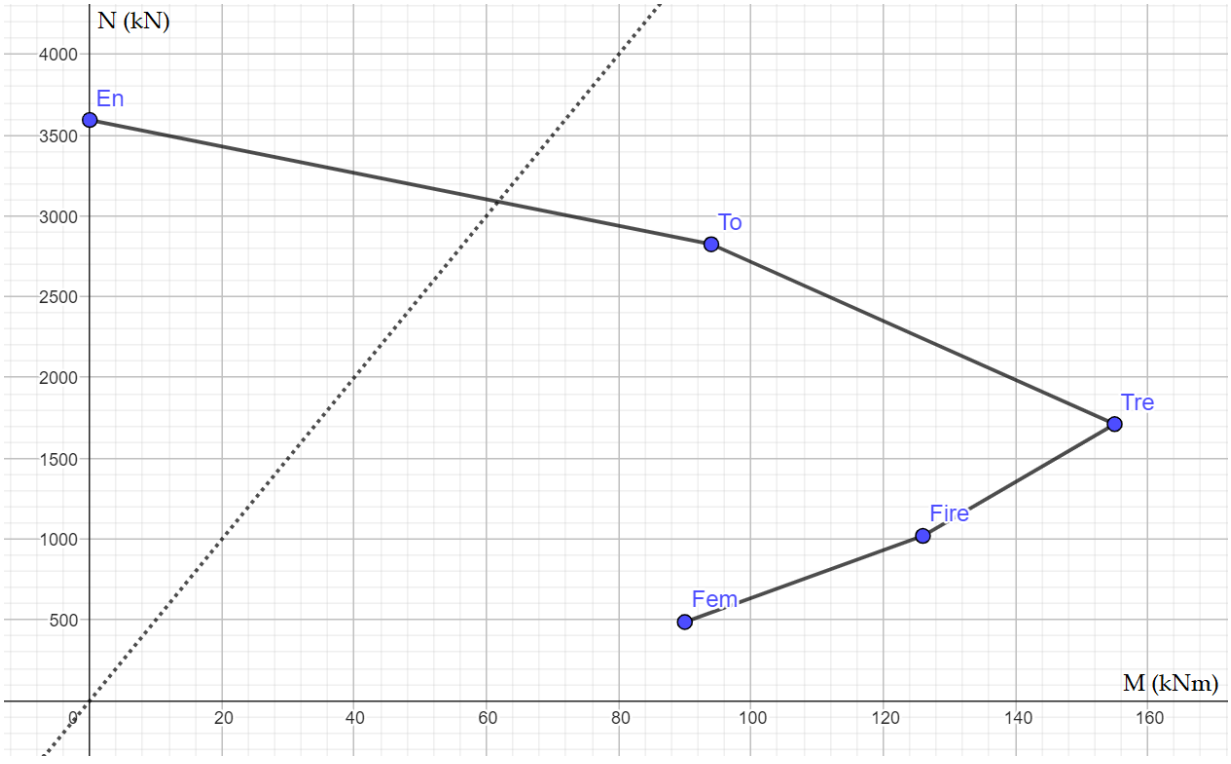
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 487 + 102 - 102 =$ **487 kN**

Momentlikevekt : $M_5 = T_c * (0.5h - 0.4\ \alpha d) + S_1 * h`/2 + S_2 * h`/2 =$

$487 * (0.5*300 - 0.4 * 53.9) + 102 * 270/2 + 102 * 270/2 =$ **90 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*1.8}{2}$ =18.2 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{285}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{294.5}{1000*285} = 0.00103$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.00103 * 20)^{\frac{1}{3}} * 1000 * 285 = 66724.5$ N = **66.7 kN**

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

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*1.8}{2}$ =66.7 → p = **43 kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*285*0.552*11.3 = 888858$ N = **889 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*1.8}{2}$ =889 → p = **652 kN**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 285 * 0.668 = 4948\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 589}{0.8 * 1.0 * 11.3 * 1000 * 285} = 0.08$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.08}{0.08} * 0.0035 = 0.040$

$\rightarrow \varepsilon_s > \varepsilon_{ud} = 0.03$ **ikke ok** EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.08 * (1-0.5 * 0{,}8 * 0.08) * 11.3 * 1000 * 285^2$

$= 56862179\ Nmm =$ **56.8 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{12} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 1.8^2}{12} =$ **5.5 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 1.8^2}{12} = 56.8 \rightarrow p =$ **134 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 589) + 347.8 * 589 = 3588198.5\ N =$ **3588 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{589}{1000*285} = 0.002$

$\eta\rho = 6.667 * 0.002 = 0.013$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.013^2 + 2 * 0.013} - 0.013 = 0.15$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 589 * (1-0.15) * (1-\frac{0.15}{3}) * 285^2 = 3.86*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*3.86*10^7 = 0.77 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*1800^4}{384*0.77*10^{13}}$ = **0.05 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

φ_3 =1.33 * 3.17 * 0.74 = 3.12

φ_{28} =1.33 * 3.17 * 0.49 = 2.07

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3)$ =4.96 * 1 = 3.12

$\varphi(\infty, 28)$ = 4.71 * 1 = 2.07

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{12} = \frac{(9)*4^2}{12} = 12$ kNm

$M_2 = \frac{q*L^2}{12} = \frac{(11.25)*4^2}{12} = 15$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_{c2}}} = \frac{12+15}{\frac{12}{7282}+\frac{15}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_s}{b*d} = \frac{589}{1000*285} = 0.002$

$\eta\rho = 23.6 * 0.002 = 0.065$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.065^2 + 2*0.065} - 0.065 = 0.30$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.3^2*(1-\frac{0.3}{3})*1000*285^3 = 9.38 * 10^8 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*9.38*10^8 = 7.96 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*1800^4}{384*7.96*10^{12}} =$ **0.07 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*f_{cm}}{f_{cm0}})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{h}{2} = \frac{300}{2} = 150$

$e = d - \alpha d = 285 - 150 = 135$

$I = \frac{b*h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000*300^3}{12} + 1000 * 300 * \left(150 - \frac{300}{2}\right)^2 + 23.6 * 589 * 135^2 = 25.03 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{589*135}{25.03*10^8} = 1.63 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{1.63*10^{-7}*1800^2}{8} =$ **0.07mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 0.07 + 0.07 =$ **0.14 mm**

$\delta_{maks} = \frac{L}{250} = \frac{1800}{250} = 7.2mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $7.2 = \frac{(7.5*1.2+1.5*q)*1800^4}{384*7.96*10^{12}} + 0.07 \rightarrow q = 1378$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25*1.8^2}{12} = 5.6$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{5.6*10^6*(1-0.3)*285}{7.96*10^{12}} = 28MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h-\alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-285); (\frac{300-0.3*285}{3}); \frac{300}{2}\} = 37.5$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{589}{1000*37.5} = 0.016$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta\rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{28 - 0.4 * \frac{2.2}{0.016} * (1 + 6.667 * 0.016)}{200000} = -1.6 * 10^{-4} \geq 0.6 * \frac{28}{200000} = 8.4 * 10^{-5}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{\phi}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.3 * 285) = 279$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 279 * 8.4 * 10^{-5} =$ **0.02** Sørensen (5.58)

$w_k > w_{max} = 0.05$ (Rissviddekrav oppfylt)

Max nyttelast:

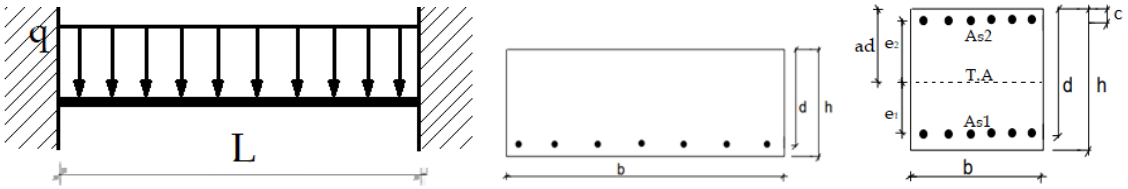
$0.6 * \frac{\sigma_s}{200000} * 279 = 0.05 \rightarrow \sigma_s = 59.7$

$200000 * \frac{M*10^6*(1-0.3)*285}{7.96*10^{12}} = 59.7 \rightarrow M = 11.9$

$\frac{(1.2*7.5+1.5*q)*1.8^2}{12} = 11.9 \rightarrow q = 23.3$

Vedlegg D.8: Snitt 8

Snitt 8:



Sikkerhets faktor

$\gamma_c = 1.5$	EC2-Tabell 2.1N
$\gamma_s = 1.15$	EC2-Tabell 2.1N
$\alpha_{cc} = 0.85$	EC2- NA.3.1.6(1)
$\gamma_G = 1.2$	EC - Tabell NA.A1.2(A)
$\gamma_Q = 1.5$	EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m	(EC1-Tabell 6.4)
$g_1 = 0$	
g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m	
$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m	(betongelementboka s304)

Geometri:

h = 300 mm

b = 1000 mm

$d = 300 - 10 - \frac{10}{2} = 285\ mm$

$c = 10 + \frac{10}{2}$ = 15mm

$h` = h - 2 * c$ = 270

L = 2800 mm

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$	EC2-Tabell 3.1
$f_{ctm} = 2.2\ N/mm^2$	EC2-Tabell 3.1
$E_{cm} = 30000\ N/mm^2$	EC2-Tabell 3.1

Standard armering

$f_{yk} = 400\ N/mm^2$	V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$	EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\, f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\mathrm{fck(3)}}{\gamma \mathrm{c}} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\mathrm{fctm}}{\mathrm{fyk}}\, b_t\, d;\ 0.0013\, b_t\, d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 285\ ;\ 0.0013 * 1000 * 285\} = 407.6\ mm^2$

Antall jern $= \frac{5\ jern}{1.4m} = 3.57$

$A_s = \pi(\frac{10}{2})^2 * 3.57 = 280 mm^2$

$A_{s1} = \mathrm{A_s} = 280\ mm^2$

$A_{s2} = 0 = 0\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st} =$ ikke gjeldende

$\Delta c_{dur,add} =$ ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Kapasitetskontroll (M-N diagram)

$\eta = \frac{E_s}{E_{c,middel}} = \frac{200000}{8483} = 23.6$ (fra langtidsnedbøyning)
$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 280 * 285}{300000 + 23.6 * 280} = 153$
$e = d - \alpha d = 285 - 153 = 132$

Punkt 1: Rent trykk

$\varepsilon_c = \varepsilon_{c3} = 0.00175$ EC2-Tabell 3.1

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174 < \varepsilon_{c3} \rightarrow$ armeringen flyter

$T_c = f_{cd} * b * h = 11.3 * 1000 * 300 = 3390000\ N = 3390\ kN$
$S_1 = \frac{f_{yk}}{\gamma_s} * A_{s1} = f_{yd} * A_{s1} = 347.8 * 280 = 97384\ N = 97\ kN$
$S_2 = 0$

Aksiell likevekt: $N_1 = T_c + S_1 + S_2 = 3390 + 97 =$ **3487 kN**
Momentlikevekt : $M_1 = T_c * (\alpha d - 0.5h) - S_1 * e$
$3390*(153-150) - 97*132 =$ **-26.34**

Punkt 2: Trykkbrudd i betong

Betong svikter samtidig som stål gir etter
$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{s1} = c * \varepsilon_{cu} / h = 15*0.0035/300 = 0{,}00018 < \varepsilon_{yd} \rightarrow$ ikke flyting

$\sigma_{sd} = E_s * \varepsilon_{s1} = 200000 * 0{,}00018 = 36\ N/mm^2$

$T_c = f_{cd} * b * 0.8 * h = 11.3*1000*0.8*300 = 2712000\ N = 2712\ kN$

$S_1 = \sigma_{sd} * A_{s1} = 36 * 280 = 10080\ N = 10\ kN$

$S_2 = f_{yd} * A_{s2} = 347.8 * 0 = 0\ N = 0\ kN$

Aksiell likevekt: $N_2 = T_c + S_1 + S_2 = 2712+10=$ **2722 kN**

Momentlikevekt: $M_2 = T_c * (\alpha d - 0{,}4h) - S_1 * e =$

$2712*(153-0.4*300) - 10*132 =$ **88 kNm**

Punkt 3: Trykkbrudd I betong samtidig med flytning i armering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_s = \varepsilon_{yd}$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + \varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$

$\alpha d_2 = 0.668 * 285 = 190.4\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{190.4-15}{190.4} * 0.0035 = 0.0032$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 190.4 = 1721216\ N = 1721\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 280 = 97384\ N = 97.4\ kN$

$S_2 = 0$

Aksiell likevekt : $N_3 = T_c + S_2 - S_1 = 1721 - 97.4 =$ **1623.6 kN**

Momentlikevekt : $M_3 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$1721 * (153 - 0.4 * 190.4) + 97.5 * 132 =$ **144 kNm**

Punkt 4: Trykkbrudd i betong og dobbel flytetøyning i strekkarmering

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 2\varepsilon_{yk}$

$\varepsilon_{cu} = 0.0035$ EC2-Tabell 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 2\varepsilon_{yk}} = \frac{0.0035}{0.0035+2*0.002} = 0.467$ Sørensen (4.22)

$\alpha d_2 = 0.467 * 285 = 133\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{133-15}{133} * 0.0035 = 0.0031$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 133 = 1202320\ N = 1020\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 280 = 97384\ N = 97.4\ kN$

$S_2 = 0$

Aksiell likevekt : $N_4 = T_c + S_2 - S_1 = 1020 + 102 - 102 =$ **1020 kN**

Momentlikevekt : $M_4 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$1020 * (153 - 0.4 * 133) + 97.4 * 132 =$ **115 kNm**

Punkt 5: Trykkbrudd i betong og stor armeringstøyning

Bruddkriterium: $\varepsilon_c = \varepsilon_{cu3}$ og $\varepsilon_{s1} = 0.015$

$\varepsilon_{cu} = 0.0035$ EC2-Table 3.1

$\varepsilon_{yk} = \frac{f_{yk}}{Es} = \frac{400}{200000} = 0.002$

$\alpha = \frac{\varepsilon_{cu}}{\varepsilon_{cu} + 0.015} = \frac{0.0035}{0.0035+0.015} = 0.189$ Sørensen (4.22)

$\alpha d_2 = 0.189 * 285 = 53.9\ mm$

$\varepsilon_{s2} = \frac{\alpha d - c}{\alpha d} * \varepsilon_{cu} = \frac{53.9-15}{53.9} * 0.0035 = 0.0025$ (flyter)

$T_c = f_{cd} * b * 0.8 * \alpha d_2 = 11.3 * 1000 * 0.8 * 53.9 = 487256\ N = 487\ kN$

$S_1 = f_{yd} * A_{s1} = 347.8 * 280 = 97384\ N = 97.4\ kN$

$S_2 = 0$

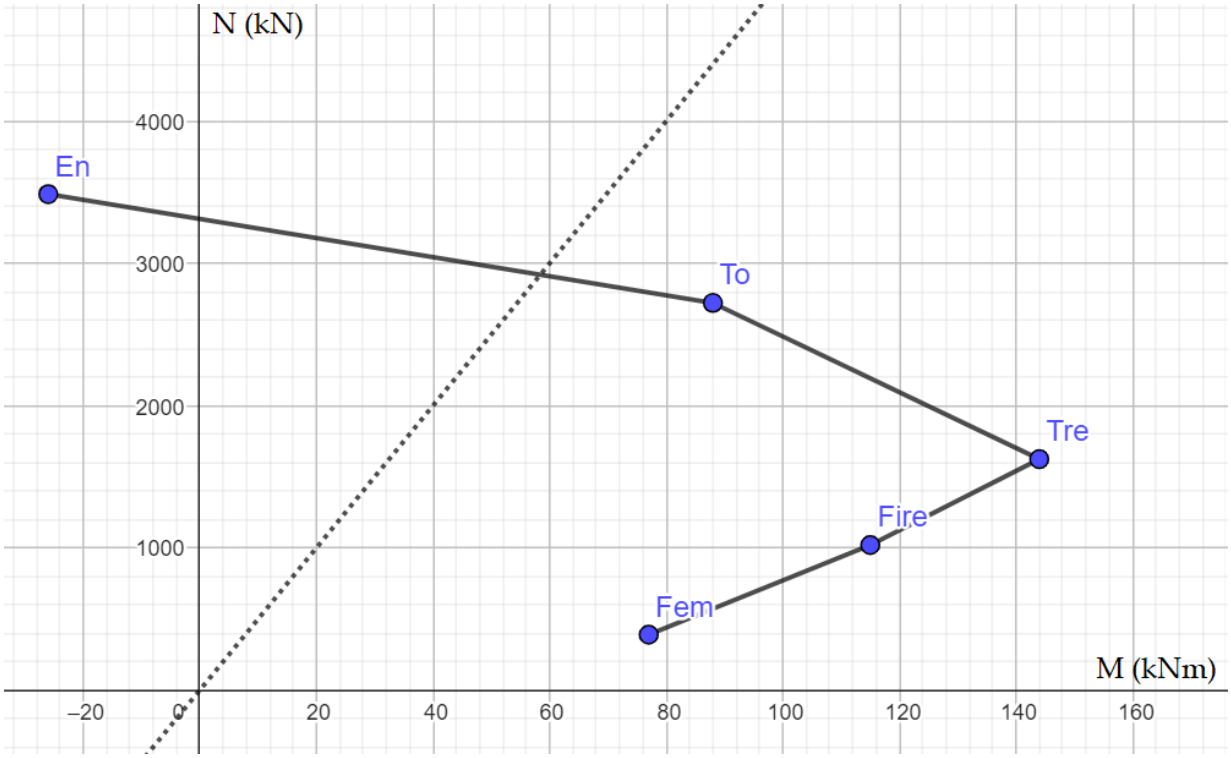
Aksiell likevekt : $N_5 = T_c + S_2 - S_1 = 487 - 97.4 =$ **389.6 kN**

Momentlikevekt : $M_5 = T_c * (\alpha d - 0.4\ \alpha d_2) + S_1 * e =$

$487 * (153 - 0.4 * 53.9) + 97.4 * 132 =$ **76.9 kNm**

e_0 = max {h/30, 20mm} =20mm EC2-6.1 (4)

Resulterende interaksjonsdiagram:



Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*2.8}{2}$ =28.4 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{285}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{280}{1000*285} = 0.00098$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.00098 * 20)^{\frac{1}{3}} * 1000 * 285 = 65950.2$ N = **65.0 kN**

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

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*2.8}{2}$ =65 → p = **24.9 kN**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*285*0.552*11.3 = 888858$ N = **889 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*2.8}{2}$ =889 → p = **417 kN**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 285 * 0.668 = 4948\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 280}{0.8 * 1.0 * 11.3 * 1000 * 285} = 0.04$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.04}{0.04} * 0.0035 = 0.084$

$\rightarrow \varepsilon_s > \varepsilon_{ud} = 0.03$ **ikke ok** EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.04 * (1-0.5 * 0{,}8 * 0.04) * 11.3 * 1000 * 285^2$

$= 28901025\ Nmm =$ **28.9 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{12} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 2.8^2}{12} =$ **13.2 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 2.8^2}{12} = 28.9 \rightarrow p =$ **23 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 280) + 347.8 * 280 = 3484220\ N =$ **3484 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{280}{1000*285} = 0.00098$

$\eta\rho = 6.667 * 0.00098 = 0.0065$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.0065^2 + 2 * 0.0065} - 0.0065 = 0.11$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 280 * (1-0.11) * (1-\frac{0.11}{3}) * 285^2 = 1.95*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*1.95*10^7 = 0.39 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*2800^4}{384*0.39*10^{13}}$ = **0.62 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

$\varphi_3 = 1.33 * 3.17 * 0.74 = 3.12$

$\varphi_{28} = 1.33 * 3.17 * 0.49 = 2.07$

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3) = 4.96 * 1 = 3.12$

$\varphi(\infty, 28) = 4.71 * 1 = 2.07$

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12}$ = 7282 MPa

$E_{c2} = \frac{30000}{1+2.07}$ = 9772 MPa

$M_1 = \frac{q*L^2}{12} = \frac{(9)*4^2}{12}$ = 12 kNm

$M_2 = \frac{q*L^2}{12} = \frac{(11.25)*4^2}{12}$ = 15 kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_c2}} = \frac{12+15}{\frac{12}{7282}+\frac{15}{9772}}$ = 8483 MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483}$ = 23.6

$\rho = \frac{A_S}{b*d} = \frac{280}{1000*285}$ = 0.00098

$\eta\rho$ = 23.6 * 0.00098 = 0.023

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.023^2 + 2 * 0.023} - 0.023 = 0.19$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.19^2*(1-\frac{0.19}{3})*1000*285^3 = 3.91 * 10^8 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*3.91*10^8 = 3.32 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*2800^4}{384*3.32*10^{12}}$ = **0.98 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*fcm}{fcm0})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

f_{cm0} = 10 MPa

α_{ds1} = 3 (Sement klasse S)

α_{ds2} = 0.13 (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

k_h = 0.78 EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 280 * 285}{300000 + 23.6 * 280} = 153$

$e = d - \alpha d = 285 - 153 = 132$

$I = \frac{b * h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000 * 300^3}{12} + 1000 * 300 * \left(153 - \frac{300}{2}\right)^2 + 23.6 * 280 * 132^2 = 23.68 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{280 * 132}{23.68 * 10^8} = 0.80 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{0.80 * 10^{-7} * 2800^2}{8} =$ **0.08mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 0.98 + 0.08 =$ **1.06 mm**

$\delta_{maks} = \frac{L}{250} = \frac{2800}{250} = 11.2\ mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $11.2 = \frac{(7.5 * 1.2 + 1.5 * q) * 2800^4}{384 * 3.32 * 10^{12}} + 0.08 \rightarrow q = 147.7\ kN/m$

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05\ mm$ Sørensen (tabell 5.2)

$M = \frac{20.25 * 2.8^2}{12} = 13\ kNm$

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{13 * 10^6 * (1 - 0.19) * 285}{3.32 * 10^{12}} = 181MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h-\alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-285); (\frac{300 - 0.3 * 285}{3}); \frac{300}{2}\} = 37.5$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{280}{1000 * 37.5} = 0.0075$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta \rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{181 - 0.4 * \frac{2.2}{0.0075} * (1 + 6.667 * 0.0075)}{200000} = \mathbf{2.9 * 10^{-4} \geq 0.6 * \frac{181}{200000} = 5.43 * 10^{-4}}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{\phi}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.19 * 285) = 320$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 320 * 5.43 * 10^{-4} =$ **0.17** Sørensen (5.58)

$w_k > w_{max} = 0.05$ (Rissviddekrav ikke oppfylt)

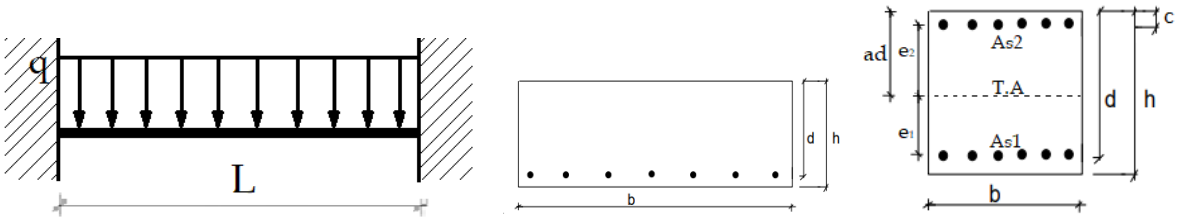
Max nyttelast:

$$320 * \left(0.6 * \frac{200000 * \frac{M * 10^6 * (1 - 0.19) * 285}{3.32 * 10^{12}}}{200000}\right) = 0.05 \rightarrow M = 3.74$$

$$\frac{(1.2 * 7.5 + q * 1.5) * 2.8^2}{12} = 3.75 \rightarrow q = -2.17$$

Vedlegg D.9: Snitt 9 (snitt 2 med redusert armeringstverrsnitt)

Snitt 9: Snitt 2 med redusert armeringstverrsnitt (ø13 til ø12)



Sikkerhets faktor

$\gamma_c = 1.5$ EC2-Tabell 2.1N

$\gamma_s = 1.15$ EC2-Tabell 2.1N

$\alpha_{cc} = 0.85$ EC2- NA.3.1.6(1)

$\gamma_G = 1.2$ EC - Tabell NA.A1.2(A)

$\gamma_Q = 1.5$ EC - Tabell NA.A1.2(A)

Last:

p = 7.5 kN/m^2 *1m= 7.5 kN/m (EC1-Tabell 6.4)

$g_1 = 0$

g_2 = 25kN/m^3 *0,3m*1m = 7.5 kN/m

$q_{Ed} = \gamma_G * g + \gamma_Q * p = 1.2 * 7.5 + 1.5*7.5 = 20.25$ kN/m (betongelementboka s304)

Geometri:

$h = 300\ mm$

$b = 1000\ mm$

$d = 300 - 10 - \frac{12}{2} = 284\ mm$

$c = 10 + \frac{12}{2} = 16$mm

$h` = h - 2 * c = 268$

$L = 4000\ mm$

Betong: B300 (V413 tabell 2.1.2-1)

$f_{ck} = 20\ N/mm^2$

$f_{cd} = \alpha_{cc}\frac{fck}{\gamma c} = 11.3\ N/mm^2$

$f_{cm} = 28\ N/mm^2$ EC2-Tabell 3.1

$f_{ctm} = 2.2\ N/mm^2$ EC2-Tabell 3.1

$E_{cm} = 30000\ N/mm^2$ EC2-Tabell 3.1

Standard armering:

$f_{yk} = 400\ N/mm^2$ V413 Tabell 2.1.2-2

$f_{yd} = \frac{fyk}{ys} = 347.8\ N/mm^2$

$E_s = 200000\ N/mm^2$ EC2- 3.2.7(4)

Betong styrke ved: t= 3 dager EC2-3.1.2

$s = 0.38$ For sement klasse S

$\beta_{cc}(3) = e\exp(s(1-(\frac{28}{t})^{0,5}) = 0.458$

$f_{cm}(3) = \beta_{cc}(3)\, f_{cm} = 12.8\ N/mm^2$

$f_{ck}(3) = f_{cm}(3) - 8\ MPa = 4.8\ N/mm^2$

$f_{cd}(3) = \alpha_{cc}\frac{\mathrm{fck(3)}}{\gamma c} = 2.72\ N/mm^2$ EC2-3.1.6

Minimums armering: (EC2-9.2.1.1)

$A_{s,min} = \max\{0.26\frac{\mathrm{fctm}}{\mathrm{fyk}}\, b_t\, d;\ 0.0013\, b_t\, d\} =$

$\max\{0.26\frac{2.2}{400} * 1000 * 284\ ;\ 0.0013 * 1000 * 284\} = 406.1\ mm^2$

Antall jern $= \frac{28\ jern}{3.7m} = 7.5$

$A_s = \pi(\frac{12}{2})^2 * 7.5 = 848.2\ mm^2$

$A_{s1} = A_s = 848.2\ mm^2$

$A_{s2} = 0 = 0\ mm^2$

Minste overdekning: (EC2-4.4.1.2 og NA)

$c_{min,b} = 13\ mm$

$c_{min.dur} = 60\ mm$ EC2-Tabell NA.4.4N

$\Delta c_{dur,\gamma} = 0$

$\Delta c_{dur,st}$ = ikke gjeldende

$\Delta c_{dur,add}$ = ikke gjeldende

$c_{min} = \max\{c_{min,b};\ c_{min,dur} + \Delta c_{dur,\gamma} - \Delta c_{dur,st} - \Delta c_{dur,add};\ 10mm\} = 60\ mm$

Nominell overdekning: (EC2-4.4.1.1(2))

$c_{nom} = c_{min} + \Delta c_{dev} = 60 + 10 = 70\ mm$

Faktisk overdekning = 10mm

c_{nom}=10mm

Skjærkapasitet:

Dimensjonerende skjærkraft: $V_{Ed} = \frac{q_{Ed}*L}{2} = \frac{20.25*4}{2}$ =40.5 kN

Skjærstrekkapasitet: $V_{Rd,c} = C_{Rd,c} * K * (100 * P_L * f_{ck})^{\frac{1}{3}} * b_w * d$ Sørensen (4.43)

$K = 1 + \sqrt{\frac{200}{d}} \leq 2.0$

$=1 + \sqrt{\frac{200}{284}} = 1.84$

$P_L = \frac{A_{sL}}{b_w * d} \leq 0.02$

$=\frac{848.2}{1000*284} = 0.003$

$K_2 = 0.15$ EC2-NA.6.2.2 (1)

$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$

$V_{Rd,c} = 0.1 * 1.84 * (100 * 0.003 * 20)^{\frac{1}{3}} * 1000 * 284 = 94955.5$ N = **95.0 kN**

$V_{Rd,c} > V_{Ed}$ (ok)

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2}$ =95 → p = **25.6kN/m**

Skjærtrykkapasitet: $V_{Rd,max} = 0.5 * b_w * d * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*284*0.552*11.3 = 885739.2$ N = **885 kN**

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

Max nyttelast : $\frac{(7.5*1.2+p*1.5)*4}{2}$ =885 → p = **289 kN/m**

Momentkapasitet:

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

$\lambda = 0.8$ EC2-3.1.7 (3)

$\eta = 1.0$ EC2-3.1.7 (3)

$A_{s,b} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * b * d * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 284 * 0.668 = 4931\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b}$

$\lambda * \eta * f_{cd} * b * d * \alpha - f_{yd} * A_s = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_s}{\lambda * \eta * f_{cd} * b * d} = \frac{347.8 * 848.2}{0.8 * 1.0 * 11.3 * 1000 * 284} = 0.115$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.115}{0.115} * 0.0035 = 0.0269$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rd} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * b * d^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.115 * (1-0.5 * 0{,}8 * 0.115) * 11.3 * 1000 * 284^2$

$= 80557200.5\ Nmm =$ **80.5 kNm**

$M_{Ed} = \frac{[1.2(g_1+g_2)+1.5 \cdot p] * L^2}{24} = \frac{(1.2 * 7.5 + 1.5 * 7.5) * 4^2}{24} =$ **13.5 kNm**

$M_{Rd} > M_{Ed}$ OK.

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 4^2}{24} = 80.5 \rightarrow p =$ **74.5 kN/m**

Aksialkraftkapasitet:

$A_c = b * h = 1000 * 300 = 300000\ mm^2$

$N_{Rd} = f_{cd}(A_c - A_s) + f_{yd} * A_s$ Sørensen (4.5)

$= 11.3 * (300000 - 848.2) + 347.8 * 848.2 = 3675419.3\ N =$ **3675 kN**

Nedbøyning:

E_{cm} = 30000 N/mm^2 EC2-Tabell 3.1

E_s = 200000 N/mm^2

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\rho = \frac{A_s}{b*d} = \frac{848.2}{1000*284} = 0.003$

$\eta\rho = 6.667 * 0.003 = 0.020$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.02^2 + 2 * 0.02} - 0.02 = 0.18$ Sørensen (5.5)

$I_s = A_s * (1-\alpha)*(1-\frac{\alpha}{3}) * d^2 = 848.2 * (1-0.18) * (1-\frac{0.18}{3}) * 284^2 = 5.27*10^7 mm^4$ Sørensen (5.11)

$EI = E_s * I_s = 200000*5.27*10^7 = 1.05 * 10^{13}$ Nmm^2 Sørensen (5.12)

q = 15 kN/m

Nedbøyning (bruksgrensetilstand) : $\delta_{II} = \frac{1}{384} * \frac{q* L^4}{EI} = \frac{15*4000^4}{384*1.05*10^{13}}$ = **0.95 mm**

Langtidsnedbøyning:

permanent last:

g = 7.5 * 1.2 = 9 kN/m

p = 7.5 * 1.5 = 11.25 kN/m (antar 100% permanent)

lasttilfelle 1: g = 9 kN/m , $\varphi(\infty, 3)$

lasttilfelle 2 : p = 11.25 kN/m , $\varphi(\infty, 28)$

$h_0 = \frac{2A_c}{u} = \frac{2*300*1000}{2*(300+1000)} = 231mm$

Kryptall : utendørsforhold EC2-Tillegg B

$\varphi(t, t_0) = \varphi_0 * \beta(t,t_0)$

$\varphi_0 = \varphi_{RH} * \beta(f_{cm}) * \beta(t_0)$

RH = 80 (utendørsforhold)

$\varphi_{RH} = 1 + \frac{1-\frac{RH}{100}}{0.1* \sqrt[3]{h_0}} = 1 + \frac{1-\frac{80}{100}}{0.1* \sqrt[3]{231}} = 1.33$

$\beta(f_{cm}) = \frac{16.8}{\sqrt{f_{cm}}} = \frac{16.8}{\sqrt{28}} = 3.17$

$\beta(t_0) = \frac{1}{(0.1+{t_0}^{0.20})}$

$\beta(3) = \frac{1}{(0.1+3^{0.20})} = 0.74$

$\beta(28) = \frac{1}{(0.1+28^{0.20})} = 0.49$

$\varphi_3 = 1.33 * 3.17 * 0.74 = 3.12$

$\varphi_{28} = 1.33 * 3.17 * 0.49 = 2.07$

$\beta(t,t_0) = [\frac{(t-t_0)}{(\beta_H+t-t_o)}]^{0.3}$

$\beta(\infty, 3) \rightarrow 1$

$\beta(\infty, 28) \rightarrow 1$

$\varphi(\infty, 3) = 4.96 * 1 = 3.12$

$\varphi(\infty, 28) = 4.71 * 1 = 2.07$

$E_{c1} = \frac{E_{cm}}{1+\varphi(t,t_0)}$

$E_{c1} = \frac{30000}{1+3.12} = 7282$ MPa

$E_{c2} = \frac{30000}{1+2.07} = 9772$ MPa

$M_1 = \frac{q*L^2}{24} = \frac{(9)*4^2}{24} = 6$ kNm

$M_2 = \frac{q*L^2}{24} = \frac{(11.25)*4^2}{24} = 7.5$ kNm

$E_{c,middle} = \frac{M_1+M_2}{\frac{M_1}{E_{c1}}+\frac{M_2}{E_{c2}}} = \frac{6+7.5}{\frac{6}{7282}+\frac{7.5}{9772}} = 8483$ MPa

$\eta = \frac{E_S}{E_{c,middel}} = \frac{200000}{8483} = 23.6$

$\rho = \frac{A_S}{b*d} = \frac{848.2}{1000*284} = 0.0030$

$\eta\rho = 23.6 * 0.003 = 0.071$

$\alpha = \sqrt{(\eta\rho)^2 + 2\eta\rho} - \eta\rho = \sqrt{0.071^2 + 2*0.071} - 0.071 = 0.31$ Sørensen (5.5)

$I_c = 0.5*\alpha^2*(1-\frac{\alpha}{3})*b*d^3 = 0.5*0.31^2*(1-\frac{0.31}{3})*1000*284^3 = 0.99 * 10^9 mm^4$ Sørensen (5.9)

$EI = E_{c,middel} * I_c = 8483*0.99*10^9 = 8.4 * 10^{12}$ Nmm^2 Sørensen (5.10)

Nedbøyning midt på bjelken:

$\delta_{Lang} = \frac{1}{384} * \frac{q*L^4}{EI} = \frac{20.25*4000^4}{384*8.4*10^{12}} =$ **1.61 mm**

Nedbøyning pga svinn:

$\varepsilon_{cd,0} = 0.85\ [(220+110 * \alpha_{ds1})*e^{(\frac{-\alpha_{ds2}*fcm}{fcm0})}]\ 10^{-6} * \beta_{RH}$ Sørensen (5.27)

$f_{cm0} = 10$ MPa

$\alpha_{ds1} = 3$ (Sement klasse S)

$\alpha_{ds2} = 0.13$ (Sement klasse S)

$\beta_{RH} = 1.55[1-(\frac{RH}{RH_0})^3] = 1.55[1-(\frac{80}{100})^3] = 0.76$ Sørensen (5.28)

$\varepsilon_{cd,0} = 0.85\ [(220+110 * 3)*e^{(\frac{-0.13*28}{10})}]\ 10^{-6} * 0.76 = 2.47 * 10^{-4}$

$\varepsilon_{cd}(t) = \beta_{ds}(t,t_s) * k_h * \varepsilon_{cd,0}$ Sørensen (5.29)

$\beta_{ds}(t,t_s) = \frac{(t-t_s)}{(t-t_s)+0.4\sqrt{h_0{}^3}}$: $t \to \infty \rightarrow \beta_{ds} = 1$

$k_h = 0.78$ EC2-Tabell 3.3

$\varepsilon_{cd}(\infty) = 1 * 0.78 * 2.47 * 10^{-4} = 1.93 * 10^{-4}$

$\varepsilon_{ca}(\infty) = 2.5\ (f_{ck} - 10) * 10^{-6} = 2.5\ (20 - 10) * 10^{-6} = 2.5 * 10^{-5}$ Sørensen (5.31)

$\varepsilon_{cs} = \varepsilon_{cd} + \varepsilon_{ca} = 1.93 * 10^{-4} + 2.5 * 10^{-5} = 2.18 * 10^{-4}$ Sørensen (5.26)

Svinnkrumning:

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

$\alpha d = \frac{A_c * 0.5h + \eta * A_s * d}{A_c + \eta * A_s} = \frac{300000 * 0.5 * 300 + 23.6 * 848.2 * 284}{300000 + 23.6 * 848.2} = 158.4$

$e = d - \alpha d = 284 - 158.4 = 125.6$

$I = \frac{b * h^3}{12} + b * h * \left(ad - \frac{h}{2}\right)^2 + \eta * A_s * e^2$

$= \frac{1000 * 300^3}{12} + 1000 * 300 * \left(158.4 - \frac{300}{2}\right)^2 + 23.6 * 848.2 * 125.6^2 = 25.87 * 10^8 mm^4$

$K_s = 2.18 * 10^{-4} * 23.6 * \frac{848.2 * 125.6}{25.87 * 10^8} = 2.12 * 10^{-7}\ mm^{-1}$

$\delta_{svinn} = \frac{K_s * L^2}{8} = \frac{2.12 * 10^{-7} * 4000^2}{8} =$ **0.42mm**

$\delta_{total} = \delta_{lang} + \delta_{svinn} = 1.61 + 0.42 =$ **2.03 mm**

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16mm > \delta_{total} \rightarrow$ ok EC2-7.4.1 (4)

Max nyttelast : $16 = \frac{(7.5 * 1.2 + 1.5 * q) * 4000^4}{384 * 8.4 * 10^{12}} + 0.42 \rightarrow q = 124.8$ kN/m

Rissviddekontroll:

$k_c = c_{nom}/c_{min,dur} = 10/60 = 0.1667$

$w_{max} = 0{,}3 * k_c = 0.3 * 0.1667 = 0.05$ mm Sørensen (tabell 5.2)

$M = \frac{20.25 * 4^2}{24} = 13.5$ kNm

$\sigma_s = E_s * \frac{M(1-\alpha)d}{EI} = 200000 * \frac{13.5 * 10^6 * (1 - 0.31) * 284}{8.4 * 10^{12}} = 63MPa$ Sørensen (5.55)

$k_t = 0.4$ (langvarig last)

$f_{ct,eff} = f_{cmt} = 2.2MPa$ EC2-Tabell 3.1

$h_{c,eff} = \min\{2.5(h-d); (\frac{h - \alpha d}{3}); \frac{h}{2}\} = \min\{2.5(300-284); (\frac{300 - 0.31 * 284}{3}); \frac{300}{2}\} = 40$

$\rho_{\rho,eff} = \frac{A_s}{A_{c,eff}} = \frac{848.2}{1000 * 40} = 0.021$ Sørensen (s.153)

$\eta = \frac{E_s}{E_{cm}} = \frac{200000}{30000} = 6.667$

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{\sigma_s - k_t * \frac{f_{ct,eff}}{\rho_{p,eff}} * (1 + \eta \rho_{p,eff})}{E_s} \geq 0.6 * \frac{\sigma_s}{E_s}$ Sørensen (5.59)

$\varepsilon_{sm} - \varepsilon_{cm} = \frac{63 - 0.4 * \frac{2.2}{0.021} * (1 + 6.667 * 0.021)}{200000} = 7.61 * 10^{-5} \geq 0.6 * \frac{63}{200000} = 1.89 * 10^{-4}$

$C_{nom} = 10mm$

$5 * (c_{nom} + \frac{\phi}{2}) = 5 * (10 + \frac{13}{2}) = 82.5 <$ senteravstand $= 300$

$S_{r,max} = 1.3 * (h - \alpha d) = 1.3 * (300 - 0.31 * 284) = 275.5$ Sørensen (5.61)

$w_k = S_{r,max} * (\varepsilon_{sm} - \varepsilon_{cm}) = 275.5 * 1.89 * 10^{-4} =$ **0.052** Sørensen (5.58)

$w_k > w_{max} = 0.05$ (Rissviddekrav ikke oppfylt)

Max nyttelast:

$0.6 * \frac{\sigma_s}{200000} * 275.5 = 0.05 \rightarrow \sigma_s = 60.4$

$200000 * \frac{M*10^6*(1-0.31)*284}{8.4*10^{12}} = 60.4 \rightarrow M = 12.9$

$\frac{(1.2*7.5+1.5*q)*4^2}{24} = 12.9 \rightarrow q = 6.9$

Vedlegg D.10: Toveisplate (plate 1-4)

Toveisplate beregning

Plate: 1-4

Sørensen (tabell 2.1.1og 2.1.2)

L_y/L_x = 4m/4m =1

α =27.2

β = 27.2

γ = 0.0485

θ_x = 2.96

θ_y = 2.96

d_x =283.5mm

d_y = 283.5 – 13 = 270.5mm

A_{sx} = 995.5mm^2

A_{sy} = 929mm^2

Moment: (bruddgrense)

$M_x = qL_x^2/\alpha = \frac{20.25 * 4^2}{27.2}$ = 11.9 kNm/m Sørensen (tabell 2.1.1)

$M_y = qL_y^2/\beta = \frac{20.25 * 4^2}{27.2}$ = 11.9 kNm/m Sørensen (tabell 2.1.1)

$\varepsilon_{yd} = \frac{f_{yd}}{E_s} = \frac{347.8}{200000} = 0.00174$

$\alpha_b = \frac{\varepsilon_{cu}}{\varepsilon_{cu}+\varepsilon_{yd}} = \frac{0.0035}{0.0035+0.00174} = 0.668$ Sørensen (4.20)

λ=0.8 EC2-3.1.7 (3)

η=1.0 EC2-3.1.7 (3)

$A_{s,b,x} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * 10^3 * d_x * \alpha_b = 0.8*1.0* \frac{11.3}{347.8} * 1000*283.5*0.668 = 4922$ mm^2 Sørensen (4.21)

→ $A_s < A_{s,b,x}$

$\lambda*\eta * f_{cd} * 10^3 * d_x * \alpha - f_{yd} * A_{sx} = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_{sx}}{\lambda*\eta* f_{cd}*10^3*d_x} = \frac{347.8*995.5}{0.8*1.0*11.3*1000*283.5} = 0.135$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.135}{0.135} * 0.0035 = 0.0224$

→ $\varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rdx} = \lambda\eta\alpha * (1-0.5* \lambda\alpha) * f_{cd} * 10^3 * d_x^2$ Sørensen (4.14)

= 0.8*1.0*0.135*(1-0.5*0,8*0.135) * 11.3*1000*283.5^2

= 92789634 Nmm/m = **92.7 kNm/m**

$A_{s,b,y} = \lambda\eta * \frac{f_{cd}}{f_{yd}} * 10^3 * d_y * \alpha_b = 0.8 * 1.0 * \frac{11.3}{347.8} * 1000 * 270.5 * 0.668 = 4696\ mm^2$ Sørensen (4.21)

$\rightarrow A_s < A_{s,b,y}$

$\lambda * \eta * f_{cd} * 10^3 * d_y * \alpha - f_{yd} * A_{sy} = 0$ Sørensen (4.19)

$\rightarrow \alpha = \frac{f_{yd} * A_{sy}}{\lambda * \eta * f_{cd} * 10^3 * d_y} = \frac{347.8 * 929}{0.8 * 1.0 * 11.3 * 1000 * 270.5} = 0.132$

$\varepsilon_s = \frac{1-\alpha}{\alpha} * \varepsilon_{cu} = \frac{1-0.132}{0.132} * 0.0035 = 0.0230$

$\rightarrow \varepsilon_s < \varepsilon_{ud} = 0.03$ EC2- Tabell NA.3.5 (901)

$M_{Rdy} = \lambda\eta\alpha * (1-0.5 * \lambda\alpha) * f_{cd} * 10^3 * d_y^2$ Sørensen (4.14)

$= 0.8 * 1.0 * 0.132 * (1-0.5 * 0{,}8 * 0.132) * 11.3 * 1000 * 270.5^2$

$= 82702490.9$ Nmm/m = **82.7 kNm/m**

$M < M_{Rd}$ (ok)

Max nyttelast : $\frac{(7.5 * 1.2 + p * 1.5) * 4^2}{27.2} = 82.7 \rightarrow p =$ **87.7 kN/m²**

Nedbøyning: (bruddgrense)

$E_{c,middel} = 8483$ MPa (vedlegg D.1)

$A_{sx} = 995.5 mm^2/m$ (vedlegg D.1)

$d_x = 283.5$mm (vedlegg D.1)

$\rho_x = \frac{A_{sx}}{10^3 * d_x} = \frac{995.5}{10^3 * 283.5} = 0.0035$ Sørensen (2.1.8)

$\eta = \frac{E_s}{E_{c,middel}} = \frac{200000}{8483} = 23.6$ Sørensen (2.1.9)

$\eta\rho_x = 0.0035 * 23.6 = 0.083$

$\alpha_x = \sqrt{(\eta\rho_x)^2 + 2 * \eta\rho_x} - \eta\rho_x = \sqrt{0.083^2 + 2 * 0.083} - 0.083 = 0.33$ Sørensen (2.1.10)

$I_{cx} = \frac{1}{2} * \alpha_x^2 * \left(1 - \frac{\alpha_x}{3}\right) * 10^3 * d_x^3$ Sørensen (2.1.11)

$\frac{1}{2} * 0.33^2 * \left(1 - \frac{0.33}{3}\right) * 10^3 * 283.5^3 = 1.1 * 10^9$

$h_{eff} = \sqrt[3]{\frac{12 * I_{cx}}{10^3}} = \sqrt[3]{\frac{12 * 1.1 * 10^9}{10^3}} = 236.3$ Sørensen (2.1.13)

$Eh^3 = E_{c,middel} * h_{eff}^3$

$w = \frac{\gamma * q L_x^4}{Eh^3} = \frac{0.0485 * 20.25 * 10^{-3} * 4000^4}{8483 * 236.3^3} = 2.25$mm Sørensen (tabell 2.1.1)

$\delta_{maks} = \frac{L}{250} = \frac{4000}{250} = 16$mm > w → ok

Max nyttelast: $\frac{0.0485 * (7.5 * 1.2 + p * 1.5) * 10^{-3} * 4000^4}{8483 * 236.3^3} = 16 \rightarrow p =$ **90.1 kN/m²**

Skjærkapasitet: (bruddgrense)
Dimensjonerende skjærkraft:
$V_x = \frac{q*l_x}{\theta_x} = \frac{20.25*4}{2.96} = 27.36$ kN Sørensen (Tabell 2.1.2)
$V_y = \frac{q*l_y}{\theta_y} = \frac{20.25*4}{2.96} = 27.36$ kN Sørensen (Tabell 2.1.2)

Skjærstrekkapasitet:
$V_{Rd,c,x} = C_{Rd,c} * K_x * (100 * P_{L,x} * f_{ck})^{\frac{1}{3}} * 10^3 * d_x$ Sørensen (4.43)
$K_x = 1 + \sqrt{\frac{200}{d_x}} \leq 2.0$
$=1 + \sqrt{\frac{200}{283.5}} = 1.84$
$P_{L,x} = \frac{A_{sL,x}}{10^3 * d_x} \leq 0.02$
$=\frac{497.75}{1000*283.5} = 0.00176$
$K_2 = 0.15$ EC2-NA.6.2.2 (1)
$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$
$V_{Rd,c,x} = 0.1 * 1.84 * (100 * 0.00176 * 20)^{\frac{1}{3}} * 1000 * 283.5 = 79350.9$ N = **79.3 kN**

$V_{Rd,c,y} = C_{Rd,c} * K_y * (100 * P_{L,y} * f_{ck})^{\frac{1}{3}} * 10^3 * d_y$ Sørensen (4.43)
$K_y = 1 + \sqrt{\frac{200}{d_y}} \leq 2.0$
$=1 + \sqrt{\frac{200}{270.5}} = 1.86$
$P_{L,y} = \frac{A_{sL,y}}{10^3 * d_y} \leq 0.02$
$=\frac{464.5}{1000*270.5} = 0.00172$
$K_2 = 0.15$ EC2-NA.6.2.2 (1)
$C_{Rd,c} = \frac{K_2}{\gamma_c} = \frac{0.15}{1.5} = 0.1$
$V_{Rd,c,y} = 0.1 * 1.86 * (100 * 0.00172 * 20)^{\frac{1}{3}} * 1000 * 270.5 = 75950.92$ N = **75.9 kN**
$V_{Rd,c} > V$
Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2.96} = 75.9 \rightarrow$ p = **31.4 kN/m²**

Skjærtrykkapasitet:

$V_{Rd,max,x} = 0.5 * 10^3 * d_x * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max,x} = 0.5 * 1000*283.5*0.552*11.3 = 884179.8$ N = **884 kN**

$V_{Rd,max} > V$

$V_{Rd,max,y} = 0.5 * 10^3 * d_y * v * f_{cd}$

$v = 0.6 * (1 - \frac{f_{ck}}{250}) = 0.6 * (1 - \frac{20}{250}) = 0.552$ Sørensen (4.51)

$V_{Rd,max} = 0.5 * 1000*270.5*0.552*11.3 = 843635.4$ N = **843.6 kN**

$V_{Rd,max} > V$

Max nyttelast: $\frac{(7.5*1.2+p*1.5)*4}{2.96} = 843.6 \rightarrow$ p = **410 kN/m^2**