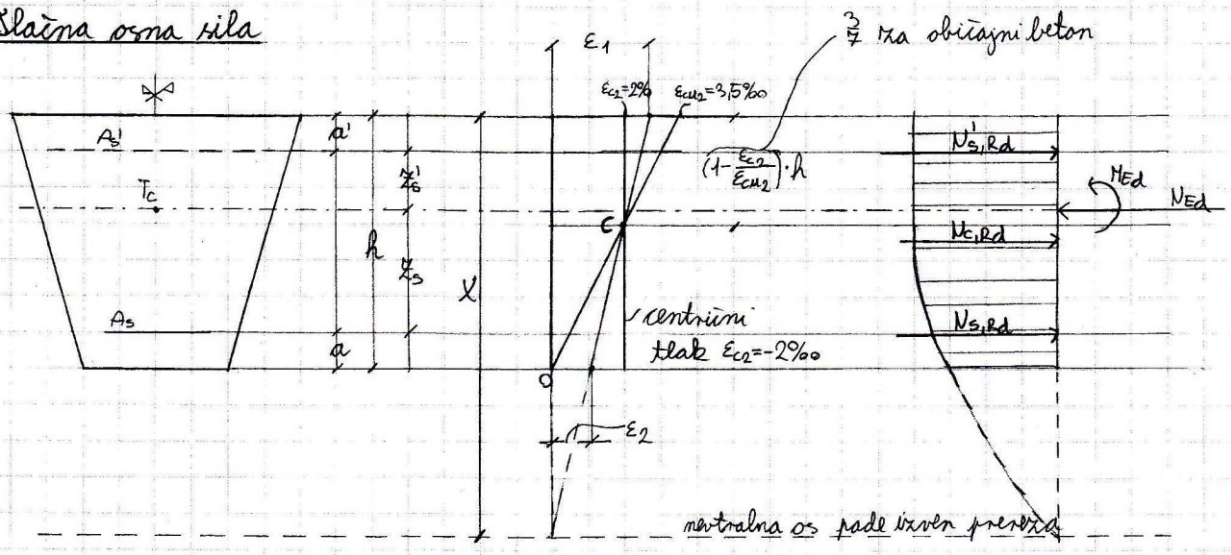
1.2. Osna upogibna obremenitev - mala ekscentričnost (po celem preseku napetosti in deformacije enakega predznaka)

- tlačna ali natezna osna sila; po celem preseku deformacije enakega predznaka
- zbrajni obremenitvi (centrični tlak, centrični nateg)

Tlačna osna sila



$\boxed{\delta = \frac{a}{h}}$

A_s'... bolj tlačena armatura

A_s... manj tlačena armatura

$\boxed{e = \frac{M_{Ed}}{N_{Ed}}}$ => če < jedra preseza j (za $\square$ = h/6) => potem mala ekscentričnost

S predpisanim ε_2 → določen potek deformacij $\boxed{\varepsilon_1 = \varepsilon_{cu2} - \frac{3}{4}\varepsilon_2}$

$x = k_x \cdot h \qquad k_x = \frac{\varepsilon_1}{\varepsilon_1 - \varepsilon_2}$

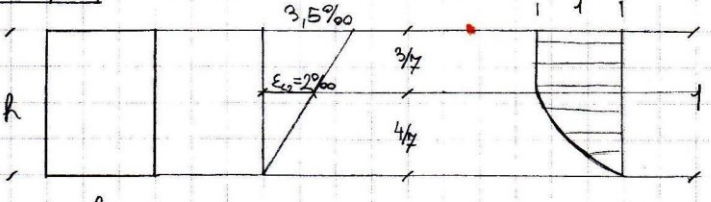
$\boxed{\varepsilon_s = \frac{k_x - 1 + \delta}{k_x - 3/4} \cdot \varepsilon_{c2}}$ < 2‰

$\sigma_s = \sigma_s(\varepsilon_s) \qquad \sigma_s' = \sigma_s'(\varepsilon_s')$

$\boxed{|\varepsilon_s| < \varepsilon_{yd} \rightsquigarrow \sigma_s = E_s \cdot \varepsilon_s}$ $\boxed{|\varepsilon_s| > \varepsilon_{yd} \rightarrow \sigma_s = f_{yd}}$

$\boxed{N_{c,Rd} = n_{cd} \cdot A_c \cdot f_{cd}}$

↳ naprimer



$n_{cd} = \underbrace{(\frac{3}{7}\cdot 1 + \frac{2}{3}\cdot 1 \cdot \frac{4}{7})}_{\text{ploščina}} = \underline{0,80935}$ glej stari priročnik (tabela 7 str. 211; n_{cu})

Primer: pravokotni prerez

Znane so dimenzije preseka in razmerje armature. Uporaba interakcijskega diagrama.

$N_{Ed} = -6825\ kN$ (tlak) $\quad M_{Ed} = 279\ kNm \quad k = \frac{A_s'}{A_s} = 1{,}0$

C40/50 $\rightsquigarrow f_{cd} = \frac{4}{1{,}5} = 2{,}67\ kN/cm^2$ $\quad$ S400 $\rightsquigarrow f_{yd} = \frac{40}{1{,}15} = 34{,}8\ kN/cm^2$ (stari priročnik)

$b = 45cm \quad h = 65cm \quad a = a' = 4{,}5cm$

$A_c = b \cdot h = 45 \cdot 65 = \underline{2925cm}$

$\delta = \frac{a}{h} = \frac{4{,}5}{65} = \underline{0{,}07}$

$n_{Ed} = \frac{N_{Ed}}{A_c f_{cd}} = \frac{-6825}{2925 \cdot 2{,}67} = \underline{-0{,}874}$

$m_{Ed} = \frac{M_{Ed}}{A_c \cdot h \cdot f_{cd}} = \frac{279 \cdot 100}{2925 \cdot 65 \cdot 2{,}67} = \underline{0{,}055}$

V stari priročniku odčitam za S400, $k=1$, $\delta = 0{,}07$

$\bar{\omega}_0 \cong 0{,}05$

$$\boxed{\omega = \frac{\bar{\omega}_0}{1+k} \cdot \frac{f_{cd}}{f_{yd}}} \qquad \omega = \frac{0{,}05}{1+1{,}0} \cdot \frac{2{,}67}{34{,}8} = \underline{0{,}0019}$$

$A_s = \omega \cdot A_c = 0{,}0019 \cdot 2925 = \underline{5{,}6cm^2}$ $\quad$ ($2\phi 19$; $A_{s,dej} = \underline{5{,}67cm^2}$)

$A_s' = k \cdot A_s = 1{,}0 \cdot 5{,}6 = \underline{5{,}6cm^2}$ $\quad$ ($2\phi 19$; $A_{s,dej} = \underline{5{,}67cm^2}$)

Drugačna rešitev

Identično k prejšnjem primeru razen S500 $\rightsquigarrow f_{yd} = 43{,}48\ kN/cm^2$

$A_c = 2925cm^2 \quad \delta = 0{,}07 \quad n_{Ed} = -0{,}874 \quad m_{Ed} = 0{,}055$

V novem priročniku odčitam za S500, $k=1$, $\delta = 0{,}07 \rightsquigarrow \delta = 0{,}10$ ali $\delta = 0{,}05$ ~ bar da več armature (da manj)

$\delta = 0{,}10 \Rightarrow \bar{\omega}_0 = 0{,}1 \Rightarrow \omega = \frac{\bar{\omega}_0}{1+k} \cdot \frac{f_{cd}}{f_{yd}} = \frac{0{,}1}{1+1{,}0} \cdot \frac{2{,}67}{43{,}48} = \underline{0{,}0031}$

$A_s = \omega \cdot A_c = 0{,}0031 \cdot 2925 = \underline{9{,}0cm^2}$ $\quad$ ($4\phi 17$; $A_{s,dej} = 9{,}08cm^2$)

$A_s' = k \cdot A_s = 1{,}0 \cdot 9{,}0 = \underline{9{,}0cm^2}$ $\quad$ ($4\phi 17$; $A_{s,dej} = 9{,}08cm^2$)

Minimalna armatura

- **stebri** ($b \le 4h$)

$$\boxed{A_{s,min} = \max\left(\frac{0{,}1 \cdot N_{Ed}}{f_{yd}};\ 0{,}002\, A_c\right)}$$

- **nosilci, plošče**

$$\boxed{A_{s,min} = \max\left(\frac{0{,}26\, f_{ctm}}{f_{yk}} b_t \cdot d;\ 0{,}0013\, b_t d\right)}$$

(f_{yk}: karakteristična S500 $\rightsquigarrow f_{yk} = 50\ kN/cm^2$)

b_t.. srednja širina natezne cone

f_{ctm}... natezna trdnost betona

Maksimalna armatura

• za vse

$A_{s,max} = 0{,}04 A_c$; če presežemo pogoj → povečanj dimenzij, boljši material, ...

Centrični tlak

• dvojno simetrični prerezi

Pravokotni prerez

C 30/37 ⇝ $f_{cd} = 2{,}0 kN/cm^2$ $\varepsilon_c = \varepsilon_{c2} = -2‰$ (2‰) mejna def.

S500 ⇝ $\sigma_s = \sigma_s(\varepsilon_s) = E_s \cdot \varepsilon_s = 20000 \cdot 0{,}002 = \underline{40 kN/cm^2}$

$\sigma_c = f_{cd} = 2{,}0 kN/cm^2$

$N_{Ed} = -5000 kN$ $M_{Ed} = 0 kNm$ $b/h = 45/50 cm$

$$|N_{Ed}| = A_c \cdot f_{cd} + \sum A_s \cdot \sigma_s$$

$\sum A_s = (|N_{Ed}| - A_c \cdot f_{cd}) / \sigma_s = (5000 - 45 \cdot 50 \cdot 2{,}0) / 40 = \underline{12{,}5 cm^2}$ → če pride prerez armature negativen pomeni, da vso obtežbo prevzame beton, v prerez pa damo $A_{s,min}$.

Preverim $\sum A_{s,min}$ in $\sum A_{s,max}$

$\sum A_{s,min} = max\left(\frac{0{,}1 \cdot N_{Ed}}{f_{yd}}; 0{,}002 A_c\right) = max(11{,}5; 4{,}5) = \underline{11{,}5 cm^2}$

$\sum A_{s,max} = 0{,}04 A_c = 0{,}04 \cdot 45 \cdot 50 = \underline{90 cm^2}$

Izračunan prerez armature $\sum A_s$ ustreza zadnjima pogojema

$\sum A_s = 12{,}5 cm^2$ ($4\phi 20$; $A_{s,dej} = 12{,}37 cm^2$)

Število armaturnih palic v prerezu

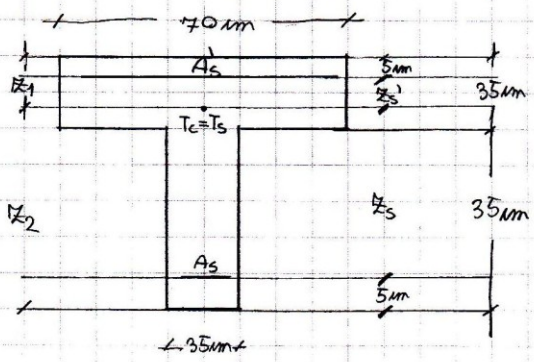
• v kvadratnem prerezu vsaj ena palica v vsakem vogalu

• v okroglem prerezu vsaj 4 armaturne palice

• enojno simetričen prerez

T - prerez

$\varepsilon = -2‰ \rightsquigarrow$ za beton in armaturo



$z_1 = 29{,}2$ cm $\quad z_2 = 40{,}8$ cm $\quad A_c = 3675\,cm^2$

$N_{Ed} = -12000$ kN (tlak) $\quad \boxed{M_{Ed} = 0}$

S 500 $\rightsquigarrow f_{yd} = 43{,}48\,kN/cm^2$

C 40/45 $\rightsquigarrow f_{cd} = 2{,}67\,kN/cm^2$

$z_s' = z_1 - 5 = 29{,}2 - 5 = \underline{24{,}2\,cm} \qquad z_s = z_2 - 5 = 40{,}8 - 5 = \underline{35{,}8\,cm}$

$\sum A_{s,min} = max\left(\frac{0{,}10 \cdot N_{Ed}}{f_{yd}} ; 0{,}002 \cdot A_c\right) = max(27{,}6 ; 7{,}4) = \underline{27{,}6\,cm^2}$

$N_{Ed} = A_c \cdot f_{cd} + \sum A_s \cdot \sigma_s \rightsquigarrow \sum A_s = (|N_{Ed}| - A_c \cdot f_{cd})/\sigma_s = (12000 - 3673 \cdot 2{,}67)/40 = \underline{54{,}7\,cm^2}$

Razporeditev: $T_s = T_c \Rightarrow M_{Rd} = 0$

1. pogoj $\quad \boxed{A_s \cdot z_s = A_s' \cdot z_s'}$

2. pogoj $\quad \boxed{\sum A_s = A_s + A_s'}$

$A_s = \sum A_s - A_s' \rightsquigarrow z_s (\sum A_s - A_s') = A_s' \cdot z_s'$

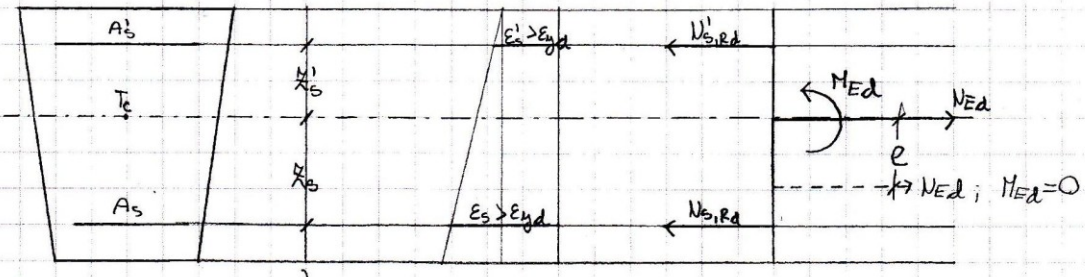
$A_s' (z_s + z_s') = \sum A_s \cdot z_s$

$\boxed{A_s' = \frac{\sum A_s \cdot z_s}{z_s' + z_s}} \qquad A_s' = \underbrace{\frac{54{,}7 \cdot 35{,}8}{24{,}2 + 35{,}8}}_{h} = \underline{32{,}6\,cm^2}$

$A_s = \sum A_s - A_s' = 54{,}7 - 32{,}6 = \underline{22{,}1\,cm^2}$

Notranja osna sila (mala ekscentričnost)

$\varepsilon > 0 \rightsquigarrow$ beton pri MSN „ne sodeluje"



$\boxed{e = \frac{M_{Ed}}{N_{Ed}}}$ → odmik armature od težišča

Ravnotežna momentna pogoja:

1.) Momentni ravnotežni pogoj na $N_{s,Rd}'$:

$N_{Ed} \cdot (z_s' + e) - N_{s,Rd} \cdot (z_s' + z_s) = 0 \Rightarrow N_{s,Rd} = N_{Ed} \cdot \frac{z_s' + e}{z_s' + z_s}$

$A_s = \frac{N_{s,Rd}}{f_{yd}} \qquad \boxed{A_s = \frac{N_{Ed}}{f_{yd}} \cdot \frac{z_s' + e}{z_s' + z_s}}$

2.) Momentni ravnotežni pogoj na $N_{s,Rd}$:

$$N'_{s,Rd} \cdot (z_s + z'_s) - N_{Ed} \cdot (z_s - e) = 0 \Rightarrow N'_{s,Rd} = N_{Ed} \cdot \frac{z_s - e}{z_s + z'_s}$$

$$A'_s = \frac{N'_{s,Rd}}{f_{yd}} \qquad \boxed{A'_s = \frac{N_{Ed}}{f_{yd}} \cdot \frac{z_s - e}{z_s + z'_s}}$$

Te enačbe veljajo, če je $e \leq z_s$ oziroma $e \leq z'_s$

Centrični nateg $e = 0$

- nesimetrični prerez $\boxed{A_s = \frac{N_{Ed}}{f_{yd}} \cdot \frac{z'_s}{z_s + z'_s}}$ V zgornji splošni enačbi za A_s in A'_s vstavimo $e = 0$

$$\boxed{A'_s = \frac{N_{Ed}}{f_{yd}} \cdot \frac{z_s}{z_s + z'_s}}$$

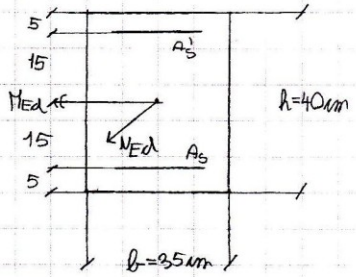
- simetrični prerez $\boxed{z_s = z'_s}$

$$\boxed{A_s = A'_s = \frac{N_{Ed}}{2 f_{yd}}}$$

Postavitev armature

- centrični nateg: enakomerno po preseku (po obodu) $T_s \cong T_c$
- ekscentrični nateg: težišče vse armature se ujema s prijemališčem sile N_{Ed} (e)

Primer: Ekscentrični nateg – simetrični prerez



S 500 ⇝ $f_{yd} = 43{,}48\ kN/cm^2$

C 30/37 ⇝ $\alpha_{cc} f_{cd} = 2{,}0\ kN/cm^2$

Obremenitev: Stalna $N_g = 500\ kN$, $M_g = 15\ kNm$

Spremenljiva $N_q = 200\ kN$, $M_q = 10\ kNm$

$N_{Ed} = 1{,}35 \cdot 500 + 1{,}5 \cdot 200 = \underline{975\ kN}$

$M_{Ed} = 1{,}35 \cdot 15 + 1{,}5 \cdot 10 = \underline{35{,}25\ kNm}$

$e = \frac{M_{Ed}}{N_{Ed}} = 35{,}25/975 = \underline{0{,}036m}$; $z_s = z'_s = 0{,}15m > e \Rightarrow$ mala ekscentričnost

Če bi bil $e > z_s = z'_s$ bi računali po enačbah za veliko ekscentričnost (kd ...)

$$A_s = \frac{N_{Ed}}{f_{yd}} \cdot \frac{z'_s + e}{z'_s + z_s} = \frac{975}{43{,}48} \cdot \frac{15 + 3{,}6}{15 + 15} = \underline{13{,}9\ cm^2}$$

$$A'_s = \frac{N_{Ed}}{f_{yd}} \cdot \frac{z_s - e}{z_s + z'_s} = \frac{975}{43{,}48} \cdot \frac{15 - 3{,}6}{15 + 15} = \underline{8{,}52\ cm^2}$$

Dimenzije betonskega prereza določimo po MSU (mejno stanje uporabnosti) oziroma je potrebno preveriti. Ena izmed MSU je mejno stanje razpok.