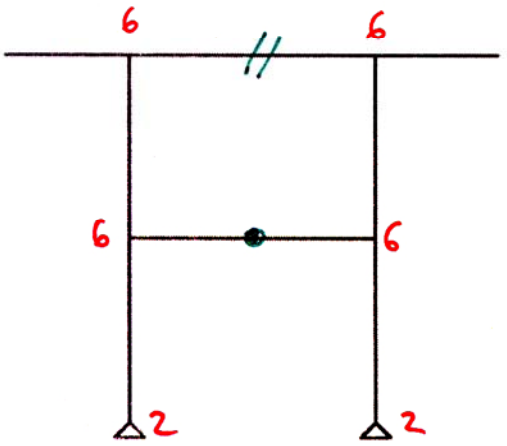
1)



Počet stupňů volnosti: $3 \times 8 = 24$

Počet odebraných stupňů volnosti:

$6 \times 4 + 2 \times 2 = 28$

$\Rightarrow$ konstrukce je 4x staticky neurčitá

- 2. možnost – převedu na stat. určitou konstrukci

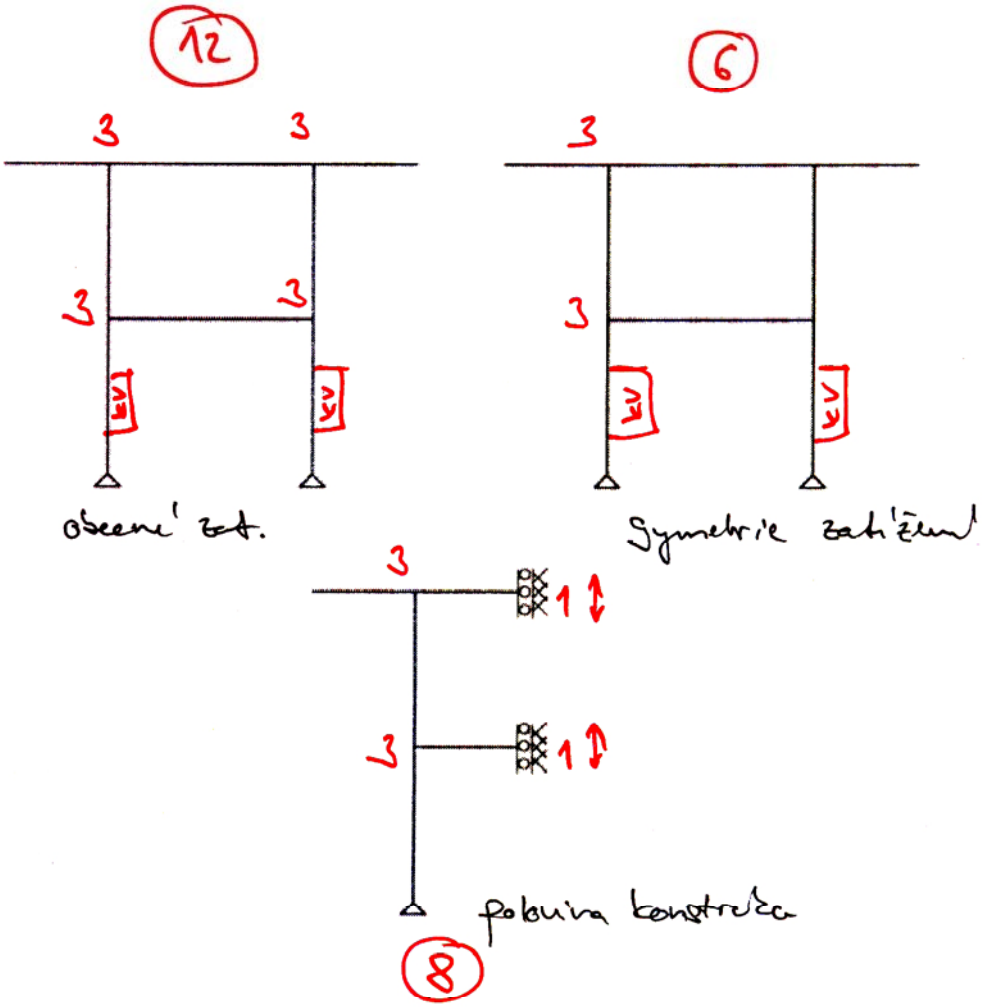
přídavný klub – 1 s.v.

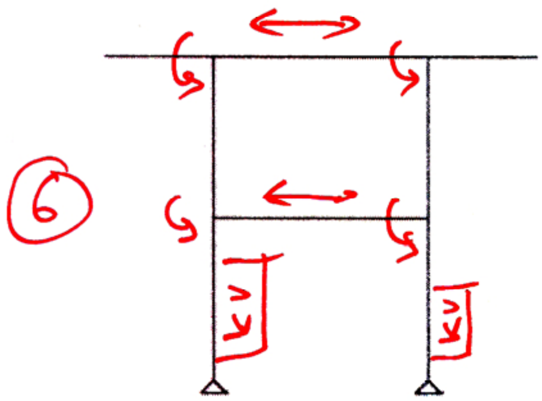
rozříznutí 3 s.v.

Σ 4 s.v.

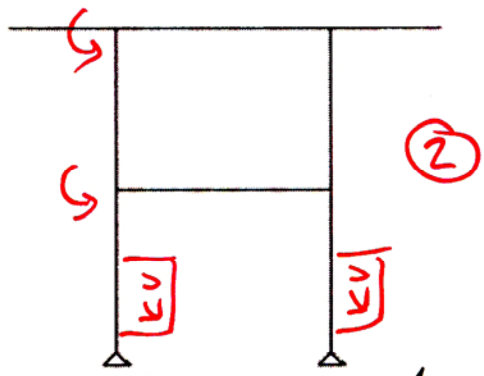
2) Počet neznámých

a) ODM

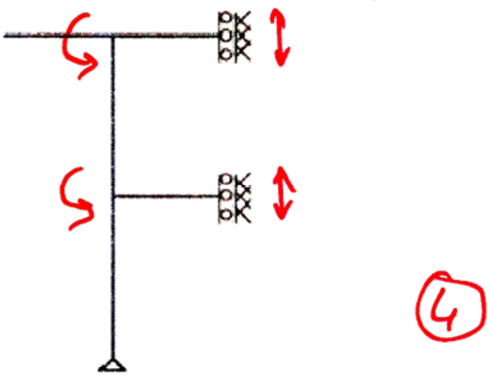




obecné zat.

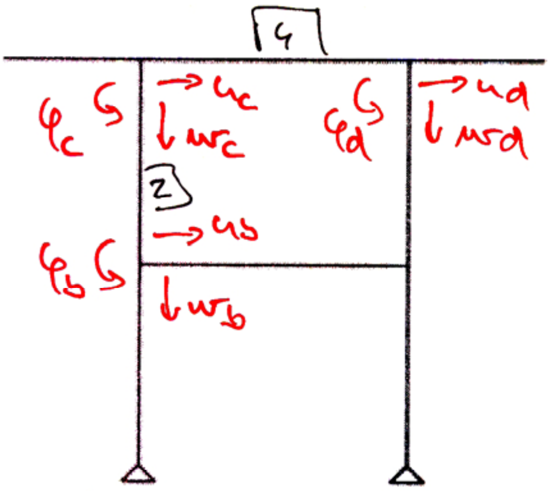


symetrické zat.



polovina konstrukce

3) Podmínky rovnováhy pro styčník c



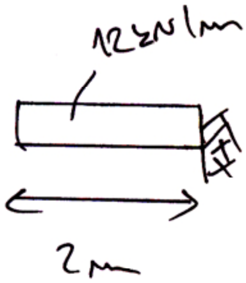
Symetrická konstrukce i zatížení

→ $\varphi_c = -\varphi_d$

$w_c = w_d$

$u_c = -u_d$

Zatížení na konzole nahradíme osamělou silou a osamělým momentem



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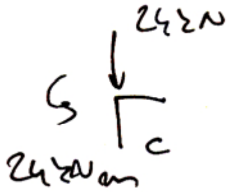


Koncové síly na prutech

1) prut 4 $\quad L_4 = 4\,m$, typ VV

$$n_4 = \frac{EA}{L_4} = \frac{30 \cdot 0{,}12}{4} = 0{,}9\ GN/m = 900\ MN/m$$

$$k_4 = \frac{2EI}{L_4} = \frac{2 \cdot 30 \cdot 36 \cdot 10^{-4}}{4} = 0{,}054\ GN \cdot m = 54\ MN/m$$

- $M_{cd} = \bar{M}_{cd} + k_4\left(2\varphi_c + \varphi_d + \frac{3(w_d - w_c)}{L_4}\right)$, $\quad -\varphi_c$

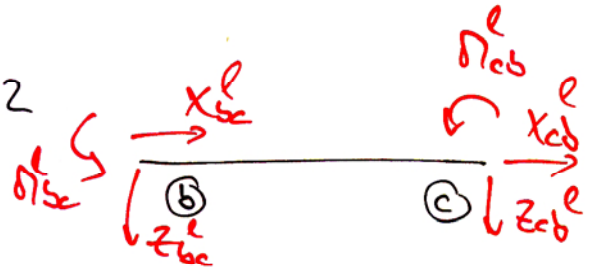
$$\bar{M}_{cd} = \frac{1}{12} \cdot 12 \cdot 4^2 = 16\ kNm$$

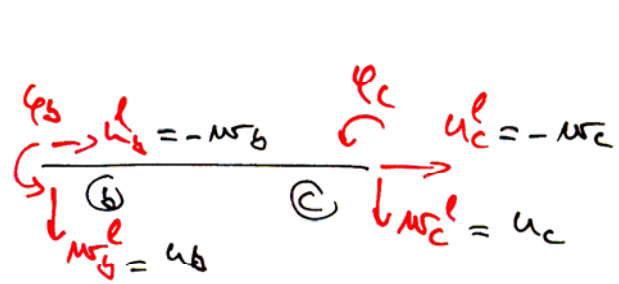
$$M_{cd} = 16 + 54(2\varphi_c - \varphi_c) = 16 + 54\varphi_c$$

- $Z_{cd} = \bar{Z}_{cd} - \frac{3k_4}{L_4}\left(\varphi_c + \varphi_d + \frac{2(w_d - w_c)}{L_4}\right) = \bar{Z}_{cd} = -12 \cdot \frac{4}{2} = -24\ kN$, $\quad 0$

- $X_{cd} = \bar{X}_{cd} - n_4(u_d - u_c) = -n_4(-u_c - u_2) = 2 \cdot n_4 \cdot u_c = 1800 \cdot u_c$

2) Prut 2





$L_2 = 3\,m$, typ VV

$$n_2 = \frac{EA}{L_2} = \frac{30 \cdot 0{,}196}{3} = 1{,}96\ GN/m = 1960\ MN/m$$

$$k_2 = \frac{2EI}{L_2} = \frac{2 \cdot 30 \cdot 30{,}68 \cdot 10^{-4}}{3} = 0{,}061366\ GN\,m = 61{,}36\ MN \cdot m$$

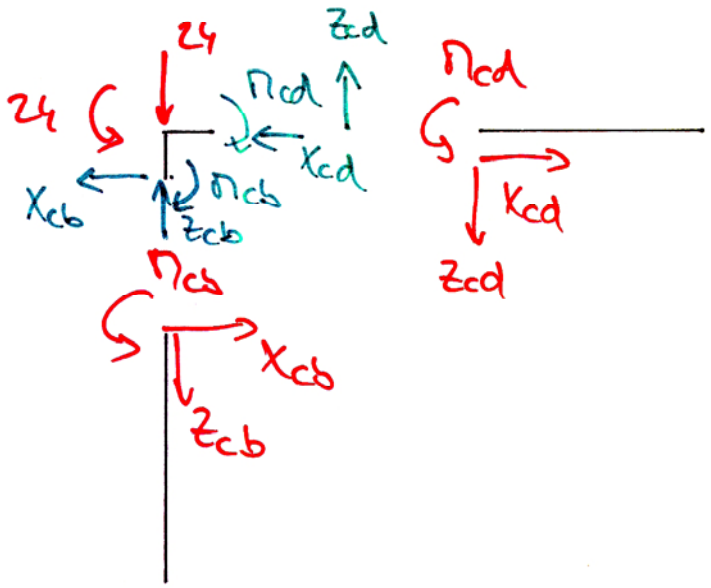
- $\Pi_{cb} = \bar{\Pi}_{cb} + k_2\left(2\varphi_c + \varphi_b + \frac{3(u_c - u_b)}{L_2}\right) = 61{,}36\left[2\varphi_c + \varphi_b + u_c - u_b\right]$, $\quad \bar{\Pi}_{cb} = 0$

- $Z^l_{cb} = \bar{Z}^l_{cb} + \frac{3k_2}{L_2}\left(\varphi_b + \varphi_c + \frac{2(u_c - u_b)}{L_2}\right) = 61{,}36\left[\varphi_b + \varphi_c + \frac{2}{3}(u_c - u_b)\right]$, $\quad \bar{Z}^l_{cb} = 0$

- $X^l_{cb} = \bar{X}^l_{cb} + n_2(-w_c + w_b) = 1960(w_b - w_c)$

$X_{cb} = Z^l_{cb}$; $\quad Z_{cb} = -X^l_{cb}$

Podmínky rovnováhy



$\rightarrow: \quad x_{cb} + x_{cd} = 0$

$\uparrow: \quad z_{cb} + z_{cd} = 24$

$\circlearrowleft: \quad \eta_{cb} + \eta_{cd} = 24$

$\rightarrow: \quad 61{,}36\left[\varphi_b + \varphi_c + \frac{2}{3}(u_c - u_b)\right] + 1800\, u_c = 0$

$3{,}95412 \qquad -3{,}95406 \qquad \Rightarrow$ ok

$\uparrow: \quad 1960\,(w_c - w_b) - 24 = 0$ $\qquad \Rightarrow$ ok

$48{,}0004$

$\circlearrowleft: \quad 16 + 54\,\varphi_c + 61{,}36\left[2\varphi_c + \varphi_b + u_c - u_b\right] = 24$

$18{,}0029 \qquad 5{,}99711$

$2\cdot\eta_{cd} \qquad 2\cdot\eta_{cb} \qquad \Rightarrow$ ok

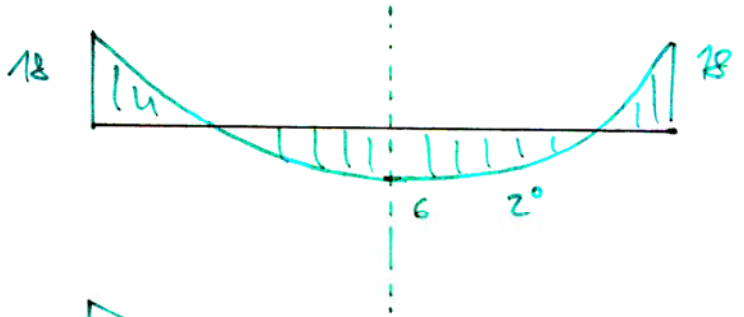
④ Podmínky rovnováhy jsou splněny

5) Průběh uvítřních sil na prutech 2,4

1) Prut [4]

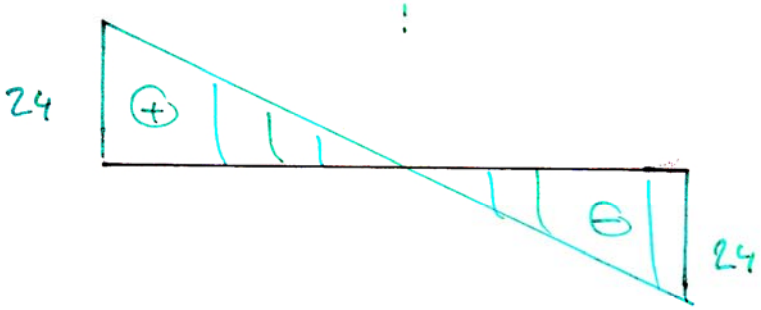
$M_{cd} = \cancel{5,997}$ 18 kNm

$M_{max} = -18 + 24 \cdot 2 - 12 \cdot \frac{2^2}{2} =$
$= 6$ kNm



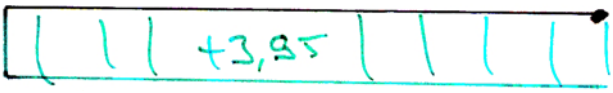
M [kNm]

$Z_{cd} = -24$ kN



V [kN]

$X_{cd} = -3,95$ kN



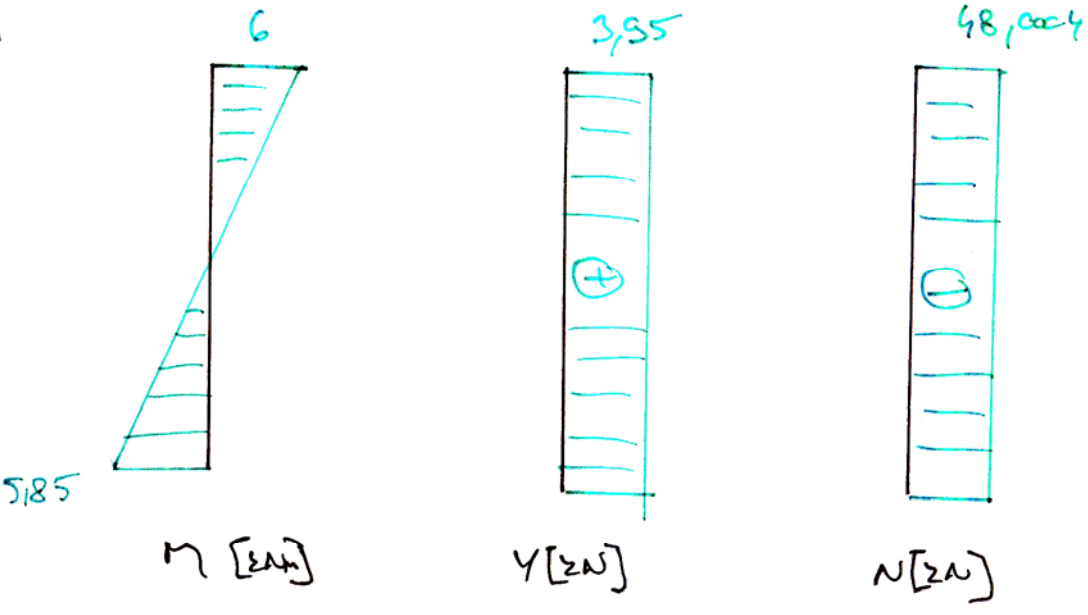
N [kN]

2) Prut [2]

$M_{cb} = 5,997$ kNm

$Z_{cb}^{l} = 3,954$ kN

$X_{cb}^{l} = -48,004$ kN

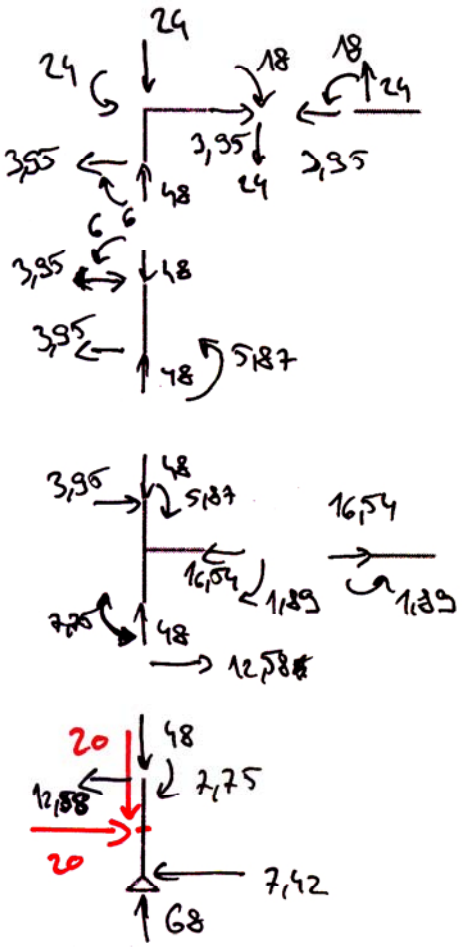


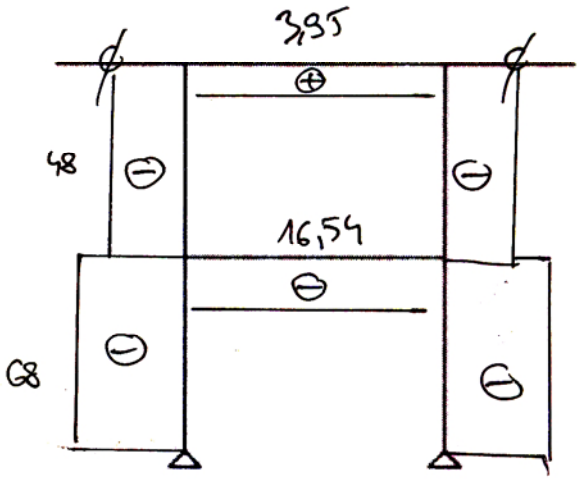
M [kNm] V [kN] N [kN]

$6 - 3,95 \cdot 3 = -5,85$

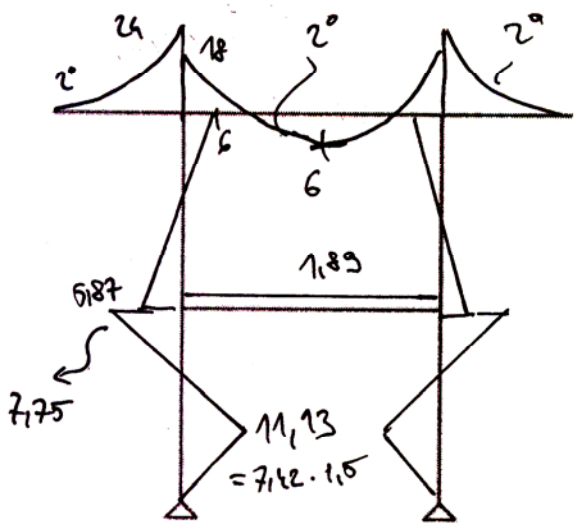
7)

Rozkreslení + reakce

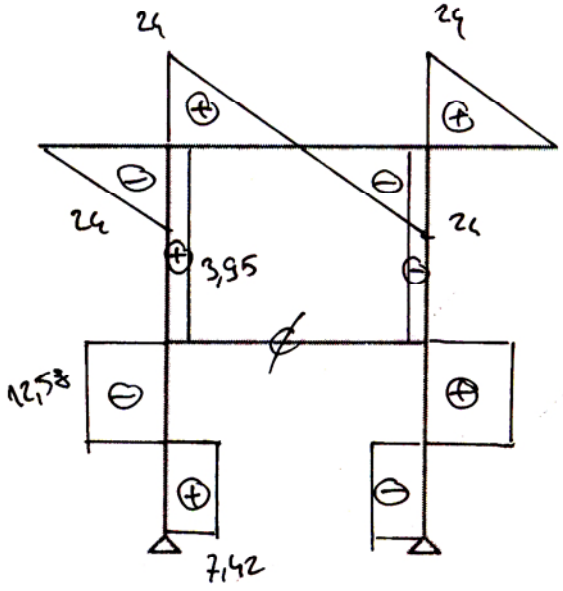




N [kN]



M [kN m]



V [kN]

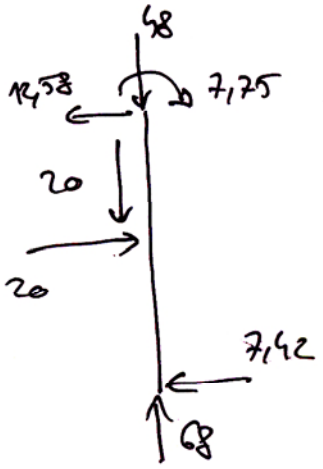
⑧ kontrola rovnovážný podmínky b

$\rightarrow$: $12,58 + 3,95 - 16,54 = -0,01$ ok

$\uparrow$: $48 - 48 = 0$ ok

$\circlearrowleft$: $7,75 - 1,89 - 5,87 = -0,01$ ok

⑨ Rovnováha prutu 1

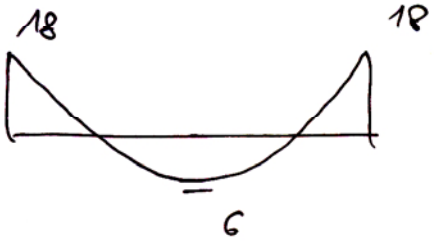


$\rightarrow$: $20 - 12,58 - 7,42 = 0$ ok

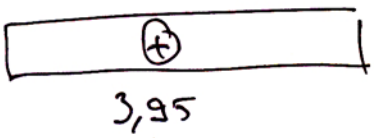
$\uparrow$: $68 - 20 - 48 = 0$ ok

$\circlearrowleft_a$: $-7,75 + 12,58 - 20 \cdot 1,5 = -0,01$ ok ($\times 3$)

⑥ Maximální normálové napětí na prutu 4



M



N

$$\sigma = \frac{N}{A} + \frac{M \cdot z}{I_y}$$

krajní vlákna $\Rightarrow z = \pm 0,3\,m$

$$\sigma_1 = \frac{3,95}{0,12} + \frac{-18 \cdot (-0,3)}{36 \cdot 10^{-4}} = 1532,92\ kPa$$

$$\sigma_2 = \frac{3,95}{0,12} + \frac{-18 \cdot 0,3}{36 \cdot 10^{-4}} = -1467,08\ kPa$$

$$\sigma_3 = \frac{3,95}{0,12} + \frac{6 \cdot (-0,3)}{36 \cdot 10^{-4}} = -467,083\ kPa$$

$$\sigma_4 = \frac{3,95}{0,12} + \frac{6 \cdot 0,3}{36 \cdot 10^{-4}} = 532,917\ kPa$$