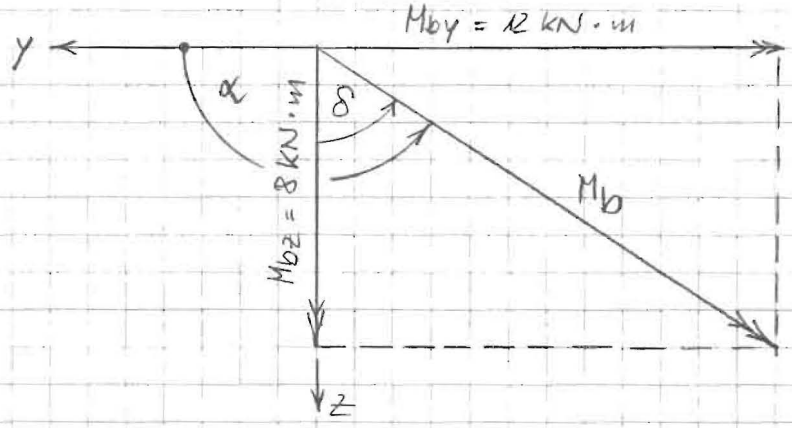
zu 1)

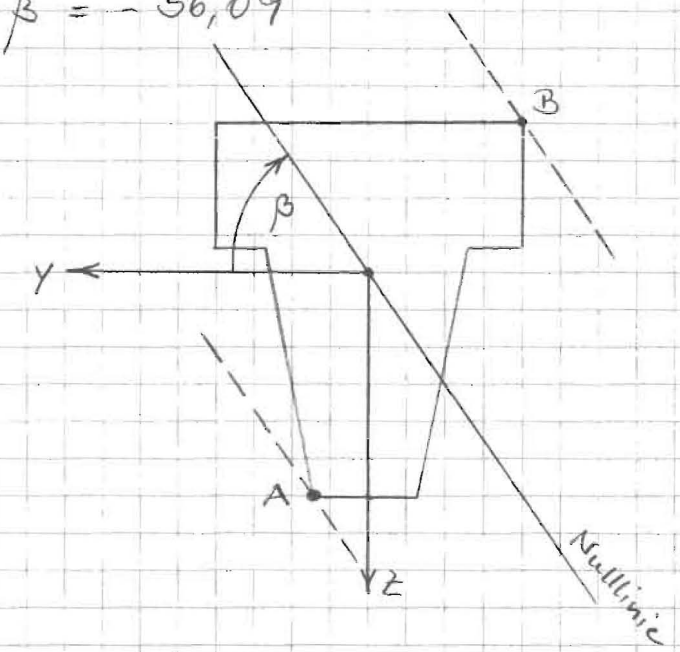


$$\tan\delta = \frac{12\ kN\cdot m}{8\ kN\cdot m} = 1{,}5\ ;\quad \delta = 56{,}31°$$

$$\alpha = 90° + \delta = 146{,}31°$$

$$\tan\beta = \frac{I_y}{I_z}\cdot\tan\alpha = \frac{2053\ cm^4}{920\ cm^4}\cdot\tan 146{,}31° = -1{,}4877$$

$$\beta = -56{,}09°$$



zu 2) Punkt A

$$y_A = 2\ cm\ ;\quad z_A = 9{,}03\ cm$$

$$\sigma_b^A = \frac{-1200\ kN\cdot cm}{2053\ cm^4}\cdot 9{,}03\ cm - \frac{800\ kN\cdot cm}{920\ cm^4}\cdot 2\ cm$$

$$\sigma_b^A = -7{,}017\ \frac{kN}{cm^2} = -70{,}17\ \frac{N}{mm^2}$$

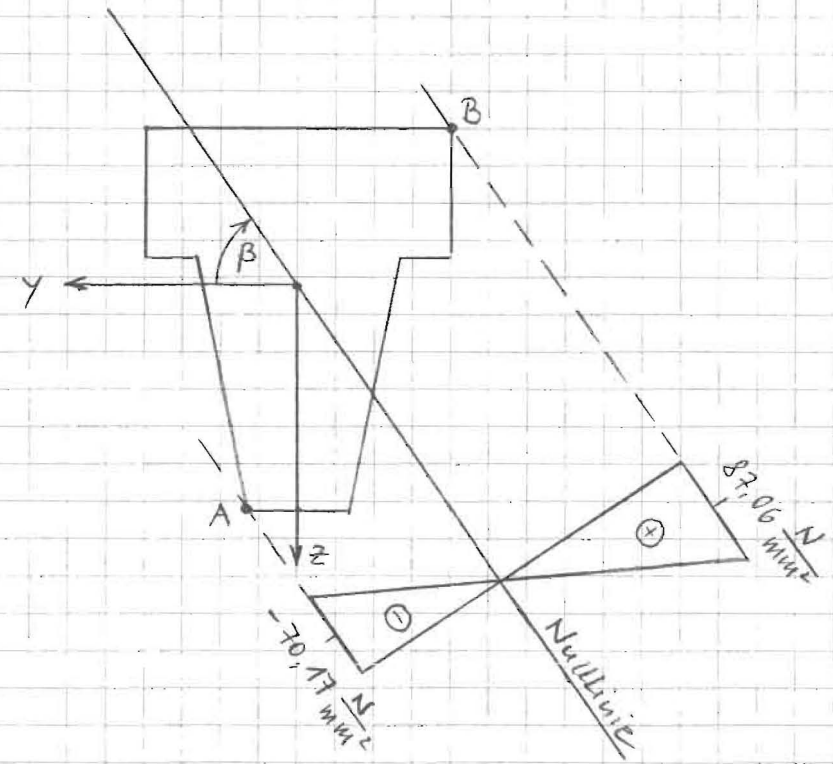
Punkt B

$y_B = -6\,cm$; $z_B = -5{,}97\,cm$

$$\sigma_b^B = \frac{-1200\,kN\cdot cm}{2053\,cm^4}\cdot(-5{,}97\,cm) - \frac{800\,kN\cdot cm}{920\,cm^4}\cdot(-6\,cm)$$

$$\sigma_b^B = 8{,}706\,\frac{kN}{cm^2} = 87{,}06\,\frac{N}{mm^2}$$

zu 3)

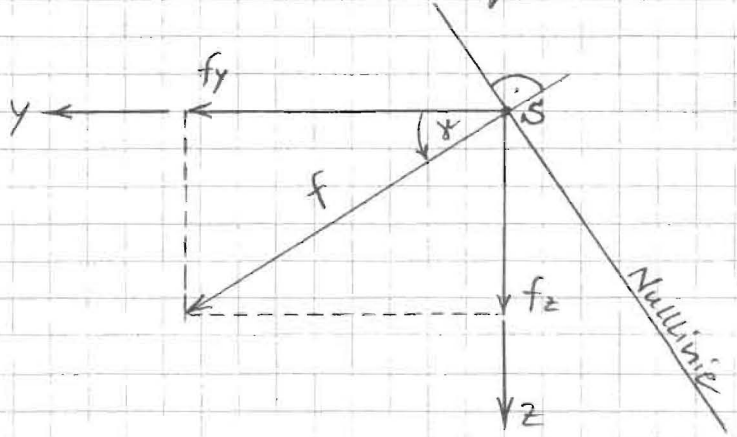


zu 4)

$$f_y = \frac{F_y\cdot \ell^3}{8\cdot E\cdot I_z} = \frac{8000N\cdot(2000\,mm)^3}{8\cdot 2{,}1\cdot 10^5\,\frac{N}{mm^2}\cdot 920\cdot 10^4\,mm^4} = 4{,}141\,mm$$

$$f_z = \frac{F_z\cdot \ell^3}{8\cdot E\cdot I_y} = \frac{12000N\cdot(2000\,mm)^3}{8\cdot 2{,}1\cdot 10^5\,\frac{N}{mm^2}\cdot 2053\cdot 10^4\,mm^4} = 2{,}783\,mm$$

$$f = \sqrt{f_y^2 + f_z^2} = \sqrt{(4{,}141\,mm)^2 + (2{,}783\,mm)^2} = 4{,}989\,mm$$



$$\gamma = \arctan\frac{2{,}783\,mm}{4{,}141\,mm} = 33{,}91°$$

$$\gamma + |\beta| = 33{,}91° + 56{,}09° = 90°$$

zu 1)

a) Achteck

$b = 6\,cm + 2 \cdot 4{,}24\,cm = 14{,}48\,cm$

$W_T = 0{,}185 \cdot b^3 = 0{,}185 \cdot (14{,}48\,cm)^3 = 561{,}665\,cm^3$

$M_{T\,zul} = \tau_{zul} \cdot W_T = 75 \frac{N}{mm^2} \cdot 561{,}665 \cdot 10^3\,mm^3$

$M_{T\,zul} = 42\,124\,875\,N \cdot mm$

$M_{T\,zul} = 42{,}125\,kN \cdot m$

b) Geschlossenes Hohlprofil

$$\tau = \frac{M_T}{2 \cdot A_m \cdot t}$$

$A_m = 4 \cdot 5{,}5\,cm \cdot 4{,}24\,cm + (5{,}5\,cm)^2 = 123{,}53\,cm^2$

$M_{T\,zul} = 2 \cdot 123{,}53 \cdot 10^2\,mm^2 \cdot 5\,mm \cdot 75 \frac{N}{mm^2}$

$M_{T\,zul} = 9264750\,N \cdot mm$

$M_{T\,zul} = 9{,}265\,kN \cdot m$

zu 2) $\varphi = \varphi_1 + \varphi_2 = \frac{M_T \cdot l_1}{G \cdot I_{T1}} + \frac{M_T \cdot l_2}{G \cdot I_{T2}}$

$I_{T1} = 0{,}108 \cdot b^4 = 0{,}108 \cdot (14{,}48\,cm)^4 = 4747{,}861\,cm^4$

$$I_{T2} = \frac{4 \cdot A_m^2}{\oint \frac{ds}{t}}$$

$$\oint \frac{ds}{t} = \frac{1}{0{,}5\,cm} \cdot (4 \cdot 5{,}5\,cm + 8 \cdot 4{,}24\,cm) = 111{,}84$$

$$I_{T2} = \frac{4 \cdot (123{,}53\,cm^2)^2}{111{,}84} = 545{,}768\,cm^4$$

$$\varphi = \frac{8 \cdot 10^6\,N \cdot mm}{8{,}1 \cdot 10^4\,\frac{N}{mm^2}} \cdot \left[\frac{2000\,mm}{4747{,}861 \cdot 10^4\,mm^4} + \frac{2000\,mm}{545{,}768 \cdot 10^4\,mm^4} \right]$$

$$\gamma = 0{,}04035$$

$$\varphi = 0{,}04035 \cdot \frac{180^\circ}{\pi} = 2{,}31^\circ$$

$$T = \tau \cdot t = \frac{M_T}{2 \cdot A_m} = \frac{8 \cdot 10^6\,N \cdot mm}{2 \cdot 123{,}53 \cdot 10^2\,mm^2}$$

$$T = 323{,}81\,\frac{N}{m}$$

zu 1)

$$I_1 = \frac{\pi \cdot d^4}{64} = \frac{\pi \cdot (120\,mm)^4}{64} = 10178760\,mm^4$$

$$I_2 = \frac{a^4}{12} = \frac{(120\,mm)^4}{12} = 17280000\,mm^4$$

$$\frac{k_2}{k_1} = \frac{\sqrt{\frac{F_K}{E \cdot I_2}}}{\sqrt{\frac{F_K}{E \cdot I_1}}} = \sqrt{\frac{I_1}{I_2}} = \sqrt{\frac{10178760\,mm^4}{17280000\,mm^4}} = 0,7675$$

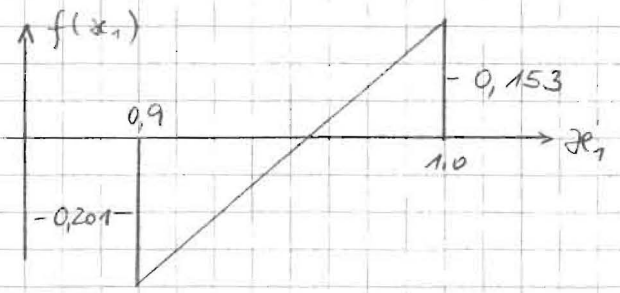
$$k_2 \cdot l_2 = \varkappa_2 = 0,7675 \cdot k_1 \cdot l_2 = 0,7675 \cdot k_1 \cdot l_1 = 0,7675 \cdot \varkappa_1$$

Knickbedingung:

$$f(\varkappa_1) = 0,7675 \cdot \tan \varkappa_1 \cdot \tan(0,7675 \cdot \varkappa_1) - 1 = 0$$

$$f(\varkappa_1 = 0,9) = -0,201$$

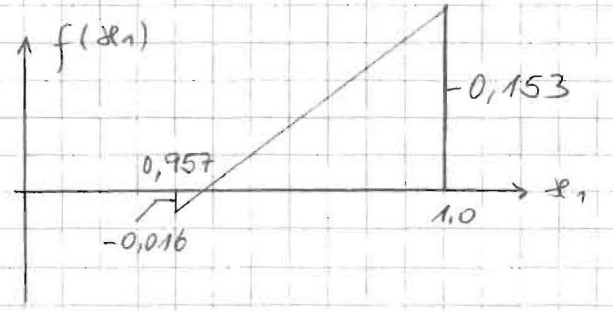
$$f(\varkappa_1 = 1) = 0,153$$



$$\frac{\Delta \varkappa_1}{0,201} = \frac{0,1}{0,201 + 0,153} \Rightarrow \Delta \varkappa_1 = 0,057$$

$$\varkappa_{1Neu} = 0,9 + 0,057 = 0,957$$

$$f(\varkappa_1 = 0,957) = -0,016$$



$$\frac{\Delta x_1}{0,016} = \frac{1 - 0,957}{0,016 + 0,153} \Rightarrow \Delta x_1 = 0,004$$

$$x_{1Neu} = 0,957 + 0,004 = 0,961$$

$$f(x_1 = 0,961) = -1,8 \cdot 10^{-3}$$

$$\beta_1 = k_1 \cdot l_1 = \sqrt{\frac{F_K}{E \cdot I_1}} \cdot l_1 = 0,961$$

$$F_K = 0,961^2 \cdot \frac{E \cdot I_1}{l_1^2} = 0,961^2 \cdot \frac{2,1 \cdot 10^5 \frac{N}{mm^2} \cdot 10178760\,mm^4}{(800\,mm)^2}$$

$$F_K = 3084473\,N$$

$$T = \frac{2,1 \cdot 10^5 \frac{N}{mm^2} \cdot 1,2 \cdot 10^{-5} K^{-1} \cdot 30\,K \cdot (800\,mm + 800\,mm)}{\frac{4 \cdot 800\,mm}{\pi \cdot (120\,mm)^2} + \frac{800\,mm}{(120\,mm)^2}}$$

$$T = 957787\,N$$

$$\nu_K = \frac{3084473\,N}{957787\,N} = 3,22$$

zu 2) $A_{min} = \frac{\pi \cdot (120\,mm)^2}{4} = 11310\,mm^2$

$$\sigma_K = \frac{3084473\,N}{11310\,mm^2} = 272,72 \frac{N}{mm^2} < 285 \frac{N}{mm^2} = \sigma_{dP}$$

$\Rightarrow$ elastische Rechnung o.k.