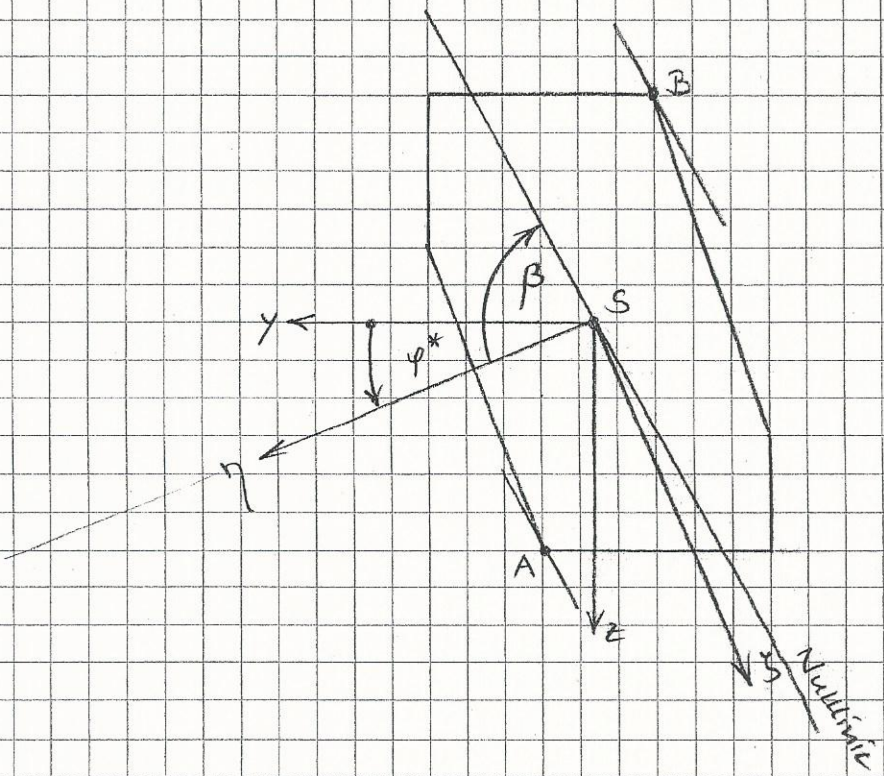
1) Spannungsnulllinie

$\alpha = -(45^\circ + 21{,}96^\circ) = -66{,}96^\circ$

$\tan\beta = \dfrac{1038\,cm^4}{279\,cm^4} \cdot \tan(-66{,}96^\circ) = -8{,}7478$

$\beta = -83{,}48^\circ$



2) $M_{b\eta} = 8\,kN\cdot m \cdot \cos(-66{,}96^\circ) = 3{,}131\,kN\cdot m$

$M_{b\zeta} = 8\,kN\cdot m \cdot \sin(-66{,}96^\circ) = -7{,}362\,kN\cdot m$

$\eta_A = 6\,cm \cdot \sin 21{,}96^\circ + 1{,}5\,cm \cdot \cos 21{,}96^\circ = 3{,}63\,cm$

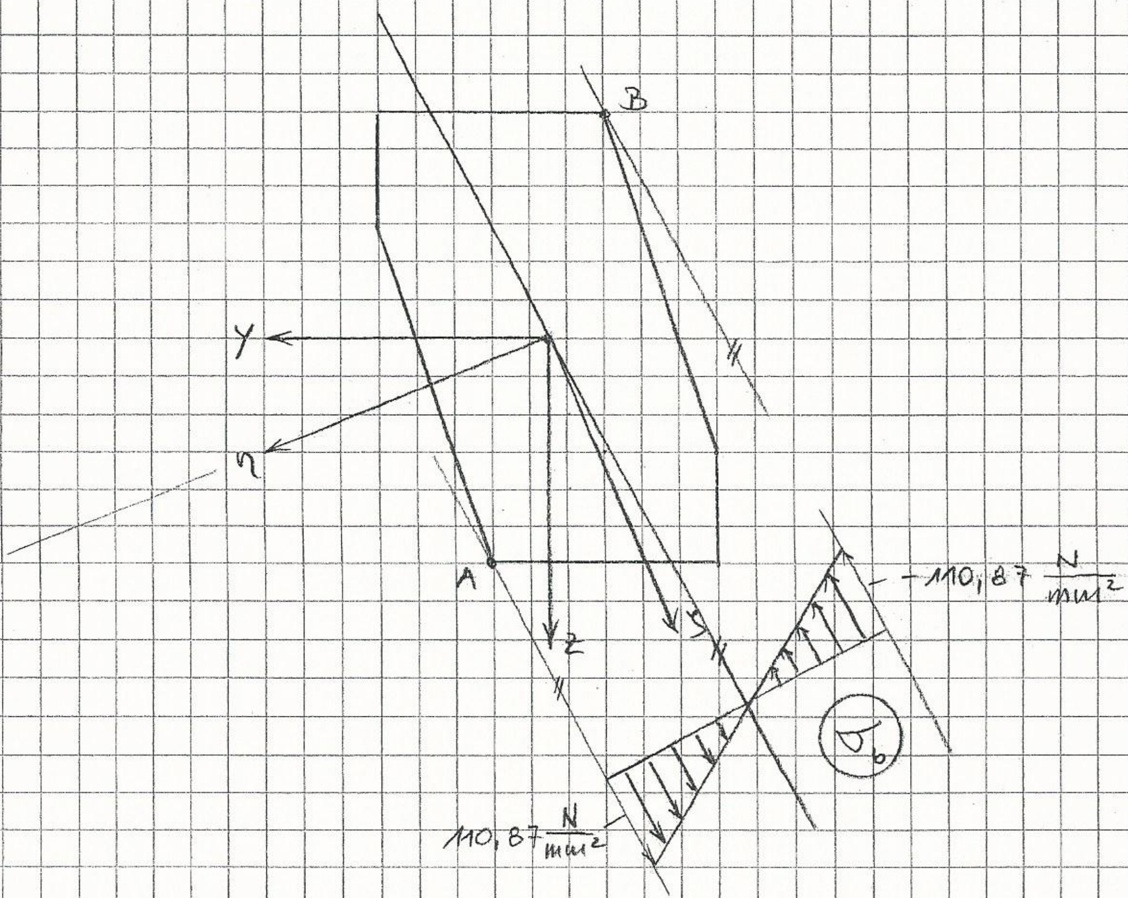
$\zeta_A = 6\,cm \cdot \cos 21{,}96^\circ - 1{,}5\,cm \cdot \sin 21{,}96^\circ = 5{,}00\,cm$

$\eta_B = -3{,}63\,cm \; ; \; \zeta_B = -5{,}00\,cm$

$$\sigma_b^A = \frac{313{,}1\ kN \cdot cm}{1038\ cm^4} \cdot 5\ cm - \frac{(-736{,}2\ kN \cdot cm)}{279\ cm^4} \cdot 3{,}63\ cm$$

$$\sigma_b^A = 11{,}087\ \frac{kN}{cm^2} = 110{,}87\ \frac{N}{mm^2}$$

$$\sigma_b^B = -110{,}87\ \frac{N}{mm^2}$$



3) $$M_{bzul} = 8\ kN \cdot m \cdot \frac{130\ \frac{N}{mm^2}}{110{,}87\ \frac{N}{mm^2}} = 9{,}38\ kN \cdot m$$

1)

Geschlossenes Hohlprofil

$$I_{T1} = \frac{4 \cdot A_m^2}{\oint \frac{ds}{t}}$$

$$A_m = 4\,cm \cdot 4{,}6\,cm + \pi \cdot (2{,}3\,cm)^2 = 35{,}019\,cm^2$$

$$\oint \frac{ds}{t} = \frac{1}{0{,}4\,cm} \cdot (2 \cdot \pi \cdot 2{,}3\,cm + 2 \cdot 4\,cm) = 56{,}128$$

$$I_{T1} = \frac{4 \cdot (35{,}019\,cm^2)^2}{56{,}128} = 87{,}395\,cm^4$$

Rechteckprofil

$$\frac{h}{b} = \frac{9\,cm}{5\,cm} = 1{,}8$$

$$\frac{\Delta\alpha}{0{,}3} = \frac{0{,}229 - 0{,}196}{0{,}5} \;;\quad \Delta\alpha = 0{,}020$$

$$\alpha = 0{,}196 + 0{,}02 = 0{,}216$$

$$I_{T2} = 0{,}216 \cdot 9\,cm \cdot (5\,cm)^3 = 243\,cm^4$$

zulässiges Moment

$$\Delta\varphi = 3^\circ \cdot \frac{\pi}{180^\circ} = 0{,}0524$$

$$\frac{M_T}{G} \cdot \left(\frac{l_1}{I_{T1}} + \frac{l_2}{I_{T2}}\right) = \Delta\varphi$$

$$M_{T\,zul} = \frac{G \cdot \Delta\varphi}{\left(\frac{l_1}{I_{T1}} + \frac{l_2}{I_{T2}}\right)}$$

$$M_{Tzul} = \frac{8{,}1 \cdot 10^4 \frac{N}{mm^2} \cdot 0{,}0524}{\frac{2000\,mm}{873950\,mm^4} + \frac{1000\,mm}{243 \cdot 10^4\,mm^4}}$$

$$M_{Tzul} = 1\,572\,010\ N \cdot mm = 1{,}572\ kN \cdot m$$

2) $$\tau_1 = \frac{1{,}5 \cdot 10^6\ N \cdot mm}{2 \cdot 35{,}019 \cdot 10^2\,mm^2 \cdot 4\,mm} = 53{,}54\ \frac{N}{mm^2}$$

$$\frac{h}{b} = 1{,}8\ ; \quad \frac{\Delta\beta}{0{,}3} = \frac{0{,}246 - 0{,}231}{0{,}5}\ ; \quad \Delta\beta = 9 \cdot 10^{-3}$$

$$\beta = 0{,}231 + 9 \cdot 10^{-3} = 0{,}24$$

$$W_T = 0{,}24 \cdot 9\,cm \cdot (5\,cm)^2 = 54\ cm^3$$

$$\tau_2 = \frac{M_T}{W_T} = \frac{1{,}5 \cdot 10^6\ N \cdot mm}{54 \cdot 10^3\,mm^3} = 27{,}78\ \frac{N}{mm^2}$$

3) $$T = \tau \cdot t = 53{,}54\ \frac{N}{mm^2} \cdot 4\,mm = 214{,}16\ \frac{N}{mm}$$

1)

$$\delta = \frac{50\,\frac{N}{mm} \cdot (1500\,mm)^3}{2{,}1 \cdot 10^5\,\frac{N}{mm^2} \cdot 19{,}4 \cdot 10^4\,mm^4} = 4{,}142$$

3|1

Knickbedingung:

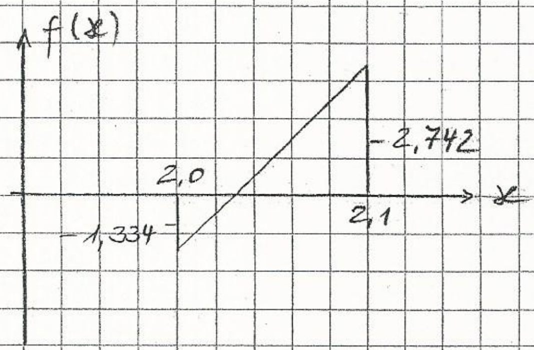
$$f(\varkappa) = 2 \cdot \varkappa^3 + 4{,}142 \cdot \tan\varkappa - 4{,}142 \cdot \varkappa = 0$$

$$f(2{,}0) = -1{,}334$$

$$f(2{,}1) = 2{,}742$$

1. Iteration

$$\frac{\Delta\varkappa}{1{,}334} = \frac{0{,}1}{1{,}334 + 2{,}742}$$



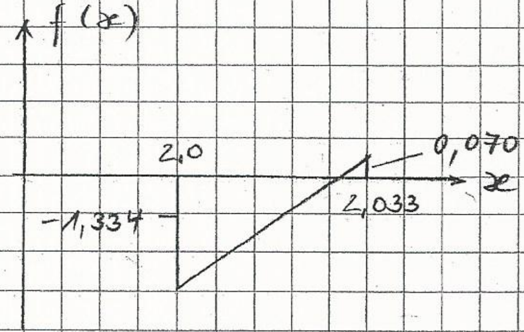
$$\Delta\varkappa = 0{,}033$$

$$\varkappa_{Neu} = 2 + 0{,}033 = 2{,}033$$

$$f(\varkappa_{Neu}) = 0{,}070$$

2. Iteration

$$\frac{\Delta\varkappa}{1{,}334} = \frac{2{,}033 - 2{,}000}{1{,}334 + 0{,}07}$$



$$\Delta\varkappa = 0{,}031$$

$$\varkappa_{Neu} = 2{,}000 + 0{,}031 = 2{,}031$$

$$f(\varkappa_{Neu}) = -0{,}013 \sim 0$$

3/2

$$\sqrt{\frac{F_K}{E \cdot I_y}} \cdot l = 2{,}031$$

$$F_K = \frac{2{,}031^2 \cdot E \cdot I_y}{l^2}$$

$$F_K = \frac{2{,}031^2 \cdot 2{,}1 \cdot 10^5 \frac{N}{mm^2} \cdot 19{,}4 \cdot 10^4 \, mm^4}{(1500 \, mm)^2}$$

$$F_K = 74689 \, N$$

$$\nu_K = \frac{74689 \, N}{20\,000 \, N} = 3{,}73$$

2) $$\frac{E \cdot I_y \cdot \pi^2}{s_K^2} = 74689 \, N$$

$$s_K = \sqrt{\frac{2{,}1 \cdot 10^5 \frac{N}{mm^2} \cdot 19{,}4 \cdot 10^4 \, mm^4 \cdot \pi^2}{74689 \, N}}$$

$$s_K = 2320 \, mm$$

$$i_y = \sqrt{\frac{I_y}{A}} = \sqrt{\frac{19{,}4 \, cm^4}{11 \, cm^2}} = 1{,}328 \, cm = 13{,}28 \, mm$$

$$\lambda = \frac{s_K}{i_y} = \frac{2320 \, mm}{13{,}28 \, mm} = 174{,}7 > \lambda_{grenz} = 105$$

$\Rightarrow$ Elastische Rechnung o.k.