

PROVJERA STABILNOSTI

Hrbat

Visina hrpta duž mosta iznosi 2720 mm. Debljina hrpta je 16 mm.
Hrbat je ukrućen trapeznim ukрутama 300/150/275/8. Broj ukruta je 3.
Razmak poprečnih nosača iznosi 4000 mm.

KLASIFIKACIJA PRESJEKA

$$\sigma_1 = 328.8 \text{ MPa (tlak)}$$

$$\sigma_2 = -277.2 \text{ MPa (vlak)}$$

$$\psi = \frac{\sigma_2}{\sigma_1} = -0.843$$

$$\varepsilon = 0.81 \rightarrow \text{tablica 4.1. (Separat Metalni mostovi str. 13.)}$$

$$\frac{d}{t_w} = \frac{2720}{16} = 170 > 42 \cdot \varepsilon \cdot (0.67 + 0.33 \cdot \psi) = 42 \cdot 0.81 \cdot (0.67 + 0.33 \cdot (-0.843)) = 86.79 ,$$

$$\text{za } \psi > -0.81$$

$\Rightarrow$ poprečni presjek klase 4. Potreban dokaz lokalne stabilnosti.

Dokaz stabilnosti proveden je po načelu ortotropne ploče (prema DIN Fachbericht 103).
Kontrola se provodi za stanje najvećeg tlačnog napona za karakteristična polja.
Hrbat je ukrućen s 3 trapezna uzdužna ukrućenja 300/150/275/8.
Osni razmak ukrućenja je 600 mm. Razmak između poprečnih nosača iznosi 4000 mm.

ZA NEUKRUĆENO POLJE:

$$\sigma_{1Ed} = 328.8 \text{ kN/mm}^2 \text{ (tlak)}$$

$$\sigma_{2Ed} = 85.0 \text{ kN/mm}^2 \text{ (tlak)}$$

$$\psi = \frac{\sigma_2}{\sigma_1} = \frac{85.0}{328.8} = 0.259$$

σ_{1Ed} – veće računsko naprezanje od dva naprezanja istog predznaka

Tlak – pozitivan predznak

Vlak – negativan predznak

$$\tau_{Ed} = 12.1 \text{ kN/mm}^2$$

$$\frac{1}{\alpha_{ult}^2} = \left(\frac{\sigma_{x,Ed}}{f_y} \right)^2 + \left(\frac{\sigma_{z,Ed}}{f_y} \right)^2 - \left(\frac{\sigma_{x,Ed}}{f_y} \right) \cdot \left(\frac{\sigma_{z,Ed}}{f_y} \right) + 3 \cdot \left(\frac{\tau_{Ed}}{f_y} \right)^2$$

$$\Rightarrow \frac{1}{\alpha_{ult}^2} = \left(\frac{\sigma_{x,Ed}}{f_y} \right)^2 + 3 \cdot \left(\frac{\tau_{Ed}}{f_y} \right)^2 = \left(\frac{328.8}{355} \right)^2 + 3 \cdot \left(\frac{12.1}{355} \right)^2 = 0.858 + 0.003 = 0.861$$

$$\alpha_{ult} = 1.078$$

Separat Metalni mostovi tablica 5.2.

$$k_{\sigma} = \frac{8.2}{1.05 + \psi} = \frac{8.2}{1.05 + 0.259} = 6.264$$

$$\frac{a}{b} = \frac{4000}{1078} = 3.711 > 1$$

Separat Metalni mostovi str. 43.

$$k_{\tau} = 5.34 + 4.0 \cdot \left(\frac{b}{a}\right)^2 + k_{rst} = 5.34 + 4.0 \cdot \left(\frac{1078}{4000}\right)^2 = 5.631$$

k_{rst} – uzima se kod ukrućenih polja

$$\sigma_E = 19000 \cdot \left(\frac{t}{b}\right)^2 = 19000 \cdot \left(\frac{1.6}{107.8}\right)^2 = 4.186 \text{ kN/cm}^2$$

$$\sigma_{crit} = k_{\sigma} \cdot \sigma_E = 6.264 \cdot 4.186 = 26.22 \text{ kN/cm}^2$$

$$\tau_{crit} = k_{\tau} \cdot \sigma_E = 5.631 \cdot 4.186 = 23.57 \text{ kN/cm}^2$$

$$\alpha_{crit,x} = \frac{\sigma_{crit,x}}{\sigma_{x,Ed}} = \frac{26.22}{32.88} = 0.797$$

$$\alpha_{crit,\tau} = \frac{\tau_{crit,x}}{\tau_{x,Ed}} = \frac{23.57}{1.21} = 19.479$$

$$\frac{1}{\alpha_{crit}} = \frac{1 + \psi_x}{4 \cdot \alpha_{crit,x}} + \frac{1 + \psi_z}{4 \cdot \alpha_{crit,z}} + \left[\left(\frac{1 + \psi_x}{4 \cdot \alpha_{crit,x}} + \frac{1 + \psi_z}{4 \cdot \alpha_{crit,z}} \right)^2 + \frac{1 - \psi_x}{2 \cdot \alpha_{crit,x}^2} + \frac{1 - \psi_z}{2 \cdot \alpha_{crit,z}^2} + \frac{1}{\alpha_{crit,\tau}^2} \right]^{\frac{1}{2}}$$

$$\Rightarrow \frac{1}{\alpha_{crit}} = \frac{1 + \psi_x}{4 \cdot \alpha_{crit,x}} + \left[\left(\frac{1 + \psi_x}{4 \cdot \alpha_{crit,x}} \right)^2 + \frac{1 - \psi_x}{2 \cdot \alpha_{crit,x}^2} + \frac{1}{\alpha_{crit,\tau}^2} \right]^{\frac{1}{2}}$$

$$\frac{1}{\alpha_{crit}} = \frac{1 + 0.259}{4 \cdot 0.797} + \left[\left(\frac{1 + 0.259}{4 \cdot 0.797} \right)^2 + \frac{1 - 0.259}{2 \cdot 0.797^2} + \frac{1}{19.479^2} \right]^{\frac{1}{2}} = 1.256$$

$$\alpha_{crit} = 0.796$$

$$\bar{\lambda}_p = \sqrt{\frac{\alpha_{ult}}{\alpha_{crit}}} = \sqrt{\frac{1.078}{0.797}} = 1.163$$

$$\rho_x = \frac{\bar{\lambda}_p - 0.055 \cdot (3 + \psi)}{\bar{\lambda}_p^2} = \frac{1.163 - 0.055 \cdot (3 + 0.259)}{1.163^2} = 0.728$$

$$\bar{\lambda}_w = 0.76 \cdot \sqrt{\frac{f_{yw}}{\tau_{crit}}} = 0.76 \cdot \sqrt{\frac{35.5}{23.57}} = 0.933$$

$$\chi_w = 0.83 / \bar{\lambda}_w = 0.83 / 0.933 = 0.890$$

$$\chi_v = \chi_w + \chi_f \leq 1.0 \rightarrow \chi_v = 0.890$$

$$\left(\frac{\sigma_{x,Ed}}{\rho_x \cdot \mathbf{f}_y / \gamma_{M1}}\right)^2 + \left(\frac{\sigma_{z,Ed}}{\rho_z \cdot \mathbf{f}_y / \gamma_{M1}}\right)^2 - \left(\frac{\sigma_{x,Ed}}{\rho_x \cdot \mathbf{f}_y / \gamma_{M1}}\right) \cdot \left(\frac{\sigma_{z,Ed}}{\rho_z \cdot \mathbf{f}_y / \gamma_{M1}}\right) + 3 \cdot \left(\frac{\tau_{Ed}}{\chi_v \cdot \mathbf{f}_y / \gamma_{M1}}\right)^2 \leq 1.0$$

$$\left(\frac{\sigma_{x,Ed}}{\rho_x \cdot f_y / \gamma_{M1}}\right)^2 + 3 \cdot \left(\frac{\tau_{Ed}}{\chi_v \cdot f_y / \gamma_{M1}}\right)^2 \leq 1.0$$

$$\left(\frac{32.88 \cdot 1.1}{0.728 \cdot 35.5}\right)^2 + 3 \cdot \left(\frac{1.21 \cdot 1.1}{0.890 \cdot 35.5}\right)^2 = 1.959 + 0.042 = 2.001 > 1.0$$

Zaključak:

Promatrano neukrućeno polje ne zadovoljava zadane uvjete te je potrebno dodati još ukrućenja.

UKRUĆENO POLJE:

$$\sigma_{1Ed} = 328.8 \text{ kN/mm}^2 \text{ (tlak)}$$

$$\sigma_{2Ed} = -277.2 \text{ kN/mm}^2 \text{ (vlak)}$$

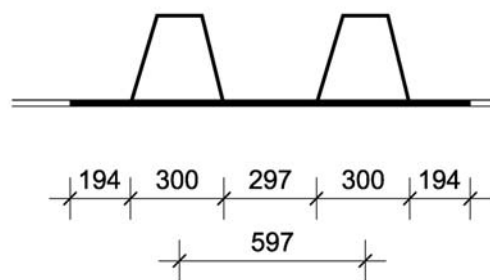
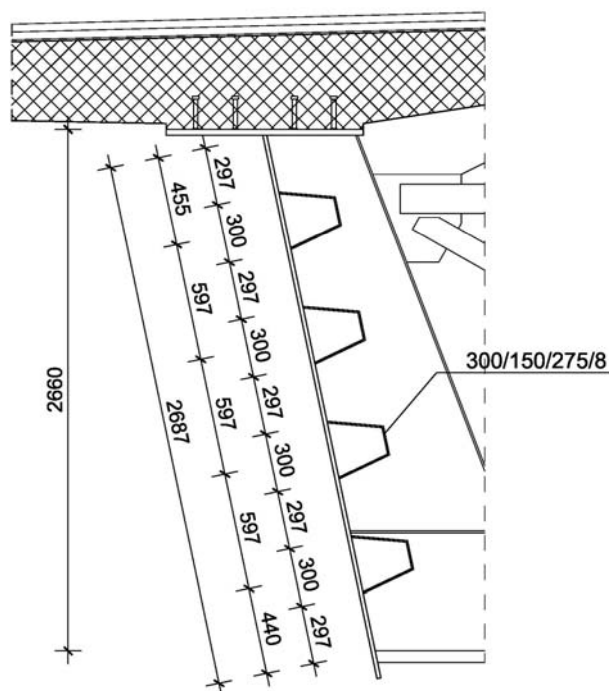
$$\psi = \frac{\sigma_{2Ed}}{\sigma_{1Ed}} = \frac{-277.2}{328.8} = -0.843$$

$$a = 4000 \text{ mm}$$

$$b = 2687 \text{ mm}$$

$t = 16\text{mm}$

$$\sigma_E = 189800 \cdot (t/b)^2 = 189800 \cdot (16/2687)^2 = 6.730 \text{ N/mm}^2$$



n – broj ukruta

A_{sl1} – površina jedne ukrute

A_{sl} – površina svih ukruta s pripadajućim sudjelujućim dijelom hrpta

A_p – površina hrpta

$$A_{sl1} = 5650 \text{ mm}^2$$

$$A_{sl} = 4 \cdot 5650 + (4 \cdot 300 + 3 \cdot 297 + 2 \cdot 194) \cdot 16 = 62264 \text{ mm}^2$$

$$A_p = 16 \cdot 2687 = 42992 \text{ mm}^2$$

$$15 \cdot \varepsilon \cdot t = 15 \cdot 0.81 \cdot 1.6 = 19.44$$

$$e = 275 + 8 - 110 = 173 \text{ mm}$$

$$A' = 597 \cdot 16 = 9552 \text{ mm}^2 \text{ – površina hrpta koji pripada jednoj ukruti}$$

$$I = I_s + \frac{A_{sl1} \cdot A'}{A_{sl1} + A'} \cdot e^2 = 3.33 \cdot 10^7 + \frac{5650 \cdot 9600}{5650 + 9600} \cdot (173)^2 = 1.397 \cdot 10^8 \text{ mm}^4$$

$$I_x = n \cdot I = 4 \cdot 1.397 \cdot 10^8 = 5.588 \cdot 10^8 \text{ mm}^4$$

$$I_p = \frac{b \cdot t^3}{(1 - \nu^2) \cdot 12} = \frac{2687 \cdot 16^3}{(1 - 0.3^2) \cdot 12} = 1.008 \cdot 10^6 \text{ mm}^4$$

$$\alpha = \frac{a}{b} = \frac{4000}{2687} = 1.471$$

$$\delta = \frac{A_{sl1}^*}{A_p} = \frac{22600}{42992} = 0.53$$

$$\gamma = \frac{I_x}{I_p} = \frac{5.588 \cdot 10^8}{1.008 \cdot 10^6} = 554.37$$

$*A_{sl1}$ ili A_{sl} (Računati sa površinom jedne ili svih ukruta prema uputama u literaturi iz kojih su

dijagrami).

$$k_\sigma = 340$$

$$\frac{a}{b} = \frac{4000}{2687} = 1.49$$

$$k_\tau = 175$$

k_σ i k_τ uzimaju se iz odgovarajućih tablica i dijagrama (npr. Klöppel/Möller)

$$\sigma_E = 19000 \cdot \left(\frac{t}{b} \right)^2 = 19000 \cdot \left(\frac{1.6}{268.7} \right)^2 = 0.674 \text{ kN/cm}^2$$

$$\sigma_{crit} = k_{\sigma} \cdot \sigma_E = 340 \cdot 0.674 = 229.16 \text{ kN/cm}^2$$

$$\tau_{crit} = k_{\tau} \cdot \sigma_E = 175 \cdot 0.674 = 117.95 \text{ kN/cm}^2$$

$$\alpha_{crit,x} = \frac{\sigma_{crit,x}}{\sigma_{x,Ed}} = \frac{229.16}{32.88} = 6.970$$

$$\alpha_{crit,\tau} = \frac{\tau_{crit,x}}{\tau_{x,Ed}} = \frac{117.95}{1.21} = 97.48$$

$$\frac{1}{\alpha_{crit}} = \frac{1+\psi_x}{4 \cdot \alpha_{crit,x}} + \frac{1+\psi_z}{4 \cdot \alpha_{crit,z}} + \left[\left(\frac{1+\psi_x}{4 \cdot \alpha_{crit,x}} + \frac{1+\psi_z}{4 \cdot \alpha_{crit,z}} \right)^2 + \frac{1-\psi_x}{2 \cdot \alpha_{crit,x}^2} + \frac{1-\psi_z}{2 \cdot \alpha_{crit,z}^2} + \frac{1}{\alpha_{crit,\tau}^2} \right]^{1/2}$$

$$\Rightarrow \frac{1}{\alpha_{crit}} = \frac{1+\psi_x}{4 \cdot \alpha_{crit,x}} + \left[\left(\frac{1+\psi_x}{4 \cdot \alpha_{crit,x}} \right)^2 + \frac{1-\psi_x}{2 \cdot \alpha_{crit,x}^2} + \frac{1}{\alpha_{crit,\tau}^2} \right]^{1/2}$$

$$\frac{1}{\alpha_{crit}} = \frac{1-0.843}{4 \cdot 6.970} + \left[\left(\frac{1-0.843}{4 \cdot 6.970} \right)^2 + \frac{1+0.843}{2 \cdot 6.970^2} + \frac{1}{97.48^2} \right]^{1/2} = 0.144$$

$$\alpha_{crit} = 6.93$$

$$\bar{\lambda}_p = \sqrt{\frac{\alpha_{ult}}{\alpha_{crit}}} = \sqrt{\frac{1.078}{6.93}} = 0.394$$

$$\rho_x = \frac{\bar{\lambda}_p - 0.055 \cdot (3 + \psi)}{\bar{\lambda}_p^2} = \frac{0.394 - 0.055 \cdot (3 - 0.843)}{0.394^2} = 1.774 \Rightarrow \rho_x = 1.00$$

$$\sigma_{cr,st} = \frac{\pi^2 \cdot E \cdot I_{sl}}{A_{sl} \cdot a^2} = \frac{\pi^2 \cdot 21000 \cdot 55880}{622.6 \cdot 400^2} = 116.14 \text{ kN/cm}^2$$

$$\xi = \frac{\sigma_{cr,p}}{\sigma_{cr,st}} - 1 = \frac{229.16}{116.14} - 1 = 0.973$$

$$\chi_v = \chi_w = \frac{0.83}{\bar{\lambda}_p} = \frac{0.83}{0.394} = 2.11 \Rightarrow \chi_v = \chi_w = 1.0$$

$$\left(\frac{\sigma_{x,Ed}}{\rho_x \cdot f_y / \gamma_{M1}} \right)^2 + \left(\frac{\sigma_{z,Ed}}{\rho_z \cdot f_y / \gamma_{M1}} \right)^2 - \left(\frac{\sigma_{x,Ed}}{\rho_x \cdot f_y / \gamma_{M1}} \right) \cdot \left(\frac{\sigma_{z,Ed}}{\rho_z \cdot f_y / \gamma_{M1}} \right) + 3 \cdot \left(\frac{\tau_{Ed}}{\chi_v \cdot f_y / \gamma_{M1}} \right)^2 \leq 1.0$$

$$\left(\frac{\sigma_{x,Ed}}{\rho_x \cdot f_y / \gamma_{M1}} \right)^2 + 3 \cdot \left(\frac{\tau_{Ed}}{\chi_v \cdot f_y / \gamma_{M1}} \right)^2 \leq 1.0$$

$$\left(\frac{32.88 \cdot 1.1}{1.0 \cdot 35.5} \right)^2 + 3 \cdot \left(\frac{1.21 \cdot 1.1}{1.0 \cdot 35.5} \right)^2 = 1.04 + 0.04 = 1.08 > 1.0$$

Zaključak: provjera nije zadovoljena