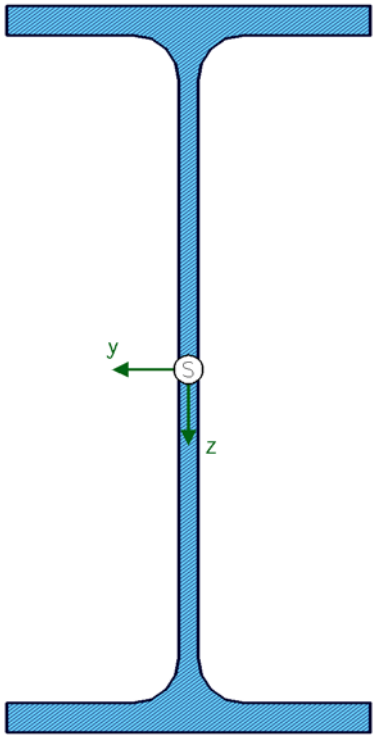
verification of stability EC 3-1-2 (12.10), NA: Deutschland 4H-EC3ST version: 12/2021-1b

1. input data

1.1. general information
verifications of stability acc. to EN 1993-1-1
c/t-verification (classification of cross-section)
lateral torsional buckling with the method of fictitious bars for N+My, interaction proof only with eqn. (6.61)

1.2. safety factor of material
resistance of cross-sections γ_{M0} = 1.00
resistance of members in stability failure γ_{M1} = 1.10

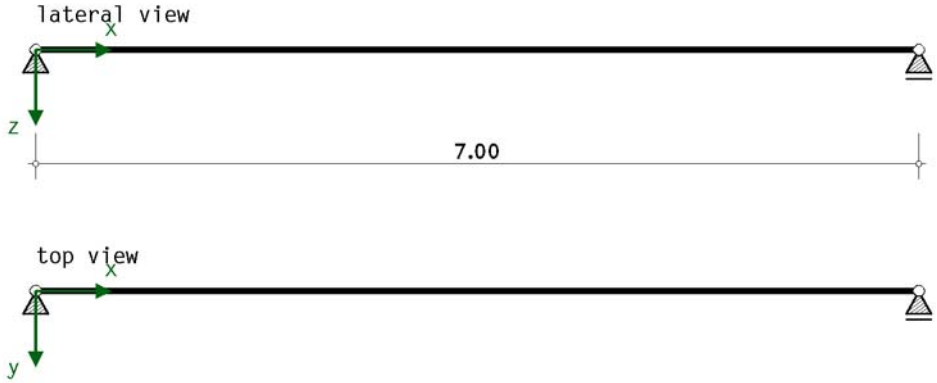
1.3. cross-section
material: S355 (St52) (E = 210000 N/mm^2, G = 80769 N/mm^2, $f_{y,k}$ = 355 N/mm^2)
section: IPE240
section scale 1:2.5



1.4. cross-section values (related to the centre of gravity S)
I_y = 3890.0 cm^4, I_z = 284.0 cm^4, I_ζ = 3890.0 cm^4, I_η = 284.0 cm^4, α = 0.0°
I_ω = 37390.0 cm^6, I_T = 12.9 cm^4
W_y = 324.0 cm^3, W_z = 47.3 cm^3, $W_{pl,y}$ = 367.0 cm^3, $W_{pl,z}$ = 74.0 cm^3
$z_{m,y}$ = 0.0 mm, $z_{m,z}$ = -0.0 mm, A = 39.1 cm^2, cross-section is torsionally soft

1.5. load application point (related to the center of the surrounding rectangle)
y_{load} = 0.0 mm (centroid)
z_{load} = -120.0 mm (upper edge of cross-section)

1.6. static system
all bearings with fork restraint, bar length 7.000 [m]
no intermediate bearing in z-direction, no intermediate bearing in y-direction



1.7. buckling coefficients

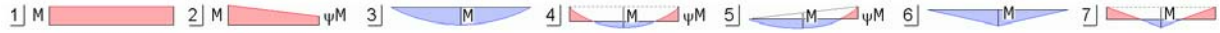
⊥ y-axis: β_y = 1.000, ⊥ z-axis: β_z = 1.000
warping restraint intensity β_0 = 1.000

1.8. design member forces (load combinations)

Lk	N_d kN	type -y-	$M_{0y,d}$ kNm	ψ_y -	$k_{c,y}$ -	ζ_y -
1	230.70	5	183.75	0.708	0.910	1.778
2	100.00	3	50.00	1.000	0.940	1.128

N_d: constant axial force in the bar; type (y): type of moment curves each direction; $M_{0y,d,\psi y}$: reference values of moment curve
$k_{C,y,\zeta y}$: coefficients for calculation

types of moment curves



1.9. torsionally elastic bedding induced by trapezoidal sheets , t_{nom} = 1.00 mm

shear field stiffness

ideal shear modulus $G_S = 10^4 / (K_1+K_2/L_S)$ = 8000.0 kN/m
with K_1 = 1.200 m/kN, K_2 = 1.000 m²/kN, L_S = 20.000 m
shear field stiffness $S = G_S \cdot L_S$ = 160000.0 kN
shear field stiffness beam $S_i = S/n$ = 26666.7 kN with n = 6
required shear field stiffness of each beam req $S_i = (E \cdot I_\omega \cdot \pi^2/L^2 + G \cdot I_T + E \cdot I_{zI} \cdot \pi^2/L^2 \cdot h^2/4) \cdot 70/h^2$ = 16686.5 kN
with h = 240.0 mm, L = 7.000 m, I_ω = 37390.00 cm⁶, I_T = 12.90 cm⁴, I_z = 284.00 cm⁴
exist S_i = 26666.7 kN ≥ req S_i = 16686.5 kN ⇒ fixed rotation axis

torsionally elastic bedding

section parameters (userdefined)
C_{100} = 5.2 kNm/m, $b_{T,max}$ = 40 mm acc. to EC 3-1-3, tab. 10.3 line 1
A = 12.00 kN/m (superimposed load between plate and beam), b_R = 280.0 mm, b_T = 40.0 mm
E = 210000 N/mm², c = 7.000 m (buckling length), I_{eff} = 1230000 mm⁴, s = 4.000 m (support width)
$C_{D,B}$: calculation acc. to DIN 18800, $C_{D,C}$: end field and equidirectional rotation of beams
k_{ba} = 1.440, k_t = 1.372, k_{bR} = 0.661, k_A = 2.045, k_{bT} = 1.000
$C_{D,A}$ = 13.884 kNm/m, $C_{D,B}$ = 53.880 kNm/m, $C_{D,C}$ = 258.300 kNm/m, C_D = 10.587 kNm/m ⇒ **I_T^* = 77.97 cm⁴**
$I_T^* = I_T + \Delta I_T$ with I_T = 12.90 cm⁴, $\Delta I_T = (C_D \cdot c^2)/(G \cdot \pi^2)$ = 65.07 cm⁴, C_D = 10.587 kNm/m, c = 7.000 m

2. verifications

2.1. classification of cross-section

2.1.1. load combination 1 ⇒ section class 1

no	c mm	t mm	c/t -	ε -	σ_1 N/mm²	σ_2 N/mm²	tab 5.2	α -	ψ -	k_σ -	class -
1	41.9	9.8	4.28	0.814	443.94	443.94	single 1/1	---	---	---	1
2	41.9	9.8	4.28	0.814	443.94	443.94	single 1/1	---	---	---	1
3	190.4	6.2	30.71	0.814	377.38	-259.38	both 3/1	0.775	---	---	1
4	41.9	9.8	4.28	0.814	-325.93	-325.93	---------	---	---	---	---
5	41.9	9.8	4.28	0.814	-325.93	-325.93	---------	---	---	---	---

2.1.2. load combination 2 ⇒ section class 1

no	c mm	t mm	c/t -	ε -	σ_1 N/mm²	σ_2 N/mm²	tab 5.2	α -	ψ -	k_σ -	class -
1	41.9	9.8	4.28	0.814	173.52	173.52	single 1/1	---	---	---	1
2	41.9	9.8	4.28	0.814	173.52	173.52	single 1/1	---	---	---	1
3	190.4	6.2	30.71	0.814	147.94	-96.79	both 3/1	0.619	---	---	1
4	41.9	9.8	4.28	0.814	-122.37	-122.37	---	---	---	---	---
5	41.9	9.8	4.28	0.814	-122.37	-122.37	---	---	---	---	---

compressive stresses have a positive sign acc. to EC 3.
verifications are carried out in the **specified** cross-section class 2: $U_{c/t} = 0.751 < 1$ ok

2.2. lateral torsional buckling

2.2.1. flexural buckling for normal force

2.2.1.1. utilisations

Lk	N_d kN	U_y -	U_z -
1	0.00	0.000	0.000
2	100.00	**0.110**	**1.009**

2.2.2. lateral torsional buckling for bending around y-axis

2.2.3. load combination 1

required torsionally elastic bedding, to avoid torsional buckling, req $C_{\vartheta,k} = M_{pl,y,k}^2/(E \cdot I_z) \cdot K_\vartheta \cdot K_v = 1.138$ kNm/m
with $M_{pl,y,k} = 130.29$ kNm, $E = 210000.0$ N/mm², $I_z = 284.00$ cm⁴
$K_\vartheta = 0.04$ for buckling curve b (fixed rotation axis), $K_v = 1.00$ for section class 2 (elastic calculation)
$C_D = 10.587$ kNm/m ≥ req $C_{\vartheta,k} = 1.138$ kNm/m ⇒ verification of torsional buckling not required

2.2.4. load combination 2

required torsionally elastic bedding, to avoid torsional buckling, req $C_{\vartheta,k} = M_{pl,y,k}^2/(E \cdot I_z) \cdot K_\vartheta \cdot K_v = 0.000$ kNm/m
with $M_{pl,y,k} = 130.29$ kNm, $E = 210000.0$ N/mm², $I_z = 284.00$ cm⁴
$K_\vartheta = 0.00$ for buckling curve b (fixed rotation axis), $K_v = 1.00$ for section class 2 (elastic calculation)
req $C_{\vartheta,k} = 0$ ⇒ verification of torsional buckling required
moment coefficients for torsionally elastic bedding and shear field stiffness:
$\zeta_{0\vartheta} = 1.128$, $\zeta_{0S} = 1.128$
critical moment due to torsionally elastic bedding:
$M_{cr,\vartheta} = \alpha_{cr} \cdot M_{Ed} = 91.54$ kNm with $\alpha_{cr} = 1.831$, $M_{Ed} = 50.00$ kNm
critical moment due to shear field stiffness:
$M_{cr,S} = \alpha_{cr} \cdot M_{Ed} = 7219.58$ kNm with $\alpha_{cr} = 144.392$, $M_{Ed} = 50.00$ kNm
critical moment: $M_{cr} = M_{cr,\vartheta} + M_{cr,S} = 7311.13$ kNm

2.2.4.1. utilisations

Lk	M_{cr} kNm	λ_{LT} -	f -	Φ_{LT} -	χ_{LT} m	$\chi_{LT,mod}$ m	M_{Ed} kNm	$M_{b,Rd}$ kNm	U -
1	---	---	---	---	---	---	---	---	---
2	7311.13	0.133	0.997	0.461	1.000	1.000	50.00	118.44	**0.422**

2.2.5. interaction

Lk	eqn.	C_{my} -	k_{yy} -	C_{mLT} -	k_{zy} -	U -
1	(6.61)	0.000	0.000	0.000	---	0.000
	(6.62)	---	---	0.000	0.000	0.000
2	(6.61)	0.950	1.025	0.950	---	0.542
	(6.62)	---	---	0.950	0.856	**1.371**

max U = 1.371 > 1 not ok !!

3. final result

maximum utilisation U = 1.371 > 1 not ok !!
c/t-utilisation U = 0.751 < 1 ok

resistance not ensured !!