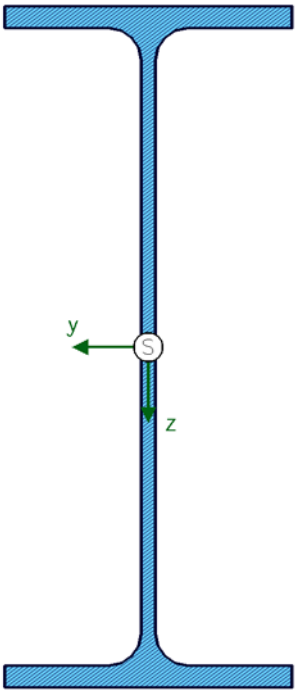
verification of stability EC 3-1-2 (12.10), NA: Deutschland 4H-EC3ST version: 12/2021-1b

# 1. input data

### 1.1. general information
verifications of stability acc. to EN 1993-1-1
c/t-verification (classification of cross-section)
verification at the end of bar
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 $\gamma_{M0}$ = 1.00
resistance of members in stability failure $\gamma_{M1}$ = 1.10

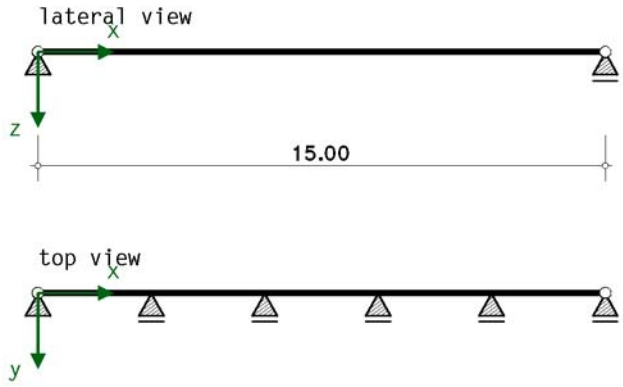
### 1.3. cross-section
material: S355 (St52) (E = 210000 N/mm$^2$, G = 80769 N/mm$^2$, $f_{y,k}$ = 355 N/mm$^2$)
section: IPE450
**section scale 1:5.0**




### 1.4. cross-section values (related to the centre of gravity S)
$I_y$ = 33740.0 cm$^4$, $I_z$ = 1680.0 cm$^4$, $I_\zeta$ = 33740.0 cm$^4$, $I_\eta$ = 1680.0 cm$^4$, $\alpha$ = 0.0°
$I_\omega$ = 791000.0 cm$^6$, $I_T$ = 67.1 cm$^4$
$W_y$ = 1500.0 cm$^3$, $W_z$ = 176.0 cm$^3$, $W_{pl,y}$ = 1702.0 cm$^3$, $W_{pl,z}$ = 275.0 cm$^3$
$z_{m,y}$ = 0.0 mm, $z_{m,z}$ = 0.0 mm, A = 98.8 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)
$z_{load}$ = -225.0 mm (upper edge of cross-section)

### 1.6. static system
all bearings with fork restraint, bar length 15.000 [m]
no intermediate bearing in z-direction, 4 intermediate bearing in y-direction




### 1.7. buckling coefficients

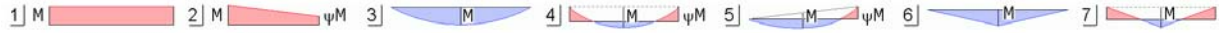
⊥ y-axis: $\beta_y$ = 1.000, ⊥ z-axis: $\beta_z$ = 1.000
warping restraint intensity $\beta_0$ = 1.000

### 1.8. design member forces (load combinations)

| Lk | $N_d$ kN | type -y- | $M_{0y,d}$ kNm | $\psi_y$ - | $k_{c,y}$ - | $\zeta_y$ - | $V_{z,d}$ kN |
|---|---|---|---|---|---|---|---|
| 1 | 24.00 | 5 | 393.80 | 0.798 | 0.910 | 1.993 | -230.70 |

$N_d$: 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; $V_{z,d}$: maximum shear force at the end of bar

types of moment curves




### 1.9. torsionally elastic bedding induced by 4 cross beams

section IPE180
h = 180.0 mm, $t_w$ = 5.3 mm, $b_f$ = 91.0 mm, $t_f$ = 8.0 mm, r = 9.0 mm
A = 23.95 cm², $I_y$ = 1316.94 cm⁴, $I_z$ = 100.83 cm⁴, $I_T$ = 5.15 cm⁴, $y_s$ = -45.5 mm, $z_s$ = 90.0 mm
E = 210000 N/mm², c = 3.000 m (distance), $I_y$/c = 4389797 mm³, s = 6.000 m (support width)
$C_{D,B}$: calculation acc. to Lindner, $C_{D,C}$: inner field
$C_{D,B}$ = 26.620 kNm/m, $C_{D,C}$ = 614.572 kNm/m, $C_D$ = 25.515 kNm/m ⇒ **$I_T^*$ = 95.91 cm⁴**
$I_T^* = I_T + \Delta I_T$ with $I_T$ = 67.10 cm⁴, $\Delta I_T = (C_D \cdot c^2)/(G \cdot \pi^2)$ = 28.81 cm⁴, $C_D$ = 25.515 kNm/m, c = 3.000 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 - | $\sigma_1$ N/mm² | $\sigma_2$ N/mm² | tab 5.2 | α - | ψ - | $k_\sigma$ - | class - |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 69.3 | 14.6 | 4.75 | 0.814 | 205.19 | 205.19 | single 1/1 | --- | --- | --- | 1 |
| 2 | 69.3 | 14.6 | 4.75 | 0.814 | 205.19 | 205.19 | single 1/1 | --- | --- | --- | 1 |
| 3 | 378.8 | 9.4 | 40.30 | 0.814 | 178.84 | -173.98 | both 3/1 | 0.509 | --- | --- | 1 |
| 4 | 69.3 | 14.6 | 4.75 | 0.814 | -200.34 | -200.34 | --- | --- | --- | --- | --- |
| 5 | 69.3 | 14.6 | 4.75 | 0.814 | -200.34 | -200.34 | --- | --- | --- | --- | --- |

compressive stresses have a positive sign acc. to EC 3.
verifications are carried out in the **specified** cross-section class 2: **$U_{c/t}$ = 0.611 < 1** ok

### 2.2. verification

| no | $N_{Ed}$ kN | $M_{y,Ed}$ kNm | $V_{z,Ed}$ kN | $\sigma_x$ N/mm² | τ N/mm² | $\sigma_v$ N/mm² | U - |
|---|---|---|---|---|---|---|---|
| 1 | -24.00 | 314.25 | -230.70 | --- | --- | --- | **0.595** |

**max U = 0.595 < 1** ok

### 2.3. lateral torsional buckling

#### 2.3.1. flexural buckling for normal force

$I_p$ = 35420 cm⁴, $I_T$ = 96 cm⁴, $i_p^2$ = 35850 mm, $c^2$ = 67105 mm², $i_m^2$ = 35850 mm²
flexural buckling around y-axis:
$i_y$ = 184.8 mm, $\beta_z$ = 1.00 (⊥ z-axis), $L_{cr,z}$ = 3.000 m, $\lambda_1$ = 76.409
$\lambda_y$ = 1.062, y-buckling curve a ⇒ $\alpha_y$ = 0.21, $\Phi_y$ = 1.155, $\chi_y$ = 0.622, **$N_{by,Rd}$ = 1983.40 kN**
flexural buckling around z-axis:
$i_z$ = 41.2 mm, $\beta_y$ = 1.00 (⊥ y-axis), $L_{cr,y}$ = 15.000 m, $\lambda_1$ = 76.409

$\lambda_z$ = 0.952, z-buckling curve b ⇒ $\alpha_z$ = 0.34, $\Phi_z$ = 1.081, $\chi_z$ = 0.628, **$N_{bz,Rd}$ = 2001.21 kN**

#### 2.3.1.1. utilisations

| Lk | $N_d$ kN | $U_y$ - | $U_z$ - |
|---|---|---|---|
| 1 | 24.00 | **0.012** | **0.012** |

### 2.3.2. lateral torsional buckling for bending around y-axis

$c^2$ = 67105 mm², buckling curve c ⇒ $\alpha_{LT}$ = 0.49, $N_{cr}$ = 3868.88 kN

#### 2.3.2.1. utilisations

| Lk | $M_{cr}$ kNm | $\lambda_{LT}$ - | f - | $\Phi_{LT}$ - | $\chi_{LT}$ m | $\chi_{LT,mod}$ m | $M_{Ed}$ kNm | $M_{b,Rd}$ kNm | U - |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 835.08 | 0.851 | 0.955 | 0.882 | 0.732 | 0.766 | 314.25 | 420.87 | **0.747** |

### 2.3.3. interaction

| Lk | eqn. | $C_{my}$ - | $k_{yy}$ - | $C_{mLT}$ - | $k_{zy}$ - | U - |
|---|---|---|---|---|---|---|
| 1 | (6.61) | 0.400 | 0.404 | 0.950 | --- | 0.314 |
| | (6.62) | --- | --- | 0.950 | 0.998 | **0.757** |

**max U = 0.757 < 1** ok

## 3. final result

| | |
|---|---|
| maximum utilisation | U = 0.757 < 1 ok |
| c/t-utilisation | U = 0.611 < 1 ok |

**verification succeeded**

## 4. Selected Design Parameters of the National Annex

DIN EN 1993-1-1 (EC 3, Hochbau), NA Deutschland

| chapter | value | definition |
|---|---|---|
| 6.1(1) | permanent/transient situation | partial safety factors for structural steel |
| | $\gamma_{M0}$ = 1.00 | collapse of cross-section |
| | $\gamma_{M1}$ = 1.10 | instability |
| | $\gamma_{M2}$ = 1.25 | fracture cross-sections in tension |
| | accidental situation | partial safety factors for structural steel |
| | $\gamma_{M0}$ = 1.00 | collapse of cross-section |
| | $\gamma_{M1}$ = 1.00 | instability |
| | $\gamma_{M2}$ = 1.25 | fracture cross-sections in tension |
| 6.3.2.2(2) | factor f to modify $\chi_{LT}$ | lateral torsional buckling general case |
| 6.3.2.3(1) | $\lambda_{LT,0}$ = 0.40 | slenderness eqn. (6.75) |
| | $\beta$ = 0.75 | correction factor eqn. (6.75) |
| 6.3.2.3(2) | coefficient $k_c$ from tab. 6.6 | calculation of the reduction factor $\chi_{LT}$ |

DIN EN 1993-1-2 (EC 3, Brandfall), NA Deutschland

| chapter | value | definition |
|---|---|---|
| 2.3(1) | event of fire | partial safety factor for |
| | $\gamma_{M,fi}$ = 1.00 | mechanical failure |

## 5. Regulations


DIN EN 1990, Eurocode 0: Grundlagen der Tragwerksplanung;
Deutsche Fassung EN 1990:2002 + A1:2005 + A1:2005/AC:2010, Ausgabe Dezember 2010
DIN EN 1990/NA, Nationaler Anhang zur DIN EN 1990, Ausgabe Dezember 2010

DIN EN 1993-1-1, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau;
Deutsche Fassung EN 1993-1-1:2005 + AC:2009, Ausgabe Dezember 2010
DIN EN 1993-1-1/A1, Ergänzungen zur DIN EN 1993-1-1, Ausgabe Juli 2014
DIN EN 1993-1-1/NA, Nationaler Anhang zur DIN EN 1993-1-1, Ausgabe Dezember 2018

J. Lindner & J.S. Schmidt: Biegedrillknicken von I-Trägern unter Berücksichtigung wirklichkeitsnaher Lasteinleitung, Der Stahlbau Heft 9, 1982