## detailed problems acc. to Eurocode 3

EC 3-1-5 (12.10), NA: Deutschland

**steel grade**

steel grade S 355

**cross-section**

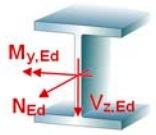
beam: section parameters (box section):
h = 2424.0 mm, $t_w$ = 8.0 mm (2x), $b_f$ = 2716.0 mm, $b_ü$ = 22.0 mm, $t_f$ = 12.0 mm
longitudinal stiffeners:
beam web: number $n_{st}$ = 2
section parameters (trapezoidal section):
h = 230.0 mm, $b_f$ = 135.0 mm, t = 8.0 mm, b = 300.0 mm
distance of the first stiffener to the top edge of beam $d_{st,0}$ = 712.0 mm
constant distance of stiffeners $d_{st}$ = 1000.0 mm
flange top: number $n_{st}$ = 3
section parameters (trapezoidal section):
h = 275.0 mm, $b_f$ = 135.0 mm, t = 6.0 mm, b = 300.0 mm
distance of the first stiffener to the edge of flange right (without projection) $d_{st,0}$ = 608.0 mm
constant distance of stiffeners $d_{st}$ = 750.0 mm
flange bottom: number $n_{st}$ = 3
section parameters (trapezoidal section):
h = 275.0 mm, $b_f$ = 135.0 mm, t = 6.0 mm, b = 300.0 mm
distance of the first stiffener to the edge of flange right (without projection) $d_{st,0}$ = 608.0 mm
constant distance of stiffeners $d_{st}$ = 750.0 mm

**parameters**

length of buckling field a = 400.0 cm
method of reduced stresses
rigid support stiffener
verification at intermediate support
effective girder length (shear distortion) $L_e$ = 2890.0 cm
calculation of buckling factors with 4H-tool

**loading**

internal forces and moments refering to the stiffened cross-section:
Lk 1: $M_{Ed}$ = -28100.0 kNm $V_{Ed}$ = 3300.0 kN

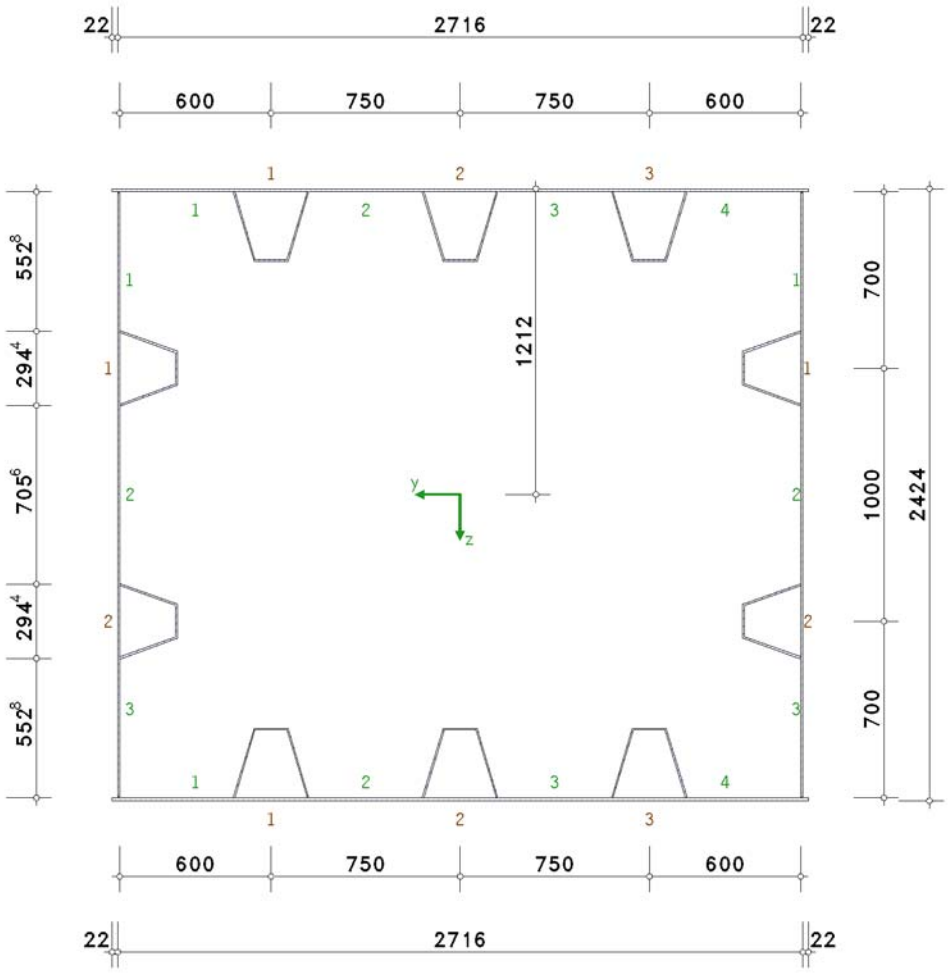



**partial safety factors for material**

resistance of cross-sections $\gamma_{M0}$ = 1.00
resistance of members in stability failure $\gamma_{M1}$ = 1.10

## verifications of buckling resistance

assumption: flange induced web buckling is excluded.
assumption: local buckling of stiffeners is excluded.
assumption: plate area is supported rigidly.




Lk 1:

**method of reduced stresses**

EC 3-convention, compressive stresses positive

shear distortion

flange top: $b_0 = b_{fo}/2 = 1354.0$ mm $\geq L_e/50 = 578.0$ mm:

factor $\beta_{ult} = \beta^{\kappa} = 0.985$, $\beta = 0.759$, $\kappa = 0.06$

effective width $b_{eff} = 2 \cdot \beta_{ult} \cdot b_0 = 2675.2$ mm, $\beta\backslash ult = 0.985$

flange bottom: $b_0 = b_{fu}/2 = 1354.0$ mm $\geq L_e/50 = 578.0$ mm:

factor $\beta_{ult} = \beta^{\kappa} = 0.985$, $\beta = 0.759$, $\kappa = 0.06$

effective width $b_{eff} = 2 \cdot \beta_{ult} \cdot b_0 = 2675.2$ mm, $\beta\backslash ult = 0.985$

replaced width from shear distortion $b_{fo} = 2675.2$ mm, $b_{fu} = 2675.2$ mm

cross-sectional properties: $A = 1483.12$ cm², $z_s = 1212.0$ mm, $I_y = 14573090.09$ cm⁴, $y_s = 0.0$ mm, $I_z = 14603346.59$ cm⁴

maximum/minimum stresses: $\sigma_o = -233.7$ N/mm², $\sigma_u = 233.7$ N/mm², $\tau = 85.9$ N/mm²

section class: 4 $\Rightarrow$ verification of buckling resistance required !!

buckling factors (4H-tool)

web: $\alpha_{cr} = 0.672$, $\alpha_{cr,1} = 7.907$, $\alpha_{cr,2} = 1.543$, $\alpha_{cr,3} = 0.804$

flange top: $\alpha_{cr} = 0.000$, $\alpha_{cr,1} = 0.000$, $\alpha_{cr,2} = 0.000$, $\alpha_{cr,3} = 0.000$, $\alpha_{cr,4} = 0.000$

flange bottom: $\alpha_{cr} = 1.007$, $\alpha_{cr,1} = 2.534$, $\alpha_{cr,2} = 2.295$, $\alpha_{cr,3} = 2.295$, $\alpha_{cr,4} = 2.534$

reduced stresses

web:

single buckling field 1:

$\sigma_{Ed} = 124.8$ N/mm², $\tau_{Ed} = 85.9$ N/mm²

non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 0.481$, $\alpha_{ult} = 1.828$, $\alpha_{cr} = 7.907$ (4H-tool)

reduction factor $\rho = 1$ for $\lambda_p < 0.5 + (0.085 - 0.055 \cdot \psi)^{1/2} = 0.500$, $\psi = 2.000$

reduction factor $\chi_w = 1.200 = \eta$ for $\lambda_w < 0.83/\eta = 0.692$

ultimate buckling stresses $\sigma_{Rd} = \rho \cdot f_y/\gamma_{M1} = 322.7$ N/mm², $\tau_{Rd} = \chi_w \cdot f_y/(3^{1/2} \cdot \gamma_{M1}) = 223.6$ N/mm²

verification: $((\sigma_{Ed}/\sigma_{Rd})^2 + (\tau_{Ed}/\tau_{Rd})^2)^{1/2} = 0.545 < 1$ ok.

buckling fields of stiffener 1: local buckling excluded ok.

single buckling field 2:

$\sigma_{Ed} = 68.0$ N/mm², $\tau_{Ed} = 85.9$ N/mm²

non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 1.186$, $\alpha_{ult} = 2.169$, $\alpha_{cr} = 1.543$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.765 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.874$, $\psi = -1.000$
reduction factor $\chi_w = 1.37/(0.7+\lambda_w) = 0.727$ for $\lambda_w \ge 1.08$
ultimate buckling stresses $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 247.0$ N/mm², $\tau_{Rd} = \chi_w\cdot f_y/(3^{1/2}\cdot\gamma_{M1}) = 135.4$ N/mm²
verification: $((\sigma_{Ed}/\sigma_{Rd})^2 + (\tau_{Ed}/\tau_{Rd})^2)^{1/2} = 0.692 < 1$ ok.

buckling fields of stiffener 2: local buckling excluded ok.

single buckling field 3:

$\sigma_{Ed} = 231.4$ N/mm², $\tau_{Ed} = 85.9$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 1.267$, $\alpha_{ult} = 1.290$, $\alpha_{cr} = 0.804$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.668 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.735$, $\psi = 0.539$
reduction factor $\chi_w = 1.37/(0.7+\lambda_w) = 0.697$ for $\lambda_w \ge 1.08$
ultimate buckling stresses $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 215.6$ N/mm², $\tau_{Rd} = \chi_w\cdot f_y/(3^{1/2}\cdot\gamma_{M1}) = 129.8$ N/mm²
verification: $((\sigma_{Ed}/\sigma_{Rd})^2 + (\tau_{Ed}/\tau_{Rd})^2)^{1/2} = 1.261 > 1$ not ok. !!

overall buckling field:

$\sigma_{Ed} = 231.4$ N/mm², $\tau_{Ed} = 85.9$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 1.386$, $\alpha_{ult} = 1.290$, $\alpha_{cr} = 0.672$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.664 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.874$, $\psi = -1.000$
critical buckling stress $\sigma_{cr,p} = \alpha_{cr}\cdot\sigma_{Ed}' = 155.5$ N/mm², $\sigma_{Ed}' = 231.4$ N/mm²
critical buckling stress $\sigma_{cr,c} = \sigma_{cr,c,sl}\cdot\sigma_1/\sigma_{sl} = 2297.6$ N/mm², $\sigma_1/\sigma_{sl} = 2.400$, $\sigma_{cr,c,sl} = 957.3$ N/mm²
reduction factor $\chi_c = 0.369 \le 1$ for $\lambda_c > 0.2$
final reduction factor $\rho = (\rho - \chi_c)\cdot\xi\cdot(2-\xi) + \chi_c = 0.369$ with $\xi = 0.000$
reduction factor $\chi_w = 1.37/(0.7+\lambda_w) = 0.657$ for $\lambda_w \ge 1.08$
ultimate buckling stresses $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 119.0$ N/mm², $\tau_{Rd} = \chi_w\cdot f_y/(3^{1/2}\cdot\gamma_{M1}) = 122.4$ N/mm²
verification: $((\sigma_{Ed}/\sigma_{Rd})^2 + (\tau_{Ed}/\tau_{Rd})^2)^{1/2} = 2.067 > 1$ not ok. !!

flange induced web buckling:

$h_w/t_w = 300.00 < (k\cdot E)/(f_y\cdot(A_w/A_{fc})^{1/2}) = 355.84$ ok. with k = 0.55, $A_w = 192.00$ cm², $A_{fc} = 160.51$ cm²

flange top:

$\sigma_{Ed} = -232.5$ N/mm² $\le 0 \Rightarrow$ verification not required

flange bottom:

single buckling field 1:

$\sigma_{Ed} = 232.5$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 0.776$, $\alpha_{ult} = 1.527$, $\alpha_{cr} = 2.534$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.923 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.673$, $\psi = 1.000$
ultimate buckling stress $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 297.9$ N/mm²
verification: $\sigma_{Ed}/\sigma_{Rd} = 0.780 < 1$ ok.

buckling fields of stiffener 1: local buckling cannot be excluded

single buckling field 2:

$\sigma_{Ed} = 232.5$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 0.816$, $\alpha_{ult} = 1.527$, $\alpha_{cr} = 2.295$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.895 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.673$, $\psi = 1.000$
ultimate buckling stress $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 289.0$ N/mm²
verification: $\sigma_{Ed}/\sigma_{Rd} = 0.805 < 1$ ok.

buckling fields of stiffener 2: local buckling cannot be excluded

single buckling field 3:

$\sigma_{Ed} = 232.5$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 0.816$, $\alpha_{ult} = 1.527$, $\alpha_{cr} = 2.295$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.895 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.673$, $\psi = 1.000$
ultimate buckling stress $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 289.0$ N/mm²
verification: $\sigma_{Ed}/\sigma_{Rd} = 0.805 < 1$ ok.

buckling fields of stiffener 3: local buckling cannot be excluded

single buckling field 4:

$\sigma_{Ed} = 232.5$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 0.776$, $\alpha_{ult} = 1.527$, $\alpha_{cr} = 2.534$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.923 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.673$, $\psi = 1.000$
ultimate buckling stress $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 297.9$ N/mm²
verification: $\sigma_{Ed}/\sigma_{Rd} = 0.780 < 1$ ok.

overall buckling field:

$\sigma_{Ed} = 232.5$ N/mm²
non-dimensional slenderness ratio $\lambda_p = \lambda_c = \lambda_w = (\alpha_{ult}/\alpha_{cr})^{1/2} = 1.231$, $\alpha_{ult} = 1.527$, $\alpha_{cr} = 1.007$ (4H-tool)
reduction factor $\rho = (\lambda_p - 0.055\cdot(3+\psi))/\lambda_p^2 = 0.667 \le 1$ for $\lambda_p > 0.5 + (0.085-0.055\cdot\psi)^{1/2} = 0.673$, $\psi = 1.000$
critical buckling stress $\sigma_{cr,p} = \alpha_{cr}\cdot\sigma_{Ed}' = 234.3$ N/mm², $\sigma_{Ed}' = 232.5$ N/mm²
critical buckling stress $\sigma_{cr,c} = \sigma_{cr,c,sl}\cdot\sigma_1/\sigma_{sl} = 1117.7$ N/mm², $\sigma_1/\sigma_{sl} = 1.000$, $\sigma_{cr,c,sl} = 1117.7$ N/mm²
reduction factor $\chi_c = 0.429 \le 1$ for $\lambda_c > 0.2$
final reduction factor $\rho = (\rho - \chi_c)\cdot\xi\cdot(2-\xi) + \chi_c = 0.429$ with $\xi = 0.000$
ultimate buckling stress $\sigma_{Rd} = \rho\cdot f_y/\gamma_{M1} = 138.6$ N/mm²
verification: $\sigma_{Ed}/\sigma_{Rd} = 1.678 > 1$ not ok. !!

**total utilization:** $U = 2.067 > 1$ not ok. !!

assumptions not succeeded !!

## Final Result

**maximum utilization:** max U = 2.067 > 1 not ok. !!
**assumptions:** not succeeded !!

**design resistance not ensured !!**

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## 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/NA, Nationaler Anhang zur DIN EN 1993-1-1, Ausgabe Dezember 2010

DIN EN 1993-1-5, Eurocode 3: Bemessung und Konstruktion von Stahlbauten -
Teil 1-5: Plattenförmige Bauteile;
Deutsche Fassung EN 1993-1-5:2006 + AC:2009, Ausgabe Dezember 2010
DIN EN 1993-1-5/NA, Nationaler Anhang zur DIN EN 1993-1-5, Ausgabe Dezember 2010