standardized IM-joint

moment resistant joints IM acc. to EC 3-1-8 (12.10), NA: Deutschland

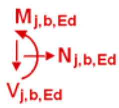
dimensions of beam, bolts, end-plate and welds, material
and arrangement of bolts are taken of the following literature:
'Typisierte Anschlüsse im Stahlhochbau nach DIN EN 1993-1-8, Ergänzungsband 2018,
Stahlbau Verlags- und Service GmbH, Ausgabe 2018'
the current number and associated parameters are recorded.
the column has no reference to the literature, web stiffeners are continuously fixed.
MN-interaction follows Cerfontaine (in Jaspart/Weynand: Design of Joints in Steel Structures).

beam-column connection, steel grade S235, bolt class of bolts 10.9

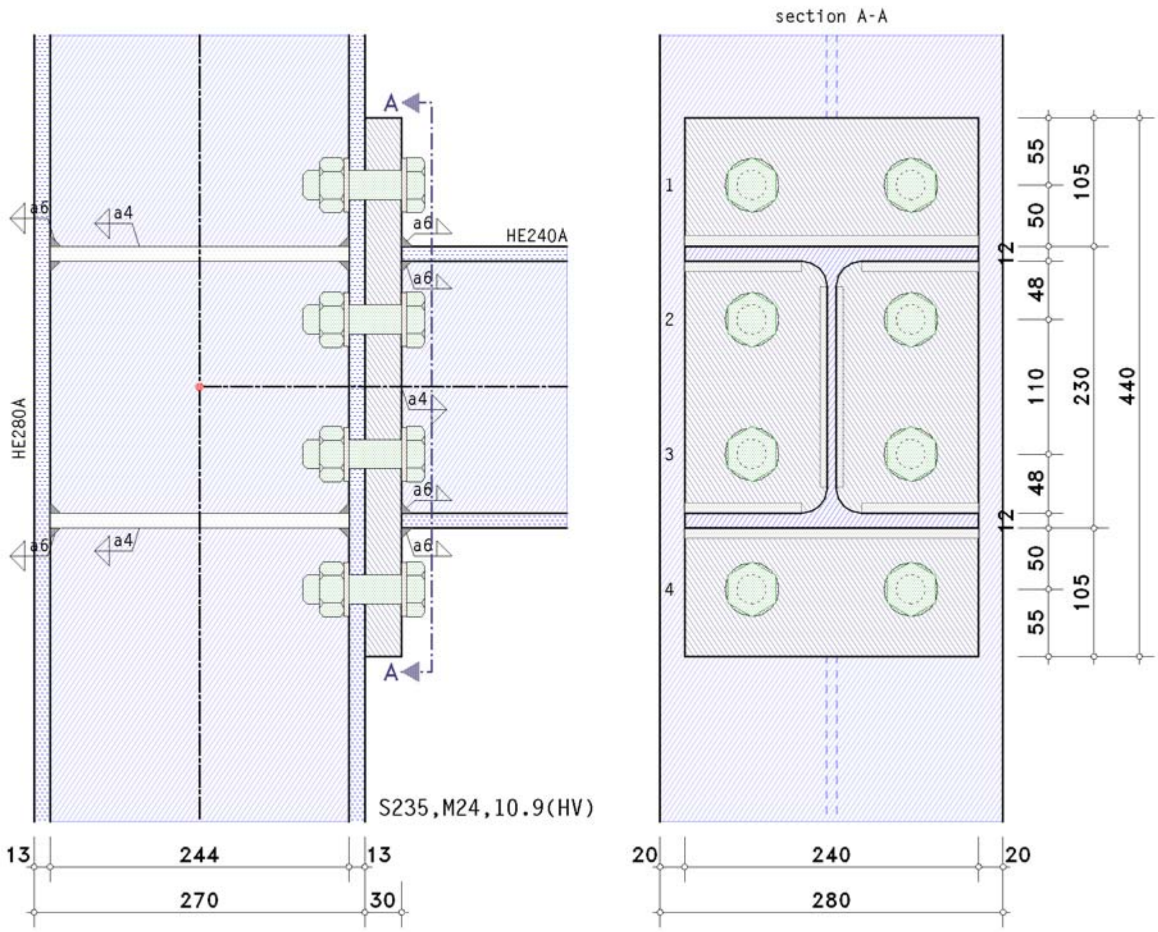
10760: beam section HEA240, bolt size M24, connection with 2 bolts per row
end-plate: t_p = 30 mm, b_p = 240 mm, h_p = 440 mm, e_1 = 55 mm, $p_{1,1}$ = 110 mm, $p_{1,2}$ = 110 mm
$p_{1,3}$ = 110 mm, u_1 = 105 mm, w = 130 mm
fillet welds: a_f = 6 mm, a_w = 4 mm

column: section HE280A
horizontal web stiffeners

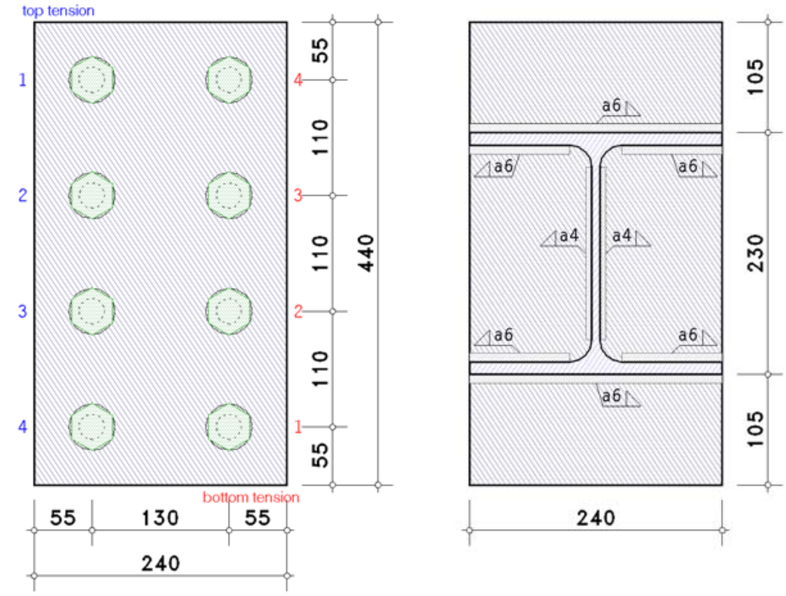
internal forces and moments in the intersection point of system axes:
Lk 1: $M_{j,b,Ed}$ = -102.02 kNm $V_{j,b,Ed}$ = 84.67 kN



Rigid beam connection



details



Component method

<u>notes</u>
connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.
no verification for cross-sections.
the welds are not regarded by calculation the T-stub resistance.
simplified calculation of shear force resistance takes all bolt-rows into account.

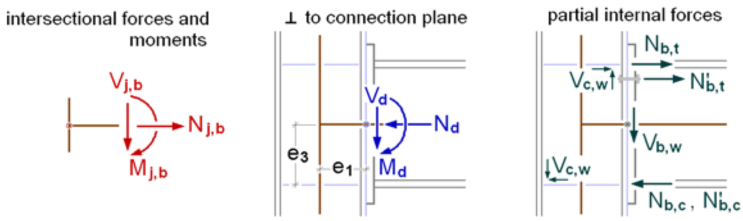
Final Result

maximum utilization: max U = 0.968 < 1 ok
minimum rotational stiffness: min S_j = 13.3 MNm/rad, $S_{j,ini}$ = 27.9 MNm/rad
maximum rotation: max $\varphi_{j,Ed}$ = 0.378°

verification succeeded

Decisive load case combination

design values



internal forces and moments in the periphery
$N_{b,Ed}$ = $-N_{j,b,Ed}$ = 26.59 kN
$M_{b,Ed}$ = $-M_{j,b,Ed} - V_{j,b,Ed} \cdot e_1$ = 90.59 kNm, e_1 = 135.0 mm
$V_{b,Ed}$ = $V_{j,b,Ed}$ = 84.67 kN
internal forces and moments perpendicular to the connection plane
N_d = $N_{b,Ed}$ = 26.59 kN
M_d = $M_{b,Ed}$ = 90.59 kNm
V_d = $V_{b,Ed}$ = 84.67 kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep}$ = 88.05 kNm
$N_{b,t}$ = $-N_d \cdot z_{bu}/z_b + M'_d/z_b$ = 390.60 kN, z_b = 218.0 mm, z_{bu} = 109.0 mm
$N_{b,c}$ = $N_d \cdot z_{bo}/z_b + M'_d/z_b$ = 417.19 kN, z_b = 218.0 mm, z_{bo} = 109.0 mm

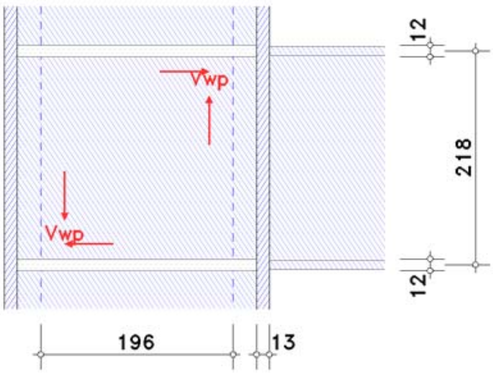
resistance of cross-section

plastic cross-sectional check for $N = -26.59$ kN, $M_y = -88.05$ kNm, $V_z = 84.67$ kN
valid normal/shear stress: zul $\sigma_{Rd} = 23.50$ kN/cm², zul $\tau_{Rd} = 13.57$ kN/cm²
top flange: resistance forces $N_{max,O} = 676.80$ kN, $N_{min,O} = -676.80$ kN
bottom flange: resistance forces $N_{max,U} = 676.80$ kN, $N_{min,U} = -676.80$ kN
web: shear force $V_S = 84.67$ kN, shear stress $\tau_S = 5.18$ kN/cm² $\Rightarrow$ $U_{\tau,S} = 0.382$
resistance forces $N_{max,S} = 355.14$ kN, $N_{min,S} = -355.14$ kN
main bending: axial force $N = -26.59$ kN, resistance forces $N_{max} = 1708.74$ kN, $N_{min} = -1708.74$ kN $\Rightarrow$ $U_N = 0.016$
moment $M_y = -88.05$ kNm, resistance moments $M_{y,max} = 166.79$ kNm, $M_{y,min} = -166.79$ kNm $\Rightarrow$ $U_{My} = 0.528$
total (possibly due to load increase): max $U = 0.545 < 1$ ok
utilizations: resistance $U_\sigma = 0.545 < 1$ ok, c/t-ratio $U_{c/t} = 0.424 < 1$ ok

basic components

basic component 1: Column web panel in shear

transformation parameter (EC 3-1-8, 5.3(9)) $\beta = 1.00$

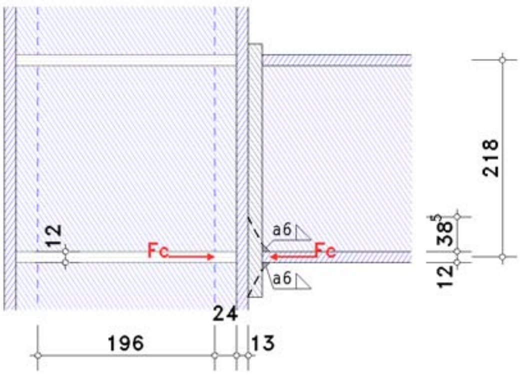


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

slenderness of column web $d_c/t_{wc} = 24.50 < 69\cdot\varepsilon = 69.00$ $\Rightarrow$ method applicable
plastic shear resistance without stiffeners $V_{wp,Rd} = (0.9\cdot f_{y,w}\cdot A_v) / (3^{1/2}\cdot\gamma_{M0}) = 387.6$ kN
placing of intermediate web stiffeners:
additional resistance $V_{wp,add,Rd} = 4\cdot M_{pl,fc,Rd}/d_{st} = 51.0$ kN
$V_{wp,add,Rd} > 2\cdot(M_{pl,fc,Rd}+M_{pl,st,Rd})/d_{st} = 44.8$ kN $\Rightarrow$ $V_{wp,add,Rd} = 44.8$ kN
plastic shear resistance with transverse stiffeners $V_{wp,Rd} = 432.4$ kN

basic component 2: column web in transverse compression

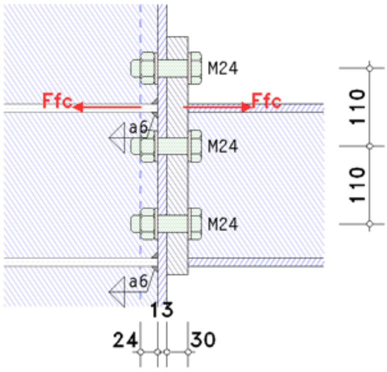
transformation parameter (EC 3-1-8, 5.3(9)) $\beta = 1.00$



Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

reinforcement of web with transverse stiffeners:
assumption: stiffeners do not buckle: $c/t = 10.3\cdot\varepsilon \leq 33\cdot\varepsilon$ $\Rightarrow$ section class $1 \leq 2$ ok
minimum demands of the moment of inertia of stiffeners:
length of buckling field (distance of stiffeners) $a = 218.0$ mm
web height between the flanges $h_{wc} = 244.0$ mm
moment of inertia of stiffeners $I_{st} = 1677.72$ cm⁴
minimum moment of inertia for $a/h_{wc} = 0.89 < 2^{1/2}$: $I_{st,min} = 23.48$ cm⁴ $< I_{st}$ ok
requirement concerning stiffeners to aviod lateral torsional buckling:
torsional moment of inertia of stiffeners $I_T = 7.14$ cm⁴
polar moment of inertia of stiffeners $I_p = 192.45$ cm⁴
$I_T / I_p \approx 0.037 > 0.006 = 5.3\cdot f_{y,st}/E_{st}$ ok
resistance of stiffened webs with transverse compression:
area of stiffeners incl. web $A_{st} = 30.72$ cm²
slenderness $\lambda = 0.035$
$\lambda \leq 0.2$ $\Rightarrow$ no deduction ($\chi = 1.0$)
design value of resistance of flexural buckling $F_{c,w,Rd} = 656.3$ kN

basic component 4: column flange in bending



Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

equivalent T-stub flange (each bolt-row decisive):

here: number of bolt-rows $n_b = 1$

row 1

effective length of the T-stub flange (column flange):

in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc},\ l_{eff,cp}) = 262.6$ mm, $l_{eff,cp} = 262.6$ mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 298.5$ mm

tension resistance of the T-stub flange:

in mode 1: $M_{pl,1,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 2.61$ kNm

in mode 2: $M_{pl,2,Rd} = (0.25 \cdot \Sigma l_{eff,2} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 2.96$ kNm

in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 508.32$ kN

mode 1: complete yielding of the T-stub flange

$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 309.77$ kN

mode 2: bolt failure simultaneously with yielding of the T-stub flange

$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 345.42$ kN

mode 3: bolt failure

$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN

tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd},\ F_{T,2,Rd},\ F_{T,3,Rd}) = 309.77$ kN

row 2

effective length of the T-stub flange (column flange):

in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc},\ l_{eff,cp}) = 262.6$ mm, $l_{eff,cp} = 262.6$ mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 302.5$ mm

tension resistance of the T-stub flange:

in mode 1: $M_{pl,1,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 2.61$ kNm

in mode 2: $M_{pl,2,Rd} = (0.25 \cdot \Sigma l_{eff,2} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 3.00$ kNm

in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 508.32$ kN

mode 1: complete yielding of the T-stub flange

$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 309.77$ kN

mode 2: bolt failure simultaneously with yielding of the T-stub flange

$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 346.27$ kN

mode 3: bolt failure

$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN

tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd},\ F_{T,2,Rd},\ F_{T,3,Rd}) = 309.77$ kN

row 3

effective length of the T-stub flange (column flange):

in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc},\ l_{eff,cp}) = 262.6$ mm, $l_{eff,cp} = 262.6$ mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 302.5$ mm

tension resistance of the T-stub flange:

in mode 1: $M_{pl,1,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 2.61$ kNm

in mode 2: $M_{pl,2,Rd} = (0.25 \cdot \Sigma l_{eff,2} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 3.00$ kNm

in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 508.32$ kN

mode 1: complete yielding of the T-stub flange

$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 309.77$ kN

mode 2: bolt failure simultaneously with yielding of the T-stub flange

$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 346.27$ kN

mode 3: bolt failure

$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN

tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd},\ F_{T,2,Rd},\ F_{T,3,Rd}) = 309.77$ kN

resistances and effective lengths of column flange in bending (per bolt-row)

$F_{t,fc,Rd,1} = 309.77$ kN, $l_{eff,1} = 262.6$ mm

$F_{t,fc,Rd,2} = 309.77$ kN, $l_{eff,1} = 262.6$ mm

$F_{t,fc,Rd,3} = 309.77$ kN, $l_{eff,1} = 262.6$ mm

equivalent T-stub flange (group of bolts 1):

here: number of bolt-rows $n_b = 2$ (between stiffeners)

effective length of the T-stub flange (column flange):

in mode 1: $\Sigma l_{eff,1} = \min(\Sigma l_{eff,nc},\ \Sigma l_{eff,cp}) = 454.1$ mm, $\Sigma l_{eff,cp} = 482.6$ mm

in mode 2: $\Sigma l_{eff,2} = \Sigma l_{eff,nc} = 454.1$ mm

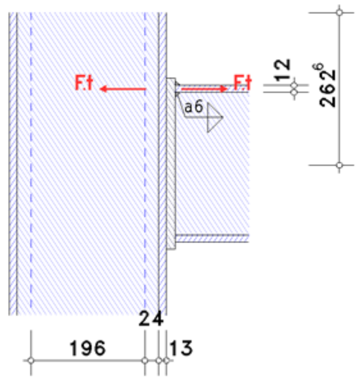
tension resistance of the T-stub flange:

in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 4.51$ kNm
in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 1016.64$ kN
mode 1: complete yielding of the T-stub flange
$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 535.58$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 660.68$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 1016.64$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 535.58$ kN

resistances and effective lengths of end-plate in bending (per bolt group):
$F_{ep,Rd,2\text{-}3} = 535.58$ kN, $\Sigma l_{eff} = 454.1$ mm, 2 rows

basic component 3: column web in transverse tension

transformation parameter (EC 3-1-8, 5.3(9)) $\beta = 1.00$



Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

each bolt-row decisive:

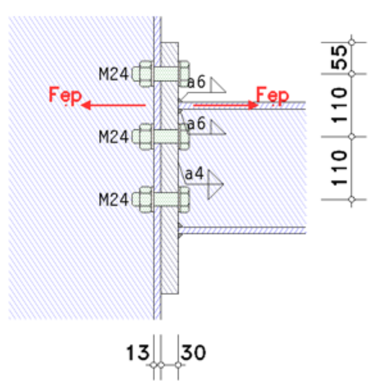
row 1
effective width $b_{eff,t} = 262.6$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.798$
resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 394.1$ kN

row 2
effective width $b_{eff,t} = 262.6$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.798$
resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 394.1$ kN

row 3
effective width $b_{eff,t} = 262.6$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.798$
resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 394.1$ kN

group of bolt-rows, group 1:
effective width $b_{eff,t} = 454.1$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.608$
resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 519.3$ kN

basic component 5: end-plate in bending



Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

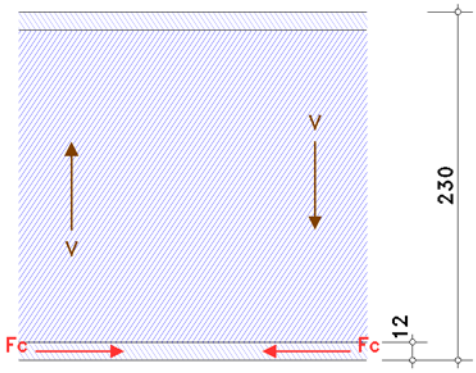
extended part of end-plate
in the extended part of the end-plate only one bolt-row is considered ($n_b = 1$).
effective length of the T-stub flange (end-plate):
in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 120.0$ mm, $l_{eff,cp} = 245.8$ mm
in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 120.0$ mm
tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 6.34$ kNm

in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 508.32$ kN
mode 1: complete yielding of the T-stub flange
$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 723.10$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 412.92$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 412.92$ kN
resistance and effective length of end-plate in bending (projection)
$F_{t,ep,Rd,1} = 412.9$ kN, $l_{eff,1} = 120.0$ mm
part of end-plate between beam flanges
equivalent T-stub flange (each bolt-row decisive):
here: number of bolt-rows $n_b = 1$
row 2
effective length of the T-stub flange (end-plate):
in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 339.3$ mm, $l_{eff,cp} = 356.4$ mm
in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 339.3$ mm
tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 17.94$ kNm
in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 508.32$ kN
mode 1: complete yielding of the T-stub flange
$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 1496.81$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 571.43$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 508.32$ kN
row 3
effective length of the T-stub flange (end-plate):
in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 339.3$ mm, $l_{eff,cp} = 356.4$ mm
in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 339.3$ mm
tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 17.94$ kNm
in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 508.32$ kN
mode 1: complete yielding of the T-stub flange
$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 1496.81$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 571.43$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 508.32$ kN
resistances and effective lengths of end-plate in bending (per bolt-row):
$F_{ep,Rd,2} = 508.32$ kN, $l_{eff,1} = 339.3$ mm
$F_{ep,Rd,3} = 508.32$ kN, $l_{eff,1} = 339.3$ mm

equivalent T-stub flange (group of bolts 1):
here: number of bolt-rows $n_b = 2$
effective length of the T-stub flange (end-plate):
in mode 1: $\Sigma l_{eff,1} = \min(\Sigma l_{eff,nc}, \Sigma l_{eff,cp}) = 493.0$ mm, $\Sigma l_{eff,cp} = 576.4$ mm
in mode 2: $\Sigma l_{eff,2} = \Sigma l_{eff,nc} = 493.0$ mm
tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 26.07$ kNm
in mode 3: $\Sigma F_{t,Rd} = 2 \cdot n_b \cdot F_{t,Rd} = 1016.64$ kN
mode 1: complete yielding of the T-stub flange
$F_{T,1,Rd} = ((8 \cdot n - 2 \cdot e_w) \cdot M_{pl,1,Rd}) / (2 \cdot m \cdot n - e_w \cdot (m+n)) = 2174.75$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 967.15$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 1016.64$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 967.15$ kN
resistances and effective lengths of end-plate in bending (per bolt group):
$F_{ep,Rd,2\text{-}3} = 967.15$ kN, $\Sigma l_{eff} = 493.0$ mm, 2 rows

basic component 7: beam flange and web in compression

flange bottom: section class for $c/(\varepsilon \cdot t) = 7.94$: 1
web: section class for $\alpha = 0.52$ and $c/(\varepsilon \cdot t) = 21.87$: 1
section class of beam: 1
taking into account the moment-shear force-interaction $V_{Ed} = 84.7$ kN

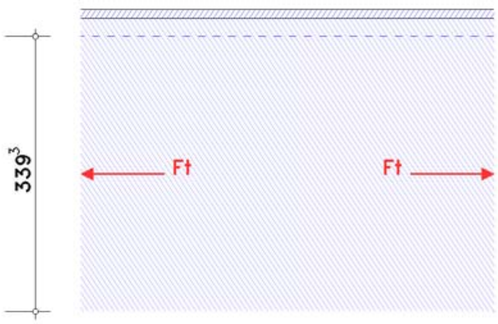


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

stress due to bending with shear force: $V_{Ed} = 84.7\text{ kN} \le 170.8\text{ kN} = V_{pl,Rd}/2 \Rightarrow$ no effect
resistance $M_{c,Rd} = M_{pl,Rd} = (W_{pl} \cdot f_y) / \gamma_{M0} = 175.07$ kNm, $W_{pl} = 745.00$ cm^3
resistance of a flange (and web) with compression
$F_{c,f,Rd} = M_{c,Rd} / (h - t_f) = 803.10$ kN

resistance of upper beam flange:
stress due to bending with shear force: $V_{Ed} = 84.7\text{ kN} \le 170.8\text{ kN} = V_{pl,Rd}/2 \Rightarrow$ no effect
resistance $M_{c,Rd} = M_{pl,Rd} = (W_{pl} \cdot f_y) / \gamma_{M0} = 175.07$ kNm, $W_{pl} = 745.00$ cm^3
resistance of a flange (and web) with compression
$F_{c,f,Rd} = M_{c,Rd} / (h - t_f) = 803.10$ kN

basic component 8: beam web in tension

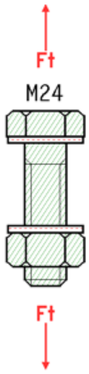


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

each bolt-row decisive:
row 2
effective width $b_{eff,t,wb} = 339.3$ mm (l_{eff} from bc 5)
resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0} = 598.1$ kN
row 3
effective width $b_{eff,t,wb} = 339.3$ mm (l_{eff} from bc 5)
resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0} = 598.1$ kN

group of bolt-rows, group 1:
effective width $b_{eff,t,wb} = 493.0$ mm (l_{eff} from bc 5)
resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0} = 869.0$ kN

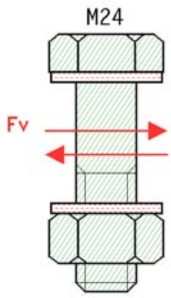
basic component 10: bolts in tension



Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

tension resistance of one bolt $F_{t,Rd} = (k_2 \cdot f_{ub} \cdot A_s) / \gamma_{M2} = 254.16$ kN, $k_2 = 0.90$
punching shear load capicity $B_{p,Rd} = (0.6 \cdot \pi \cdot d_m \cdot t_p \cdot f_u)) / \gamma_{M2} = 304.17$ kN, $t_p = 13.0$ mm
tension-/punching shear load capicity for 2 bolts: $\Sigma F_{tp,Rd} = 2 \cdot \min(F_{t,Rd}, B_{p,Rd}) = 508.32$ kN

basic component 11: bolts in shear

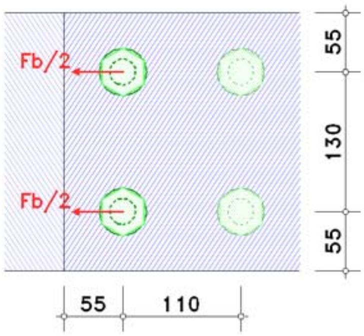


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

shear resistance per shear plane $F_{v,Rd} = \alpha_v \cdot f_{ub} \cdot A / \gamma_{M2} = 217.15$ kN, $\alpha_v = 0.60$
shear resistance of 2 bolts (1-shear): $\Sigma F_{v,Rd} = 2 \cdot F_{v,Rd} = 434.29$ kN

basic component 12: plate with bearing resistance

Only the essential sizes are sketched to scale.
The connection geometry is only hinted.



row 1
- end-plate:
  - bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 365.54$ kN, $k_1 = 2.50$, $\alpha_b = 0.71$
  - bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 365.54$ kN, $k_1 = 2.50$, $\alpha_b = 0.71$
  - bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 731.08$ kN
- column flange:
  - bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
  - bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
  - bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 449.28$ kN

row 2
- end-plate:
  - bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 518.40$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
  - bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 518.40$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
  - bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 1036.80$ kN
- column flange:
  - bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
  - bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
  - bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 449.28$ kN

row 3
- end-plate:
  - bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 518.40$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$

bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 518.40$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 1036.80$ kN
column flange:
bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 449.28$ kN

row 4
end-plate:
bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 518.40$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 518.40$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 1036.80$ kN
column flange:
bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 224.64$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 449.28$ kN

bearing resistance (4 rows)
$\Sigma F_{b,Rd,1} = 449.28$ kN
$\Sigma F_{b,Rd,2} = 449.28$ kN
$\Sigma F_{b,Rd,3} = 449.28$ kN
$\Sigma F_{b,Rd,4} = 449.28$ kN

connection capacity

moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 274.0$ mm, $h_2 = 164.0$ mm, $h_3 = 54.0$ mm

resistance per bolt-row (MNV-interaction)
row 1: $F_{tr,Rd} = 309.8$ kN
row 2: $F_{tr,Rd} = 92.3$ kN
row 3: $F_{tr,Rd} = 0.0$ kN
$\Sigma F_{tr,Rd} = 402.1$ kN

resistance of flanges (MNV-interaction)
$F_{c,Rd} = 432.4$ kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 100.0$ kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd} = 402.1$ kN
compression resistance
$N_{j,c,Rd} = F_{c,Rd} = 432.4$ kN

shear/bearing resistance

$V_{j,Rd} = 96.6$ kN (MNV-interaction)

shear resistance

shear resistance of end plate
plate: $V_{ep,Rd} = 667.53$ kN
resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2}) = 360.0$ N/mm²
welds: $F_{w,Rd} = 272.69$ kN
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd} = 272.69$ kN

shear resistance of column web
$V_{wp,Rd}/\beta = 432.4$ kN

plastic shear resistance
$V_{pl,Rd} = 0.5 \cdot A_v \cdot (f_y/3^{1/2}) / \gamma_{M0} = 170.8$ kN (requirement, s. 'Typisierte Anschlüsse')

total

$M_{j,Rd} = 100.0$ kNm $N_{j,t,Rd} = 402.1$ kN $N_{j,c,Rd} = 432.4$ kN $V_{j,Rd} = 96.6$ kN $V_{wp,Rd}/\beta = 432.4$ kN $V_{pl,Rd} = 170.8$ kN
$V_{ep,Rd} = 272.7$ kN

verifications

verification of the connection capacity by means of the component method

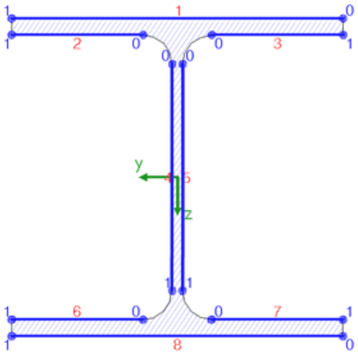
$U_{MNV} = 0.877 < 1$ ok
$V_{wp,Ed}/(V_{wp,Rd}/\beta) = 0.968 < 1$ ok
$V_{Ed}/V_{pl,Rd} = 0.496 < 1$ ok
$V_{Ed}/V_{ep,Rd} = 0.310 < 1$ ok

verification of welds at beam section

weld 1: beam flange in tension outer
welds 2,3: beam flange in tension inner
welds 4,5: beam web double-sided
weld 8: beam flange in compression outer
welds 6,7: beam flange in compression inner

weld 4: NA-DE: plate thickness $t_{max} \geq 30$ mm: weld thickness a = 4.0 mm < a_{min} = 5 mm !!
weld 4: weld thickness a = 4.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 3.7 mm !!
weld 5: NA-DE: plate thickness $t_{max} \geq 30$ mm: weld thickness a = 4.0 mm < a_{min} = 5 mm !!
weld 5: weld thickness a = 4.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 3.7 mm !!

calculation section:



weld 1:	a_w = 6.0 mm	l_w = 240.0 mm
weld 2:	a_w = 6.0 mm	l_w = 95.3 mm
weld 3:	siehe weld 2	
weld 4:	a_w = 4.0 mm	l_w = 164.0 mm
weld 5:	siehe weld 4	
weld 6:	a_w = 6.0 mm	l_w = 95.3 mm
weld 7:	siehe weld 6	
weld 8:	a_w = 6.0 mm	l_w = 240.0 mm

design values refering to centroid of the section:
N_{Ed} = -26.59 kN, $M_{y,Ed}$ = -90.59 kNm, $V_{z,Ed}$ = 84.67 kN
cross-sectional properties refering to centroid of the line cross-section:
ΣA_w = 64.78 cm², $A_{w,z}$ = 13.12 cm², Σl_w = 118.9 cm
$I_{w,y}$ = 6528.08 cm⁴, $I_{w,z}$ = 2754.52 cm⁴, $W_{w,t}$ = 61.47 cm³, Δz_w = 0.0 mm
verifications in the edge points of the individual welds:

weld 1,	pt. 0:	$\sigma_{w,x}$ = 155.48 N/mm²		⇒ U_w = 0.611 < 1 ok
weld 2,	pt. 0:	$\sigma_{w,x}$ = 138.83 N/mm²		⇒ U_w = 0.545 < 1 ok
weld 4,	pt. 0:	$\sigma_{w,x}$ = 109.69 N/mm²	$\tau_{w,z}$ = 64.53 N/mm²	⇒ U_w = 0.531 < 1 ok
	pt. 1:	$\sigma_{w,x}$ = -117.89 N/mm²	$\tau_{w,z}$ = 64.53 N/mm²	⇒ U_w = 0.558 < 1 ok
weld 6,	pt. 0:	$\sigma_{w,x}$ = -147.04 N/mm²		⇒ U_w = 0.578 < 1 ok
weld 8,	pt. 0:	$\sigma_{w,x}$ = -163.69 N/mm²		⇒ U_w = 0.643 < 1 ok

Result:
weld 8, pt. 1: $\sigma_{w,x}$ = -163.69 N/mm²
Max: $\sigma_{1,w,Ed}$ = 23.15 kN/cm² < $f_{1w,d}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 11.57 kN/cm² < $f_{2w,d}$ = 25.92 kN/cm² ⇒ U_w = 0.643 < 1 ok

verification of web stiffeners

compression stiffener
$F_{c,Ed}$ = 427.00 kN
forces per rib
$F = 0.5 \cdot F_{c,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 170.8 kN, $H = F \cdot e_F/e_H$ = 56.0 kN
assumption: stiffeners do not buckle: $c/t = 10.3 \cdot \varepsilon \leq 33 \cdot \varepsilon$ ⇒ section class 1 ≤ 2 ok
cross-section at flange
compression resistance $N_{c,Rd} = (A \cdot f_y) / \gamma_{M0}$ = 248.16 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 196.4 kN
F_{Ed} = 196.4 kN < F_{Rd} = 248.2 kN ⇒ U = 0.792 < 1 ok
cross-section at web
shear resistance V_{Rd} = 397.26 kN
design value: F_{Ed} = F = 170.8 kN
F_{Ed} = 170.8 kN < F_{Rd} = 397.3 kN ⇒ U = 0.430 < 1 ok
flange welds
design values: $F_{Ed}(\sigma_s) = F / (2 \cdot b_1)$ = 9.70 kN/cm, $F_{Ed}(\tau_p) = H / (2 \cdot b_1)$ = 3.18 kN/cm, b_1 = 88.0 mm
$\sigma_{1,w,Ed}$ = 18.60 kN/cm² < $f_{1w,d}$ = 36.00 kN/cm² ⇒ U = 0.517 < 1 ok
$\sigma_{2,w,Ed}$ = 16.17 kN/cm² < $f_{2w,d}$ = 25.92 kN/cm² ⇒ U = 0.624 < 1 ok
web welds
design value: $F_{Ed}(\tau_p) = F / (2 \cdot l_1)$ = 4.97 kN/cm, l_1 = 172.0 mm
$\sigma_{1,w,Ed}$ = 21.50 kN/cm² < $f_{1w,d}$ = 36.00 kN/cm² ⇒ U = 0.597 < 1 ok
stiffener in tension
$F_{t,Ed}$ = 400.42 kN
forces per rib
$F = 0.5 \cdot F_{t,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 160.2 kN, $H = F \cdot e_F/e_H$ = 52.5 kN
cross-section at flange
tension resistance $N_{t,Rd}$ = 248.16 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 184.2 kN
F_{Ed} = 184.2 kN < F_{Rd} = 248.2 kN ⇒ U = 0.742 < 1 ok
cross-section at web
shear resistance V_{Rd} = 397.26 kN
design value: F_{Ed} = F = 160.2 kN
F_{Ed} = 160.2 kN < F_{Rd} = 397.3 kN ⇒ U = 0.403 < 1 ok

flange welds

design values: $F_{Ed}(\sigma_s) = F / (2 \cdot b_1) = 9.10$ kN/cm, $F_{Ed}(\tau_p) = H / (2 \cdot b_1) = 2.98$ kN/cm, $b_1 = 88.0$ mm

$\sigma_{1,w,Ed} = 17.44$ kN/cm² $<$ $f_{1w,d} = 36.00$ kN/cm² $\Rightarrow$ $U = 0.485 < 1$ ok

$\sigma_{2,w,Ed} = 15.17$ kN/cm² $<$ $f_{2w,d} = 25.92$ kN/cm² $\Rightarrow$ $U = 0.585 < 1$ ok

web welds

design value: $F_{Ed}(\tau_p) = F / (2 \cdot l_1) = 4.66$ kN/cm, $l_1 = 172.0$ mm

$\sigma_{1,w,Ed} = 20.16$ kN/cm² $<$ $f_{1w,d} = 36.00$ kN/cm² $\Rightarrow$ $U = 0.560 < 1$ ok

verification result

maximum utilization: max $U = 0.968 < 1$ ok

rotational stiffness

stiffness coefficients

$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 5.51$ mm

$k_2 = \infty$ (stiffened)

equivalent stiffness coefficient for 2 tension-bolt-rows:

1: $k_3 = 7.50$ mm, $k_4 = 7.11$ mm, $k_5 = 36.14$ mm, $k_{10} = 8.25$ mm $\Rightarrow$ $k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 2.365$ mm

2: $k_3 = 6.49$ mm, $k_4 = 6.15$ mm, $k_5 = 32.82$ mm, $k_{10} = 8.25$ mm $\Rightarrow$ $k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 2.134$ mm

$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 4.239$ mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 235.4$ mm

rotational stiffness

initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 27881.2$ kNm/rad, $z = z_{eq} = 235.4$ mm, $\Sigma(1/k_i) = 0.417$ mm^{-1}

$N_{b,Ed} = N_d = 26.59$ kN

$|N_{b,Ed}| = 26.59$ kN $<$ $5\% \cdot N_{pl,Rd} = 90.28$ kN ok

$|M_{j,Ed}| = 87.69$ kNm $>$ $2/3\, M_{j,Rd} = 66.7$ kNm $\Rightarrow$ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 2.095$, $\Psi = 2.7$

rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 13305.4$ kNm/rad

rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.378°$