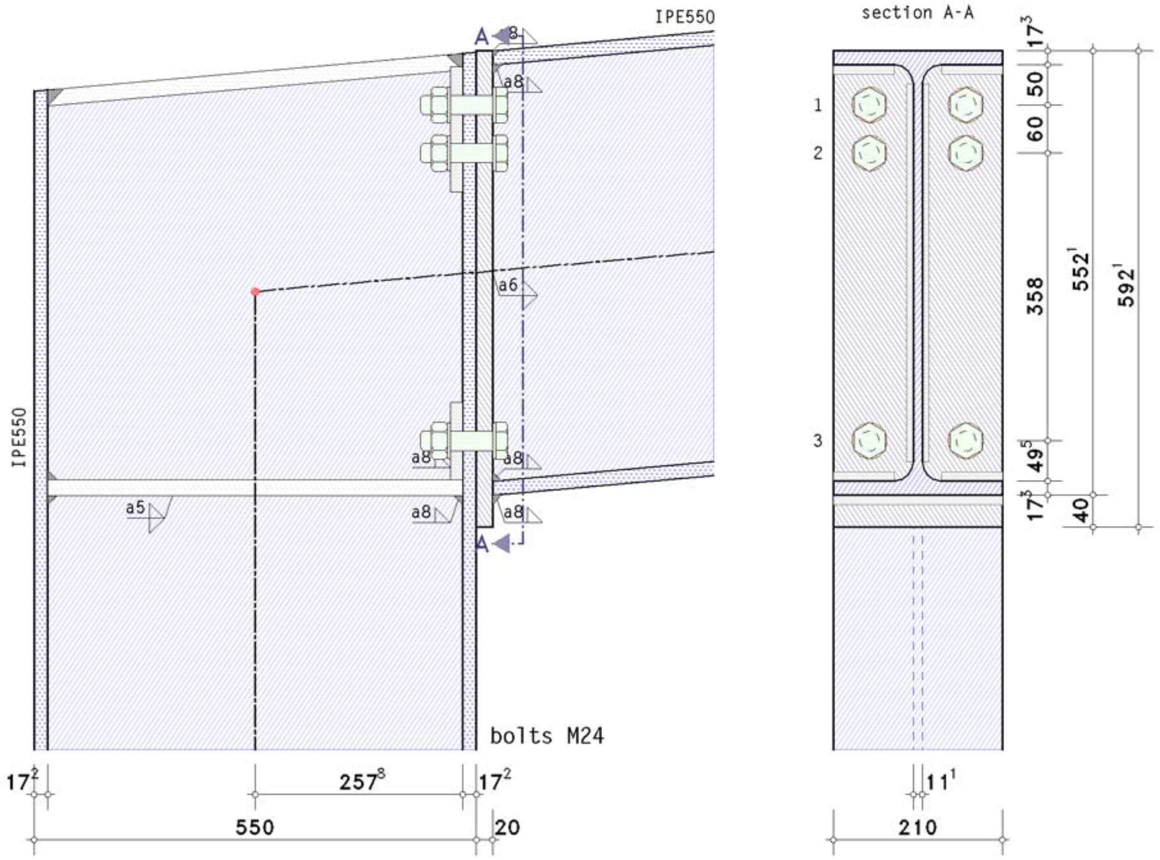
POS. 1: BAUFORUM STAHL, 3.5

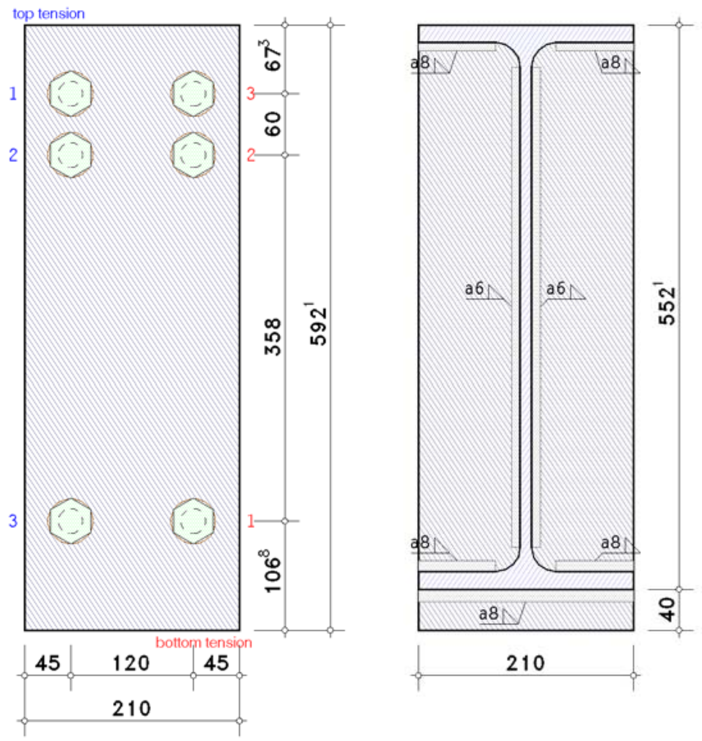
4H-EC3RE version: 5/2014-1x

frame corner

EC 3-1-8 (12.10), NA: Deutschland



details



steel grade
steel grade S 235
column parameters
section IPE550
reinforcement of the section with transverse stiffeners (web stiffeners, d_{st} = 531.6 mm):
thickness t_{st} = 20.0 mm, width b_{st} = 95.0 mm
welds $a_{st,f}$ = 8.0 mm, $a_{st,w}$ = 5.0 mm
beam parameters
section IPE550
section angle of inclination about the horizontal axis α_b = 5.00° $\Rightarrow$ section depth at the joint loc. $h_b = h/\cos(\alpha_b)$ = 552.1 mm
bolts
bolt: bolt class 10.9, bolt size M24
large width across flats (high strength bolt)
shear plane passes through the unthreaded portion of the bolt
flange reinforcement: thickness t_{bp} = 15.0 mm, length l_{bp} = 96.0 mm, width b_{bp} = 96.0 mm
verification parameters
bolted end-plate joint:
thickness t_p = 20.0 mm, length l_p = 592.1 mm, width b_p = 210.0 mm
projections $h_{p,o}$ = 0.0 mm, $h_{p,u}$ = 40.0 mm
bolts at the connection point:
3 bolt-row(s) with 2 bolts each
of these 2 bolt-rows top (M^+) in tension (rows 1-2)
and 1 bolt-row for shear transfer at tension top (row 3)
of these 1 bolt-row bottom (M^-) in tension (row 3)
and 2 bolt-rows for shear transfer at tension bottom (rows 2-3)
centre distance of the bolts to the lateral edge of the end-plate e_2 = 45.0 mm
centre distance of the first bolt-row to the upper edge of the end-plate (end row) e_o = 67.3 mm
centre distance of the last bolt-row to the bottom edge of the end-plate (end row) e_u = 106.8 mm
centre distance of the first bolt-row to the free edge of the column (end row) e_1' = 65.8 mm
centre distance of the bolt-rows from each other p_{1-2} = 60.0 mm, p_{2-3} = 358.0 mm
welds at the connection point:
beam flange top: fillet weld, weld thickness a = 8.0 mm, angle φ = 85°
beam web: fillet weld, weld thickness a = 6.0 mm
beam flange bottom: fillet weld, weld thickness a = 8.0 mm, angle φ = 95°
internal forces and moments in the intersection point of system axes (sign convention of statics)
Lk 1: Ek 4 (right frame corner)
$N_{j,b1,Ed}$ = -58.30 kN $M_{j,b1,Ed}$ = -292.00 kNm $V_{j,b1,Ed}$ = 103.30 kN
Lk 2: Ek 5 (left frame corner)
$N_{j,b1,Ed}$ = -3.00 kN $M_{j,b1,Ed}$ = 52.20 kNm $V_{j,b1,Ed}$ = -3.80 kN
Lk 3: Ek 2 (right frame corner)
$N_{j,b1,Ed}$ = -61.00 kN $M_{j,b1,Ed}$ = -281.70 kNm $V_{j,b1,Ed}$ = 117.00 kN
partial safety factors for material
resistance of cross sections γ_{M0} = 1.00
resistance of members in stability failure γ_{M1} = 1.10
resistance of bolts, welds, plates in bearing γ_{M2} = 1.25
prestressing of high strength bolts γ_{M7} = 1.10

Component method

notes
high strength bolts have to be controlled prestressed, bolt category D (tension), A (shear).
no verification for cross sections within the connection area.
no verification of web stiffeners.

distances between bolt-rows at end-plate

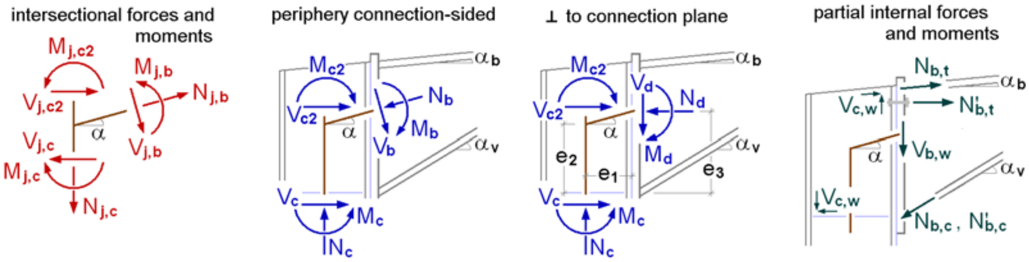
edge dist.:	e_2 = 45.0 mm > $1.2 \cdot d_0$ = 31.2 mm,	e_2 = 45.0 mm < $4 \cdot t_{min}$ + 40 mm = 108.8 mm
pitch:	p_2 = 120.0 mm > $2.4 \cdot d_0$ = 62.4 mm,	p_2 = 120.0 mm < min($14 \cdot t_{min}$, 200 mm) = 200.0 mm
edge dist.:	e_1 = 67.3 mm > $1.2 \cdot d_0$ = 31.2 mm,	e_1 = 67.3 mm < $4 \cdot t_1$ + 40 mm = 120.0 mm
edge dist.:	e_1 = 65.8 mm > $1.2 \cdot d_0$ = 31.2 mm,	e_1 = 65.8 mm < $4 \cdot t_2$ + 40 mm = 108.8 mm
pitch:	p_1 = 60.0 mm > $2.2 \cdot d_0$ = 57.2 mm,	p_1 = 60.0 mm < min($14 \cdot t_{min}$, 200 mm) = 200.0 mm
pitch:	p_1 = 358.0 mm > $2.2 \cdot d_0$ = 57.2 mm,	p_1 = 358.0 mm > min($14 \cdot t_{min}$, 200 mm) = 200.0 mm !!
edge dist.:	e_1 = 106.8 mm > $1.2 \cdot d_0$ = 31.2 mm,	e_1 = 106.8 mm < $4 \cdot t_1$ + 40 mm = 120.0 mm

horizontal distance of bolts from column edge

edge dist.:	e_2 = 45.0 mm > $1.2 \cdot d_0$ = 31.2 mm,	e_2 = 45.0 mm < $4 \cdot t_{min}$ + 40 mm = 108.8 mm

maximum values for spacings and edge distances only in order to avoid local buckling and to prevent corrosion.

design values



angle of inclination: $\alpha_b = \alpha_v = \alpha = 5.0°$

internal forces and moments in the periphery

$N_{b,Ed} = -N_{j,b,Ed} = 58.30$ kN

$M_{b,Ed} = -M_{j,b,Ed} - V_{j,b,Ed} \cdot e_1/\cos(\alpha) = 263.48$ kNm, $e_1 = 275.0$ mm

$V_{b,Ed} = V_{j,b,Ed} = 103.30$ kN

periphery column (bottom):

$N_{c,Ed} = N_{b,Ed} \cdot \sin(\alpha) + V_{b,Ed} \cdot \cos(\alpha) = 107.99$ kN

$M_{c,Ed} = M_{b,Ed} - V_{c,Ed} \cdot e_3 + N_{c,Ed} \cdot e_1 = 280.06$ kNm, $e_1 = 275.0$ mm, $e_3 = 267.4$ mm

$V_{c,Ed} = N_{b,Ed} \cdot \cos(\alpha) - V_{b,Ed} \cdot \sin(\alpha) = 49.07$ kN

internal forces and moments perpendicular to the connection plane

$N_d = N_{b,Ed} \cdot \cos(\alpha) - V_{b,Ed} \cdot \sin(\alpha) = 49.07$ kN

$M_d = M_{b,Ed} = 263.48$ kNm

$V_d = N_{b,Ed} \cdot \sin(\alpha) + V_{b,Ed} \cdot \cos(\alpha) = 107.99$ kN

partial internal forces and moments

internal forces and moments in the periphery end-plate-beam: $M'_d = M_d + N_d \cdot t_{ep} \cdot \tan(\alpha) - V_d \cdot t_{ep} = 261.41$ kN

$N_{b,t} = (-N_d \cdot z_{bu}/z_b + M'_d/z_b) / \cos(\alpha_b) = 466.00$ kN, $z_b = 534.8$ mm, $z_{bu} = 267.4$ mm

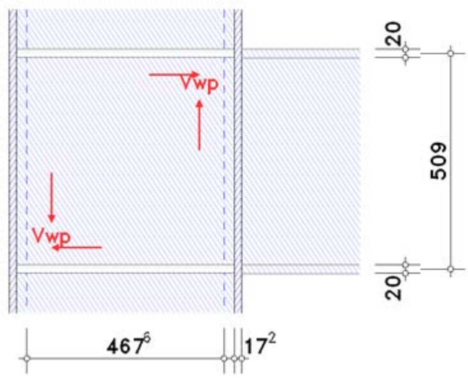
$N_{b,c} = (N_d \cdot z_{bo}/z_b + M'_d/z_b) / \cos(\alpha_b) = 515.27$ kN, $z_b = 534.8$ mm, $z_{bo} = 267.4$ mm

basic components

end-plate joint: decisive basic components: 1, 2, 3, 4, 5, 7, 8, 10, 11, 12

<u>basic component 1: Column web panel in shear</u>

transformation parameter (table 5.4) $\beta = 1.0$



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

slenderness of column web $d_c/t_{wc} = 42.13 < 69 \cdot \varepsilon = 69.00 \Rightarrow$ method applicable

plastic shear resistance without stiffeners $V_{wp,Rd} = (0.9 \cdot f_{y,wc} \cdot A_{vc}) / (3^{1/2} \cdot \gamma_{M0}) = 883.4$ kN

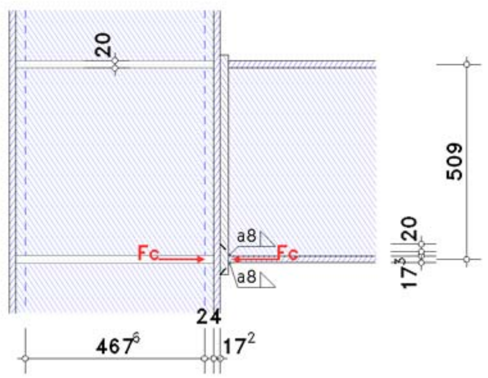
placing of intermediate web stiffeners:

additional design resistance $V_{wp,add,Rd} = 4 \cdot M_{pl,fc,Rd}/d_{st} = 28.7$ kN $\leq 2 \cdot (M_{pl,fc,Rd} + M_{pl,st,Rd})/d_{st} = 31.9$ kN **ok.**

plastic shear resistance with transverse stiffeners $V_{wp,Rd} = 912.0$ kN

basic component 2: column web in transverse compression

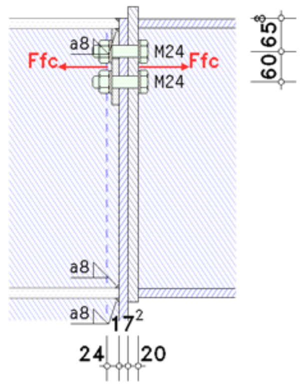
transformation parameter (table 5.4) $\beta = 1.0$
maximum longitudinal compressive stress in column web $\sigma_{com,Ed} = 105.59$ N/mm²



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: $c/t = 4.8 \cdot \varepsilon \leq 33 \cdot \varepsilon \Rightarrow$ section class $1 \leq 2$ **ok.**
minimum demands of the moment of inertia of stiffeners:
length of buckling field (distance of stiffeners) $a = 509.0$ mm
web height between the flanges $h_{wc} = 515.6$ mm
moment of inertia of stiffeners $I_{st} = 1355.45$ cm⁴
minimum moment of inertia for $a/h_{wc} = 0.99 < 2^{1/2}$: $I_{st,min} = 108.52$ cm⁴ $< I_{st}$ **ok.**
requirement concerning stiffeners to aviod lateral torsional buckling:
torsional moment of inertia of stiffeners $I_T = 25.33$ cm⁴
polar moment of inertia of stiffeners $I_p = 149.23$ cm⁴
$I_T / I_p \approx 0.170 > 0.006 = 5.3 \cdot f_{y,st}/E_{st}$ **ok.**
design resistance of stiffened webs with transverse compression:
area of stiffeners incl. web $A_{st} = 40.22$ cm²
slenderness $\lambda = 0.095$
$\lambda \leq 0.2 \Rightarrow$ no deduction ($\chi = 1.0$)
design value of resistance of flexural buckling $F_{c,w,Rd} = 859.2$ 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: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 218.3$ mm, $l_{eff,cp} = 221.5$ mm
in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 218.3$ mm
design tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 3.79$ kNm
flange reinforcement: $M_{bp,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_{bp}^2 \cdot f_{y,bp}) / \gamma_{M0} = 2.89$ 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
$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd} + 2 \cdot M_{bp,Rd}) / m = 594.33$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 378.09$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 378.09$ kN
design resistance of the weld: $F_{w,Rd} = 363.02$ kN per side
row 2
effective length of the T-stub flange (column flange):
in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 197.2$ mm, $l_{eff,cp} = 221.5$ mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 197.2$ mm
design tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 3.43$ kNm
flange reinforcement: $M_{bp,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_{bp}^2 \cdot f_{y,bp}) / \gamma_{M0} = 2.61$ 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
$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd} + 2 \cdot M_{bp,Rd}) / m = 536.97$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 368.85$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 368.85$ kN

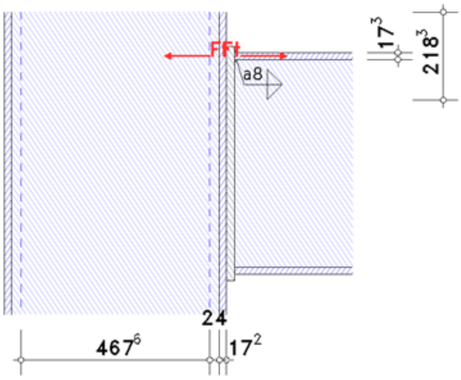
design resistance of column flange in bending (per bolt-row)
$F_{fc,Rd,1} = 378.1$ kN, $l_{eff,1} = 218.3$ mm
$F_{fc,Rd,2} = 368.9$ kN, $l_{eff,1} = 197.2$ mm

equivalent T-stub flange (group of bolt-rows decisive):
here: number of bolt rows $n_b = 2$ (between stiffeners)
effective length of the T-stub flange (column flange):
in mode 1: $\Sigma l_{eff,1} = \min(\Sigma l_{eff,nc}, \Sigma l_{eff,cp}) = 278.3$ mm, $\Sigma l_{eff,cp} = 341.5$ mm
in mode 2: $\Sigma l_{eff,2} = \Sigma l_{eff,nc} = 278.3$ mm
design tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 4.84$ kNm
flange reinforcement: $M_{bp,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_{bp}^2 \cdot f_{y,bp}) / \gamma_{M0} = 3.68$ 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
$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd} + 2 \cdot M_{bp,Rd}) / m = 757.66$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 686.78$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 1016.64$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 686.78$ kN

design resistance of column flange in bending (group of bolts, 2 rows)
$F_{fc,Rd} = 686.8$ kN, $\Sigma l_{eff,1} = 278.3$ mm

basic component 3: column web in transverse tension

transformation parameter (table 5.4) $\beta = 1.0$

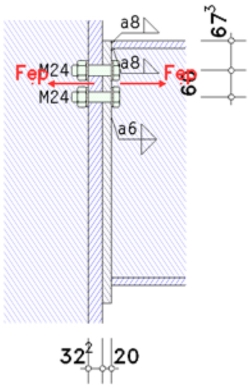


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

each bolt-row decisive:
row 1
effective width $b_{eff,t} = 218.3$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.934$
design resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 532.0$ kN
row 2
effective width $b_{eff,t} = 197.2$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.945$
design resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 486.4$ kN

group of bolt-rows decisive:
effective width $b_{eff,t} = 278.3$ mm (l_{eff} from bc 4)
reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.899$
design resistance of a column web with transverse tension
$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0} = 652.7$ kN

basic component 5: end-plate in bending



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

part of end-plate between beam flanges
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 (end-plate):
in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 277.8$ mm, $l_{eff,cp} = 299.5$ mm
in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 277.8$ mm
design tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 6.53$ 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
$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 547.85$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 387.76$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 387.76$ kN
design resistance of the weld: $F_{w,Rd} = 346.41$ kN per side
row 2
effective length of the T-stub flange (end-plate):
in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 246.9$ mm, $l_{eff,cp} = 299.5$ mm
in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 246.9$ mm
design tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 5.80$ 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
$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 486.94$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 372.09$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 508.32$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 372.09$ kN
design resistance of the weld: $F_{w,Rd} = 307.90$ kN per side

design resistances of end-plate in bending (per bolt-row):
$F_{ep,Rd,1} = 387.8$ kN, $l_{eff,1} = 277.8$ mm
$F_{ep,Rd,2} = 372.1$ kN, $l_{eff,1} = 246.9$ mm

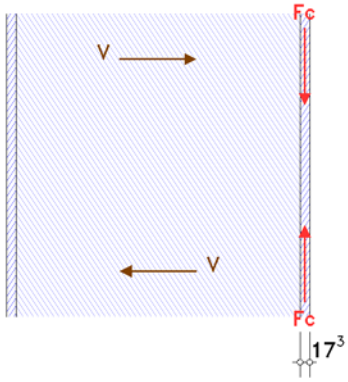
equivalent T-stub flange (group of bolt-rows decisive):
here: number of bolt rows $n_b = 2$
effective length of the T-stub flange (end-plate):
in mode 1: $\Sigma l_{eff,1} = \min(\Sigma l_{eff,nc}, \Sigma l_{eff,cp}) = 337.8$ mm, $\Sigma l_{eff,cp} = 419.5$ mm
in mode 2: $\Sigma l_{eff,2} = \Sigma l_{eff,nc} = 337.8$ mm
design tension resistance of the T-stub flange:
in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 7.94$ 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
$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 666.18$ kN
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 665.05$ kN
mode 3: bolt failure
$F_{T,3,Rd} = \Sigma F_{t,Rd} = 1016.64$ kN
tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 665.05$ kN
design resistance of the weld: $F_{w,Rd} = 421.24$ kN per side

design resistance of end-plate in bending (group of bolts, 2 row(s))

$F_{t,ep,Rd}$ = 665.0 kN, $\Sigma l_{eff,1}$ = 337.8 mm

basic component 7: beam flange and web in compression

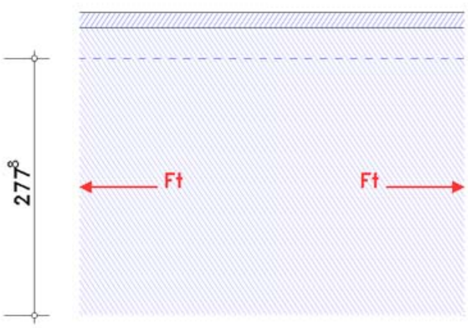
flange bottom: section class for $c/(\varepsilon \cdot t)$ = 4.37: 1
web: section class for α = 0.52 and $c/(\varepsilon \cdot t)$ = 42.30: 1
section class of the beam in connection plane: 1
taking into account the moment-shear force-interaction V_{Ed} = 108.0 kN



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

stress due to bending with shear force: V_{Ed} = 108.0 kN ≤ 492.5 kN = $V_{pl,Rd}/2$ ⇒ no effect
moment resistance $M_{c,Rd} = M_{pl,Rd} = (W_{pl} \cdot f_y) / \gamma_{M0}$ = 642.25 kNm
design resistance of a flange and web in compression
$F_{c,f,Rd} = M_{c,Rd} / (h - t_f)$ = 1200.84 kN

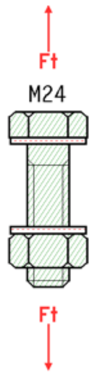
basic component 8: beam web in tension



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

each bolt-row decisive:
row 1
effective width $b_{eff,t,wb}$ = 277.8 mm (l_{eff} from bc 5)
design resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0}$ = 724.6 kN
row 2
effective width $b_{eff,t,wb}$ = 246.9 mm (l_{eff} from bc 5)
design resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0}$ = 644.0 kN
group of bolt-rows decisive:
effective width $b_{eff,t,wb}$ = 337.8 mm (l_{eff} from bc 5)
design resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0}$ = 881.1 kN

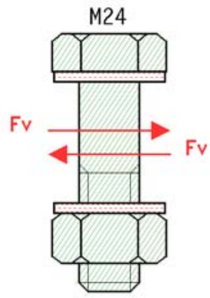
basic component 10: bolts in tension



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

bolt category D:
tension resistance of one bolt: $F_{t,Rd} = (k_2 \cdot f_{ub} \cdot A_s) / \gamma_{M2} = 254.16$ kN, $k_2 = 0.90$
p. sh. load capicity: $B_{p,Rd} = (0.6 \cdot \pi \cdot d_m \cdot t_p \cdot f_u)) / \gamma_{M2} = 402.44$ kN, $t_p = 17.2$ mm
tension-/punching shear load capicity for 2 bolts: $\Sigma F_{t,Rd} = 2 \cdot \min(F_{t,Rd}, B_{p,Rd}) = 508.32$ kN

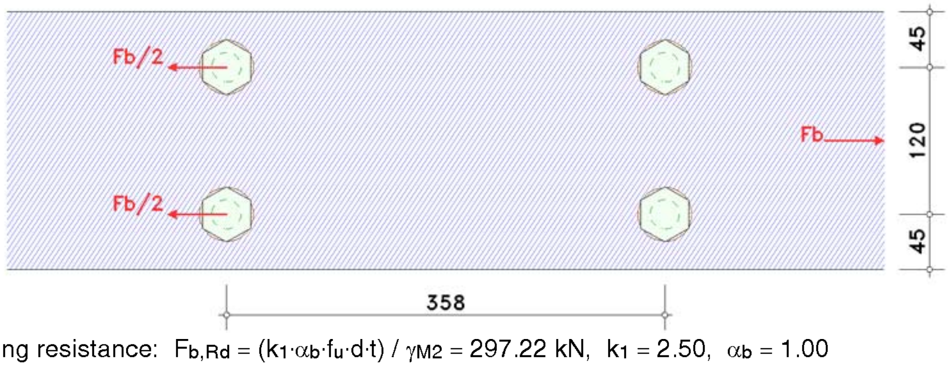
basic component 11: bolts in shear



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

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

basic component 12: bolts in bearing



bearing resistance: $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 297.22$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
design bearing resistance of 2 bolts per row: $\Sigma F_{b,Rd} = 2 \cdot F_{b,Rd} = 594.43$ kN

connection design capacity

moment resistance

distance between bolt-row(s) in tension and centre of compression:
$h_1 = 476.2$ mm, $h_2 = 416.2$ mm

design resistances acc. to 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8
row 1: $F_{tr,Rd} = 378.1$ kN
row 2: $F_{tr,Rd} = 368.9$ kN

deductions acc. to 6.2.7.2(8) for bolt-rows as part of a group (column)
decisive basic components: 3, 4

row 1: $\Sigma F_{tr,Rd} = 0.0$ kN

Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 652.7$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 686.8$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

row 2: $\Sigma F_{tr,Rd} = 378.1$ kN (row 1)

Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 274.6$ kN $\quad F_{tr,Rd} = 368.9$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 308.7$ kN $\quad F_{tr,Rd} = 274.6$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

deductions acc. to 6.2.7.2(8) for bolt-rows as part of a group (end-plate)

decisive basic components: 5, 8

row 1: $\Sigma F_{tr,Rd} = 0.0$ kN

Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 665.0$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 881.1$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

row 2: $\Sigma F_{tr,Rd} = 378.1$ kN (row 1)

Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 287.0$ kN $\quad F_{tr,Rd} = 274.6$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 503.0$ kN $\quad F_{tr,Rd} = 274.6$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

deductions acc. to 6.2.7.2(7)

decisive basic components: 1, 2, 7

row 1: $\Sigma F_{tr,Rd} = 0.0$ kN

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta - \Sigma F_{tr,Rd} = 912.0$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,wc,Rd} - \Sigma F_{tr,Rd} = 859.2$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,fb,Rd} - \Sigma F_{tr,Rd} = 1200.8$ kN $\quad F_{tr,Rd} = 378.1$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 378.1$ kN

row 2: $\Sigma F_{tr,Rd} = 378.1$ kN (row 1)

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta - \Sigma F_{tr,Rd} = 534.0$ kN $\quad F_{tr,Rd} = 274.6$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,wc,Rd} - \Sigma F_{tr,Rd} = 481.2$ kN $\quad F_{tr,Rd} = 274.6$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,fb,Rd} - \Sigma F_{tr,Rd} = 822.8$ kN $\quad F_{tr,Rd} = 274.6$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 274.6$ kN

check acc. to 6.2.7.2(9)

decisive basic component: 10

row 1: $F_{tx,Rd} = 378.1$ kN, $h_x = 476.2$ mm $\Rightarrow F_{tx,Rd} \leq 0.95 \cdot \Sigma F_{t,Rd} = 482.9$ kN, no deduction

design resistance per bolt-row (finally)

row 1: $F_{tr,Rd} = 378.1$ kN

row 2: $F_{tr,Rd} = 274.6$ kN

potential failure by basic component 3, 4

moment resistance

$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 294.3$ kNm

tension resistance

$N_{j,Rd} = \Sigma F_{tr,Rd} = 652.7$ kNm

compression resistance

$N_{j,c,Rd} = \min F_{c,Rd} = 859.2$ kNm

shear/design bearing resistance

design resistance per bolt-row

decisive basic components: 11, 12

row 3: $F_{vr,Rd} = 434.3$ kN

deductions depending on tension force (at 100% utilization of moment resistance)

decisive basic component: 10

$\Sigma F_{t,Rd} = 508.3$ kN

row 3: $F_{vr,Rd} = f_v \cdot 434.3$ kN $= 434.3$ kN $\quad$ with $f_v = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 1.000$

design resistance per bolt-row (finally)

row 3: $F_{vr,Rd} = 434.3$ kN

shear/design bearing resistance

$V_{j,Rd} = \Sigma F_{vr,Rd} = 434.3$ kN

shear resistance

decisive basic component: 1

$V_{wp,Rd}/\beta = 912.0$ kN

total

$N_{j,Rd} = 652.7$ kN $\quad N_{j,c,Rd} = 859.2$ kN $\quad M_{j,Rd} = 294.3$ kNm $\quad V_{j,Rd} = 434.3$ kN $\quad V_{wp,Rd}/\beta = 912.0$ kN

verifications

verification of the connection design capacity by means of the component method

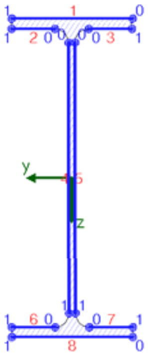
axial force: $N_{b,Ed} = |N_d \cdot \cos(\alpha) + V_d \cdot \sin(\alpha)| = 58.30$ kN $<$ 5%$\cdot N_{pl,Rd} = 158.52$ kN $\Rightarrow$ moment resistance
regarding beam axis
internal moment: $M_{Ed} = M_d - N_d \cdot z_{bu} = 250.45$ kNm, $z_{bu} = 265.7$ mm
shear force: $V_{Ed} = |V_d| = 107.99$ kN
shear force: $V_{wp,Ed} = (M_{d1,w} - M_{d2,w})/z - V_c/2 = 564.85$ kN, $M_{d,w} = 265.3$ kNm , $z = z_{eq} = 450.1$ mm

$M_{Ed}/M_{j,Rd} = 0.851 < 1$ **ok.**
$V_{wp,Ed}/(V_{wp,Rd}/\beta) = 0.619 < 1$ **ok.**
$V_{Ed}/V_{j,Rd} = 0.249 < 1$ **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

calculation section:



weld 1:	$a_w = 8.0$ mm	$l_w = 210.0$ mm
weld 2:	$a_w = 8.0$ mm	$l_w = 75.4$ mm
weld 3:	siehe weld 2	
weld 4:	$a_w = 6.0$ mm	$l_w = 469.6$ mm
weld 5:	siehe weld 4	
weld 6:	$a_w = 8.0$ mm	$l_w = 75.4$ mm
weld 7:	siehe weld 6	
weld 8:	$a_w = 8.0$ mm	$l_w = 210.0$ mm

design values:
$N_{Ed} = -49.07$ kN, $M_{y,Ed} = -263.48$ kNm, $V_{z,Ed} = 107.99$ kN
cross-sectional properties refering to centroid of the line cross section:
$\Sigma A_w = 114.09$ cm², $A_{w,z} = 56.35$ cm², $\Sigma l_w = 166.1$ cm
$I_{w,y} = 52130.50$ cm⁴, $I_{w,z} = 2461.12$ cm⁴, $\Delta z_w = 0.0$ mm
member forces distributed to the individual welds:

weld 1:	$N_w = 227.18$ kN	$M_{y,w} = -0.00$ kNm
weld 2:	$N_w = 76.35$ kN	$M_{y,w} = -0.00$ kNm
weld 4:	$N_w = -12.12$ kN	$M_{y,w} = -26.17$ kNm
weld 6:	$N_w = -81.55$ kN	$M_{y,w} = -0.00$ kNm
weld 8:	$N_w = -241.63$ kN	$M_{y,w} = -0.00$ kNm

verifications in the edge points of the individual welds:

weld 1,	pt. 0:	$\sigma_{w,x} = 135.22$ N/mm²		$\Rightarrow U_w = 0.531 < 1$ **ok.**
weld 2,	pt. 0:	$\sigma_{w,x} = 126.50$ N/mm²		$\Rightarrow U_w = 0.497 < 1$ **ok.**
weld 4,	pt. 0:	$\sigma_{w,x} = 114.37$ N/mm²	$\tau_{w,z} = 19.16$ N/mm²	$\Rightarrow U_w = 0.459 < 1$ **ok.**
	pt. 1:	$\sigma_{w,x} = -122.97$ N/mm²	$\tau_{w,z} = 19.16$ N/mm²	$\Rightarrow U_w = 0.492 < 1$ **ok.**
weld 6,	pt. 0:	$\sigma_{w,x} = -135.10$ N/mm²		$\Rightarrow U_w = 0.531 < 1$ **ok.**
weld 8,	pt. 0:	$\sigma_{w,x} = -143.83$ N/mm²		$\Rightarrow U_w = 0.565 < 1$ **ok.**

Result:
weld 8, pt. 0: $\sigma_{w,x} = -143.83$ N/mm²
$\sigma_{1,w,Ed} = 20.34$ kN/cm² $< f_{1,w,Rd} = 36.00$ kN/cm²,
$\sigma_{2,w,Ed} = 10.17$ kN/cm² $< f_{2,w,Rd} = 25.92$ kN/cm² $\Rightarrow U_w = 0.565 < 1$ **ok.**

verification result

maximum utilization: max $U = 0.851 < 1$ **ok.**

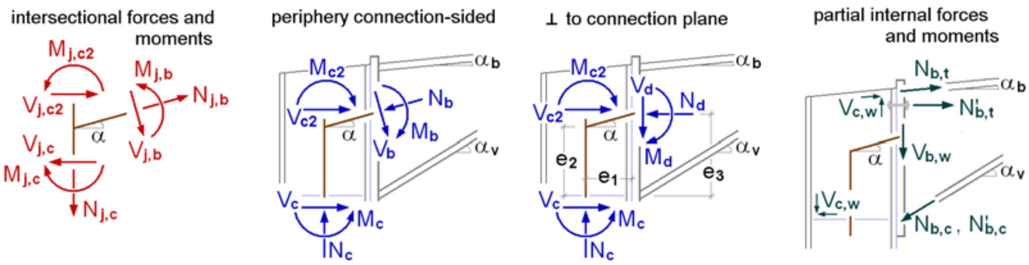
rotational stiffness

stiffness coefficients
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 6.11$ mm
$k_2 = \infty$ (stiffened)
equivalent stiffness coefficient for 2 bolt-rows:
$k_3 = 2.49$ mm, $k_4 = 15.65$ mm, $k_5 = 12.26$ mm, $k_{10} = 7.27$ mm $\Rightarrow k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 1.460$ mm
$k_3 = 2.14$ mm, $k_4 = 13.45$ mm, $k_5 = 10.20$ mm, $k_{10} = 7.27$ mm $\Rightarrow k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 1.286$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 2.733$ mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 450.1$ mm
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 80322.5$ kNm/rad, $z = z_{eq} = 450.1$ mm, $\Sigma(1/k_i) = 0.530$ mm^{-1}

$N_{b,Ed} = N_d \cdot \cos(\alpha) + V_d \cdot \sin(\alpha) = 58.30$ kN
$|N_{b,Ed}| = 58.30$ kN $<$ $5\% \cdot N_{pl,Rd} = 158.52$ kN **ok.**
$|M_{j,Ed}| = 292.00$ kNm $>$ $2/3\ M_{j,Rd} = 196.2$ kNm $\Rightarrow$ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 2.925$, $\Psi = 2.7$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 27461.0$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.609°$

```
Lk 2: Ek 5 (left frame corner)
```

design values



angle of inclination: $\alpha_b = \alpha_v = \alpha = 5.0°$

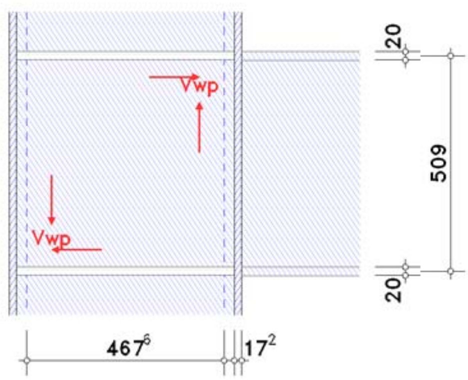
internal forces and moments in the periphery
$N_{b,Ed}$ $= -N_{j,b,Ed} = 3.00$ kN
$M_{b,Ed}$ $= -M_{j,b,Ed} - V_{j,b,Ed} \cdot e_1/\cos(\alpha) = -51.15$ kNm, $e_1 = 275.0$ mm
$V_{b,Ed}$ $= V_{j,b,Ed} = -3.80$ kN
periphery column (bottom):
$N_{c,Ed}$ $= N_{b,Ed} \cdot \sin(\alpha) + V_{b,Ed} \cdot \cos(\alpha) = -3.52$ kN
$M_{c,Ed}$ $= M_{b,Ed} - V_{c,Ed} \cdot e_3 + N_{c,Ed} \cdot e_1 = -53.01$ kNm, $e_1 = 275.0$ mm, $e_3 = 267.4$ mm
$V_{c,Ed}$ $= N_{b,Ed} \cdot \cos(\alpha) - V_{b,Ed} \cdot \sin(\alpha) = 3.32$ kN
internal forces and moments perpendicular to the connection plane
$N_d = N_{b,Ed} \cdot \cos(\alpha) - V_{b,Ed} \cdot \sin(\alpha) = 3.32$ kN
$M_d = M_{b,Ed} = -51.15$ kNm
$V_d = N_{b,Ed} \cdot \sin(\alpha) + V_{b,Ed} \cdot \cos(\alpha) = -3.52$ kN
negative internal moment M_d $\Rightarrow$ beam wird gespiegelt ($\alpha_b = \alpha = -5.0°$)
$M_d = 51.15$ kNm, $V_d = 3.52$ kN
partial internal forces and moments refering to the mirrored model
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d + N_d \cdot t_{ep} \cdot \tan(\alpha) - V_d \cdot t_{ep} = 51.07$ kN
$N_{b,t}$ $= (-N_d \cdot z_{bu}/z_b + M'_d/z_b) / \cos(\alpha_b) = 94.19$ kN, $z_b = 534.8$ mm, $z_{bu} = 267.4$ mm
$N_{b,c}$ $= (N_d \cdot z_{bo}/z_b + M'_d/z_b) / \cos(\alpha_b) = 97.53$ kN, $z_b = 534.8$ mm, $z_{bo} = 267.4$ mm

basic components

end-plate joint: decisive basic components: 1, 2, 3, 4, 5, 7, 8, 10, 11, 12

basic component 1: Column web panel in shear

transformation parameter (table 5.4) $\beta = 1.0$

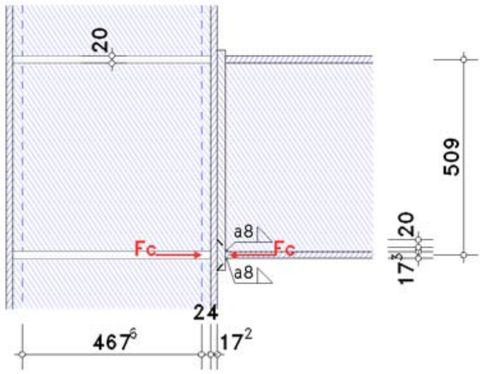


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

slenderness of column web $d_c/t_{wc} = 42.13$ $<$ $69 \cdot \varepsilon = 69.00$ $\Rightarrow$ method applicable
plastic shear resistance without stiffeners $V_{wp,Rd} = (0.9 \cdot f_{y,wc} \cdot A_{vc}) / (3^{1/2} \cdot \gamma_{M0}) = 883.4$ kN
placing of intermediate web stiffeners:
additional design resistance $V_{wp,add,Rd} = 4 \cdot M_{pl,fc,Rd}/d_{st} = 28.7$ kN $\leq$ $2 \cdot (M_{pl,fc,Rd} + M_{pl,st,Rd})/d_{st} = 31.9$ kN **ok.**
plastic shear resistance with transverse stiffeners $V_{wp,Rd} = 912.0$ kN

basic component 2: column web in transverse compression

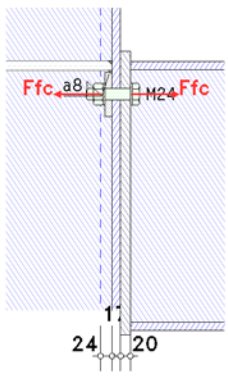
transformation parameter (table 5.4) β = 1.0



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: $c/t = 4.8 \cdot \varepsilon \leq 33 \cdot \varepsilon \Rightarrow$ section class $1 \leq 2$ **ok.**
minimum demands of the moment of inertia of stiffeners:
  length of buckling field (distance of stiffeners) a = 509.0 mm
  web height between the flanges h_{wc} = 515.6 mm
  moment of inertia of stiffeners I_{st} = 1355.45 cm^4
  minimum moment of inertia for $a/h_{wc} = 0.99 < 2^{1/2}$: $I_{st,min}$ = 108.52 cm^4 $< I_{st}$ **ok.**
requirement concerning stiffeners to aviod lateral torsional buckling:
  torsional moment of inertia of stiffeners I_T = 25.33 cm^4
  polar moment of inertia of stiffeners I_p = 149.23 cm^4
  $I_T / I_p \approx 0.170 > 0.006 = 5.3 \cdot f_{y,st}/E_{st}$ **ok.**
design resistance of stiffened webs with transverse compression:
  area of stiffeners incl. web A_{st} = 40.22 cm^2
  slenderness λ = 0.095
  $\lambda \leq 0.2 \Rightarrow$ no deduction (χ = 1.0)
  design value of resistance of flexural buckling $F_{c,w,Rd}$ = 859.2 kN

basic component 4: column flange in bending

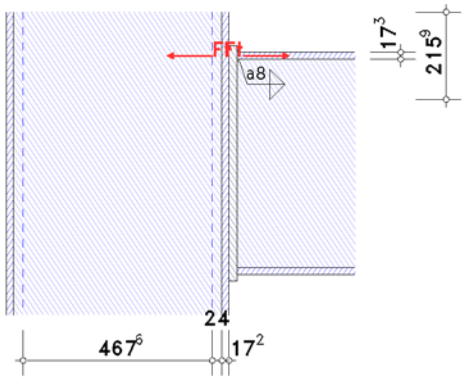


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

equivalent T-stub flange (each bolt-row decisive):
here: number of bolt rows n_b = 1
effective length of the T-stub flange (column flange):
  in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp})$ = 215.9 mm, $l_{eff,cp}$ = 221.5 mm
  in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc}$ = 215.9 mm
design tension resistance of the T-stub flange:
  in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0}$ = 3.75 kNm
  flange reinforcement: $M_{bp,Rd} = (0.25 \cdot \Sigma l_{eff,1} \cdot t_{bp}^2 \cdot f_{y,bp}) / \gamma_{M0}$ = 2.85 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
  $F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd} + 2 \cdot M_{bp,Rd}) / m$ = 587.75 kN
  mode 2: bolt failure simultaneously with yielding of the T-stub flange
  $F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n)$ = 377.03 kN
  mode 3: bolt failure
  $F_{T,3,Rd} = \Sigma F_{t,Rd}$ = 508.32 kN
  tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd})$ = 377.03 kN
  design resistance of the weld: $F_{w,Rd}$ = 359.00 kN per side
design resistance of column flange in bending (per bolt-row)
  $F_{fc,Rd,1}$ = 377.0 kN, $l_{eff,1}$ = 215.9 mm

basic component 3: column web in transverse tension

transformation parameter (table 5.4) β = 1.0



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

each bolt-row decisive:

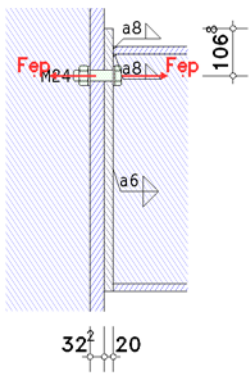
effective width $b_{eff,t}$ = 215.9 mm (l_{eff} from bc 4)

reduction factor for interaction with shear stress $\beta = 1 \Rightarrow \omega = 0.935$

design resistance of a column web with transverse tension

$F_{t,wc,Rd} = \omega \cdot (b_{eff,t} \cdot t_{wc} \cdot f_{y,wc}) / \gamma_{M0}$ = 526.9 kN

basic component 5: end-plate in bending



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

part of end-plate between beam flanges

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

here: number of bolt rows $n_b = 1$

effective length of the T-stub flange (end-plate):

in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp})$ = 278.6 mm, $l_{eff,cp}$ = 299.5 mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc}$ = 278.6 mm

design tension resistance of the T-stub flange:

in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0}$ = 6.55 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

$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m$ = 549.45 kN

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

$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n)$ = 388.17 kN

mode 3: bolt failure

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

tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd})$ = 388.17 kN

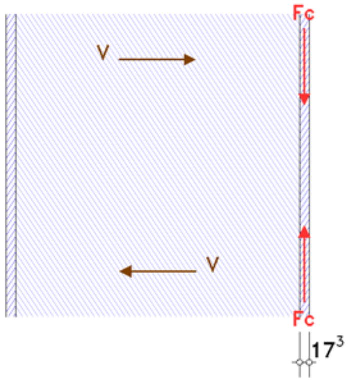
design resistance of the weld: $F_{w,Rd}$ = 347.43 kN per side

design resistances of end-plate in bending (per bolt-row):

$F_{ep,Rd,1}$ = 388.2 kN, $l_{eff,1}$ = 278.6 mm

basic component 7: beam flange and web in compression

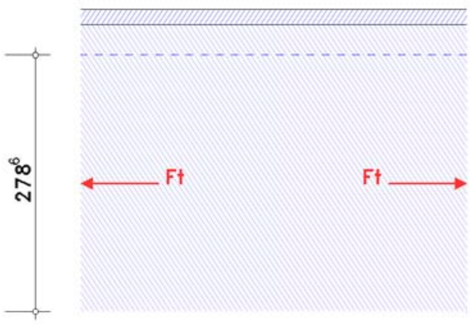
flange bottom: section class for $c/(\varepsilon \cdot t) = 4.37$: 1
web: section class for $\alpha = 0.51$ and $c/(\varepsilon \cdot t) = 42.30$: 1
section class of the beam in connection plane: 1
taking into account the moment-shear force-interaction $V_{Ed} = 3.5$ kN



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

stress due to bending with shear force: $V_{Ed} = 3.5 \text{ kN} \leq 492.5 \text{ kN} = V_{pl,Rd}/2 \Rightarrow$ no effect
moment resistance $M_{c,Rd} = M_{pl,Rd} = (W_{pl} \cdot f_y) / \gamma_{M0} = 642.25$ kNm
design resistance of a flange and web in compression
$F_{c,f,Rd} = M_{c,Rd} / (h - t_f) = 1200.84$ kN

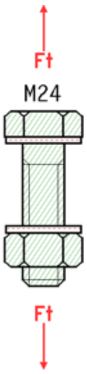
basic component 8: beam web in tension



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

each bolt-row decisive:
effective width $b_{eff,t,wb} = 278.6$ mm (l_{eff} from bc 5)
design resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0} = 726.7$ kN

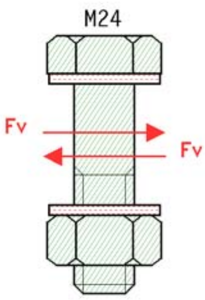
basic component 10: bolts in tension



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

bolt category D:
tension resistance of one bolt: $F_{t,Rd} = (k_2 \cdot f_{ub} \cdot A_s) / \gamma_{M2} = 254.16$ kN, $k_2 = 0.90$
p. sh. load capicity: $B_{p,Rd} = (0.6 \cdot \pi \cdot d_m \cdot t_p \cdot f_u)) / \gamma_{M2} = 402.44$ kN, $t_p = 17.2$ mm
tension-/punching shear load capicity for 2 bolts: $\Sigma F_{t,Rd} = 2 \cdot \min(F_{t,Rd}, B_{p,Rd}) = 508.32$ kN

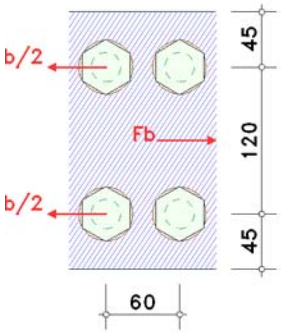
basic component 11: bolts in shear



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

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

basic component 12: bolts in bearing



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

bearing resistance: $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 154.32$ kN, $k_1 = 2.50$, $\alpha_b = 0.52$
design bearing resistance of 2 bolts per row: $\Sigma F_{b,Rd} = 2 \cdot F_{b,Rd} = 308.65$ kN

connection design capacity

moment resistance

distance between bolt-row(s) in tension and centre of compression:
$h_1 = 476.7$ mm

design resistances acc. to 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8
row 1: $F_{tr,Rd} = 377.0$ kN

deductions acc. to 6.2.7.2(7)
decisive basic components: 1, 2, 7
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta - \Sigma F_{tr,Rd} = 912.0$ kN $F_{tr,Rd} = 377.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 377.0$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,wc,Rd} - \Sigma F_{tr,Rd} = 859.2$ kN $F_{tr,Rd} = 377.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 377.0$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,fb,Rd} - \Sigma F_{tr,Rd} = 1200.8$ kN $F_{tr,Rd} = 377.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 377.0$ kN

design resistance per bolt-row (finally)
row 1: $F_{tr,Rd} = 377.0$ kN
potential failure by basic component 4

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 179.7$ kNm
tension resistance
$N_{j,Rd} = \Sigma F_{tr,Rd} = 377.0$ kNm
compression resistance
$N_{j,c,Rd} = \min F_{c,Rd} = 859.2$ kNm

shear/design bearing resistance

design resistance per bolt-row
decisive basic components: 11, 12
row 2: $F_{vr,Rd} = 308.6$ kN

row 3: $F_{vr,Rd} = 308.6$ kN

deductions depending on tension force (at 100% utilization of moment resistance)
decisive basic component: 10
$\Sigma F_{t,Rd} = 508.3$ kN
row 2: $F_{vr,Rd} = f_v \cdot 308.6$ kN $= 308.6$ kN with $f_v = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 1.000$
row 3: $F_{vr,Rd} = f_v \cdot 308.6$ kN $= 308.6$ kN with $f_v = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 1.000$

design resistance per bolt-row (finally)
row 2: $F_{vr,Rd} = 308.6$ kN
row 3: $F_{vr,Rd} = 308.6$ kN

shear/design bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd} = 617.3$ kN

shear resistance

decisive basic component: 1
$V_{wp,Rd}/\beta = 912.0$ kN

total

$N_{j,Rd} = 377.0$ kN $N_{j,c,Rd} = 859.2$ kN $M_{j,Rd} = 179.7$ kNm $V_{j,Rd} = 617.3$ kN $V_{wp,Rd}/\beta = 912.0$ kN

verifications

verification of the connection design capacity by means of the component method

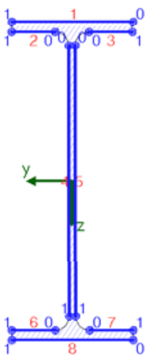
axial force: $N_{b,Ed} = |N_d \cdot \cos(\alpha) + V_d \cdot \sin(\alpha)| = 3.00$ kN $< 5\% \cdot N_{pl,Rd} = 158.52$ kN $\Rightarrow$ moment resistance
regarding beam axis
internal moment: $M_{Ed} = M_d - N_d \cdot z_{bu} = 50.26$ kNm, $z_{bu} = 269.2$ mm
shear force: $V_{Ed} = |V_d| = 3.52$ kN
shear force: $V_{wp,Ed} = (M_{d1,w} - M_{d2,w})/z - V_c/2 = 105.79$ kN, $M_{d,w} = 51.2$ kNm , $z = z_{eq} = 476.7$ mm

$M_{Ed}/M_{j,Rd} = 0.280 < 1$ **ok.**
$V_{wp,Ed}/(V_{wp,Rd}/\beta) = 0.116 < 1$ **ok.**
$V_{Ed}/V_{j,Rd} = 0.006 < 1$ **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

calculation section:



weld 1: $a_w = 8.0$ mm $l_w = 210.0$ mm
weld 2: $a_w = 8.0$ mm $l_w = 75.4$ mm
weld 3: siehe weld 2
weld 4: $a_w = 6.0$ mm $l_w = 469.6$ mm
weld 5: siehe weld 4
weld 6: $a_w = 8.0$ mm $l_w = 75.4$ mm
weld 7: siehe weld 6
weld 8: $a_w = 8.0$ mm $l_w = 210.0$ mm

design values:
$N_{Ed} = -3.32$ kN, $M_{y,Ed} = -51.15$ kNm, $V_{z,Ed} = 3.52$ kN
cross-sectional properties refering to centroid of the line cross section:
$\Sigma A_w = 114.09$ cm², $A_{w,z} = 56.35$ cm², $\Sigma l_w = 166.1$ cm
$I_{w,y} = 52130.50$ cm⁴, $I_{w,z} = 2461.12$ cm⁴, $\Delta z_w = 0.0$ mm
member forces distributed to the individual welds:
weld 1: $N_w = 45.02$ kN
weld 2: $N_w = 15.15$ kN
weld 4: $N_w = -0.82$ kN $M_{y,w} = -5.08$ kNm
weld 6: $N_w = -15.50$ kN
weld 8: $N_w = -45.99$ kN
verifications in the edge points of the individual welds:
weld 1, pt. 0: $\sigma_{w,x} = 26.80$ N/mm² $\Rightarrow U_w = 0.105 < 1$ **ok.**
weld 2, pt. 0: $\sigma_{w,x} = 25.10$ N/mm² $\Rightarrow U_w = 0.099 < 1$ **ok.**
weld 4, pt. 0: $\sigma_{w,x} = 22.75$ N/mm² $\tau_{w,z} = 0.63$ N/mm² $\Rightarrow U_w = 0.089 < 1$ **ok.**

pt. 1: $\sigma_{w,x}$ = -23.33 N/mm² $\tau_{w,z}$ = 0.63 N/mm² ⇒ U_w = 0.092 < 1 ok.
weld 6, pt. 0: $\sigma_{w,x}$ = -25.68 N/mm² ⇒ U_w = 0.101 < 1 ok.
weld 8, pt. 0: $\sigma_{w,x}$ = -27.38 N/mm² ⇒ U_w = 0.108 < 1 ok.
Result:
weld 8, pt. 0: $\sigma_{w,x}$ = -27.38 N/mm²
$\sigma_{1,w,Ed}$ = 3.87 kN/cm² < $f_{1,w,Rd}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 1.94 kN/cm² < $f_{2,w,Rd}$ = 25.92 kN/cm² ⇒ U_w = 0.108 < 1 ok.

verification result

maximum utilization: max U = 0.280 < 1 ok.

rotational stiffness

stiffness coefficients
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z)$ = 5.77 mm
$k_2 = \infty$ (stiffened)
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 3.59 mm, $b_{eff,t,wc}$ = 215.9 mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{fc}^3 / m^3$ = 22.57 mm, min l_{eff} = 215.9 mm, m = 35.2 mm
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 18.53 mm, min l_{eff} = 278.6 mm, m = 47.7 mm
$k_{10} = 1.6 \cdot A_s / L_b$ = 7.27 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2$ = 77.7 mm, t_{ges} = 52.2 mm

rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i)$ = 69354.4 kNm/rad, $z = z_{eq}$ = 476.7 mm, $\Sigma(1/k_i)$ = 0.688 mm⁻¹
$N_{b,Ed} = N_d \cdot \cos(\alpha) + V_d \cdot \sin(\alpha)$ = 3.00 kN
$|N_{b,Ed}|$ = 3.00 kN < $5\% \cdot N_{pl,Rd}$ = 158.52 kN ok.
$|M_{j,Ed}|$ = 52.20 kNm ≤ 2/3 $M_{j,Rd}$ = 119.8 kNm ⇒ μ = 1
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu$ = 69354.4 kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd}$ = 0.043°

```
Lk 3: Ek 2 (right frame corner)
```

reduced output, calculation process see Lk 1

design values

$N_d = N_{b,Ed} \cdot \cos(\alpha) - V_{b,Ed} \cdot \sin(\alpha)$ = 50.57 kN
$M_d = M_{b,Ed}$ = 249.40 kNm
$V_d = N_{b,Ed} \cdot \sin(\alpha) + V_{b,Ed} \cdot \cos(\alpha)$ = 121.87 kN
$N_{b,t} = (-N_d \cdot z_{bu}/z_b + M'_d/z_b) / \cos(\alpha_b)$ = 438.31 kN
$N_{b,c} = (N_d \cdot z_{bo}/z_b + M'_d/z_b) / \cos(\alpha_b)$ = 489.07 kN

connection design capacity

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 294.3 kNm
tension resistance
$N_{j,Rd} = \Sigma F_{tr,Rd}$ = 652.7 kNm
compression resistance
$N_{j,c,Rd}$ = min $F_{c,Rd}$ = 859.2 kNm

shear/design bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 434.3 kN

shear resistance
$V_{wp,Rd}/\beta$ = 912.0 kN

total
$N_{j,Rd}$ = 652.7 kN $N_{j,c,Rd}$ = 859.2 kN $M_{j,Rd}$ = 294.3 kNm $V_{j,Rd}$ = 434.3 kN $V_{wp,Rd}/\beta$ = 912.0 kN

verifications

verification of connection design capacity
$N_{b,Ed}$ = 61.00 kN < $5\% \cdot N_{pl,Rd}$
$M_{Ed} = M_d - N_d \cdot z_{bu}$ = 235.97 kNm
$V_{Ed} = |V_d|$ = 121.87 kN
$V_{wp,Ed}$ = 533.34 kN
$M_{Ed}/M_{j,Rd}$ = 0.802 < 1 ok.
$V_{wp,Ed}/(V_{wp,Rd}/\beta)$ = 0.585 < 1 ok.
$V_{Ed}/V_{j,Rd}$ = 0.281 < 1 ok.

verification of welds at beam section

weld 8: $\sigma_{w,x}$ = -136.50 N/mm²
$\sigma_{1,w,Ed}$ = 19.30 kN/cm² < $f_{1,w,Rd}$ = 36.00 kN/cm²,
$\sigma_{2,w,Ed}$ = 9.65 kN/cm² < $f_{2,w,Rd}$ = 25.92 kN/cm² $\Rightarrow$ U_w = 0.536 < 1 **ok.**

verification result

maximum utilization: max U = 0.802 < 1 **ok.**

rotational stiffness

initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i)$ = 80322.5 kNm/rad, $\Sigma(1/k_i)$ = 0.530 mm⁻¹
$|N_{b,Ed}|$ = 61.00 kN < 5%·$N_{pl,Rd}$ = 158.52 kN **ok.**
$|M_{j,Ed}|$ = 281.70 kNm > 2/3 $M_{j,Rd}$ = 196.2 kNm $\Rightarrow$ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi}$ = 2.655, Ψ = 2.7
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu$ = 30257.0 kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd}$ = 0.533°

Final result

maximum utilization [Lk 1]: max U = 0.851 < 1 **ok.**
minimum rotational stiffness [Lk 1]: min S_j = 27.5 MNm/rad, $S_{j,ini}$ = 80.3 MNm/rad
maximum rotation [Lk 1]: max $\varphi_{j,Ed}$ = 0.609°

verification succeeded