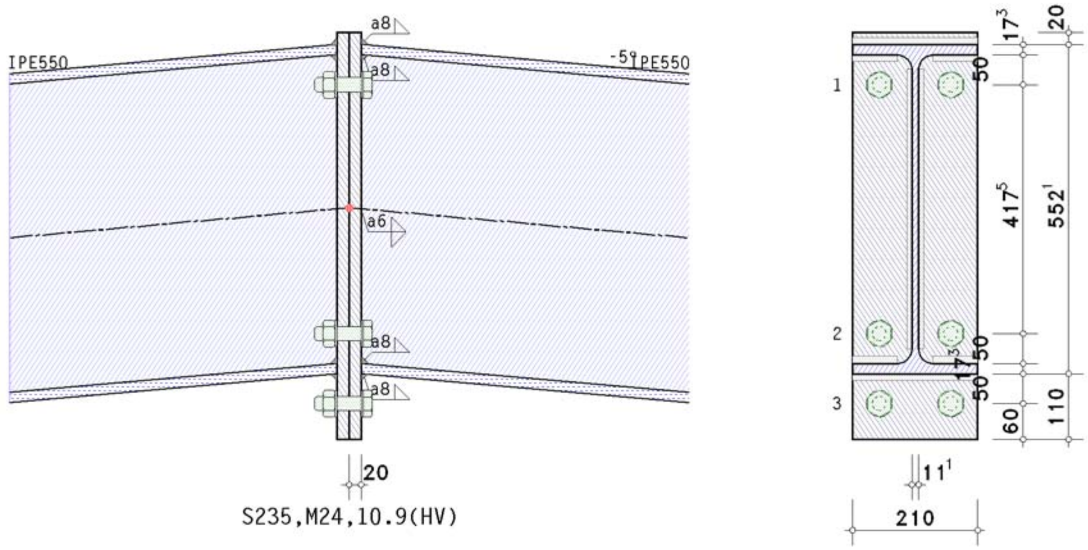
POS. 171: BAUFORUM STAHL 3.6

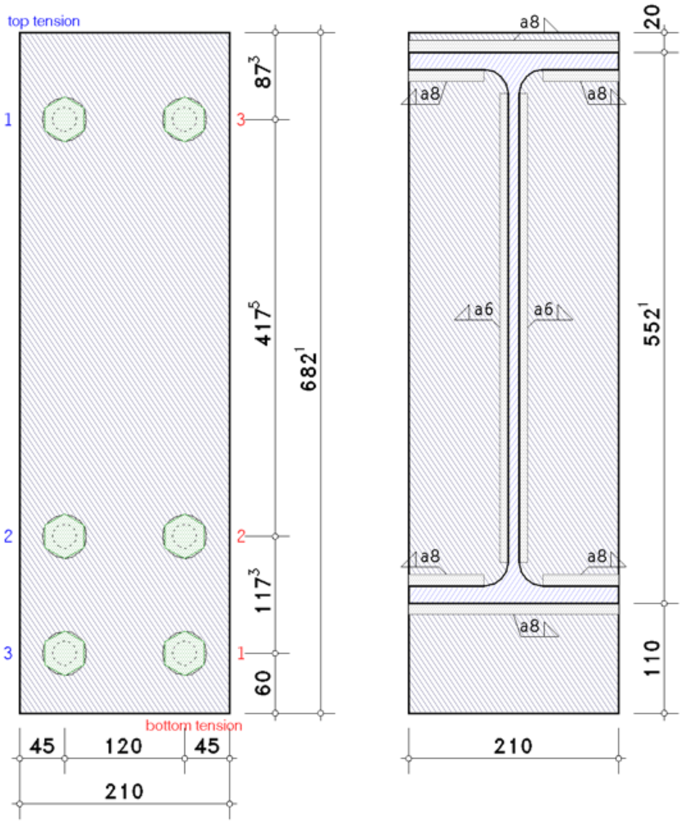
4H-ec3BT version: 4/2013-5l

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

1. input report



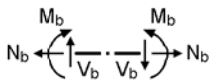
details (section A - A)



steel grade
steel grade S235
bolts
bolt class 10.9, bolt size M24
large wrench size (high strength bolt), preloaded (for info: preloading $F_{p,C}* = 0.7 \cdot f_{yb} \cdot A_s$ = 222.4 kN)
shear plane passes through the unthreaded portion of the bolt
beam parameters
section IPE550
slope angle of section about the horizontal axis α_b = -5.00°
verification parameters
bolted end-plate connection:
thickness t_p = 20.0 mm, width b_p = 210.0 mm, length l_p = 682.1 mm

projections $h_{p,o}$ = 20.0 mm, $h_{p,u}$ = 110.0 mm
bolts in connection:
3 bolt-rows with 2 bolts
of these 1 bolt-row top in tension (row 1)
and 2 bolt-rows for shear transfer top (rows 2-3)
of these 2 bolt-rows bottom in tension (rows 2-3)
and 1 bolt-row for shear transfer bottom (row 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 = 87.3 mm
centre distance of the last bolt-row to the bottom edge of the end-plate (end row) e_u = 60.0 mm
centre distance of the bolt-rows from each other p_{1-2} = 417.5 mm, p_{2-3} = 117.3 mm
welds at the connection point:
beam flange top: fillet weld, weld thickness a = 8.0 mm, angle φ = 95°
beam web: fillet weld, weld thickness a = 6.0 mm
beam flange bottom: fillet weld, weld thickness a = 8.0 mm, angle φ = 85°

internal forces and moments in the intersection point of system axes



Lk 1: Ek 3 (bzgl. rightr frame corner)
$N_{j,b,Ed}$ = -50.10 kN $M_{j,b,Ed}$ = 308.80 kNm $V_{j,b,Ed}$ = 116.70 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

check of data
ok

distances between bolt-rows at end-plate

horizontal:	e_2 = 45.0 mm > 1.2·d_0 = 31.2 mm,	e_2 = 45.0 mm < 4·t + 40 mm = 120.0 mm
horizontal:	p_2 = 120.0 mm > 2.4·d_0 = 62.4 mm,	p_2 = 120.0 mm < min(14·t, 200 mm) = 200.0 mm
vertical:	e_1 = 87.3 mm > 1.2·d_0 = 31.2 mm,	e_1 = 87.3 mm < 4·t + 40 mm = 120.0 mm
vertical:	p_1 = 417.5 mm > 2.2·d_0 = 57.2 mm,	p_1 = 417.5 mm > min(14·t, 200 mm) = 200.0 mm !!
vertical:	p_1 = 117.3 mm > 2.2·d_0 = 57.2 mm,	p_1 = 117.3 mm < min(14·t, 200 mm) = 200.0 mm
vertical:	e_1 = 60.0 mm > 1.2·d_0 = 31.2 mm,	e_1 = 60.0 mm < 4·t + 40 mm = 120.0 mm

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

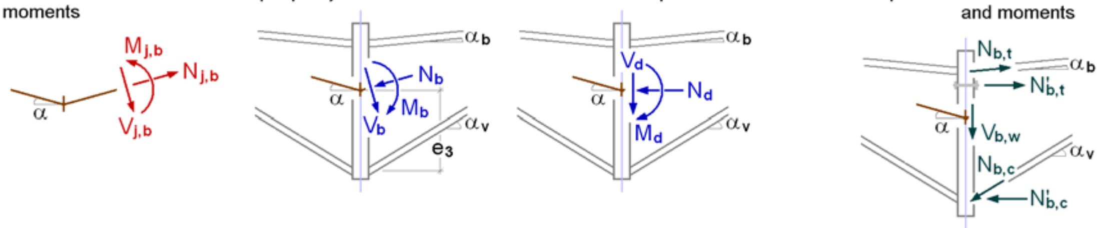
notes
no verification for cross-sections.
no verfication for welds within the connection.

2. Lk 1: Ek 3 (bzgl. rightr frame corner)

notes
connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.
calculation of T-stub-resistance with the standard method.

2.1. design values

Knotenschnittgrößen periphery connection⊥ zur connection plane partial internal forces and moments
intersectional forces and moments periphery connection-sided ⊥ to connection plane partial internal forces and moments

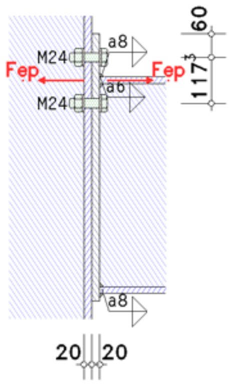


slope angle: $\alpha_b = \alpha_v = \alpha$ = -5.00°

internal forces and moments perpendicular to the connection planes
periphery beam
N_d = 60.08 kN, M_d = -308.80 kNm, V_d = 111.89 kN
negative internal moment M_d ⇒ mirrored model ($\alpha_b = \alpha_v = \alpha$ = 5.00°)
N_d = 60.08 kN, M_d = 308.80 kNm, V_d = -111.89 kN
partial internal forces and moments refering to the mirrored model
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d + N_d \cdot t_{ep} \cdot \tan(\alpha) - V_d \cdot t_{ep}$ = 311.14 kNm
$N_{b,t} = (-N_d \cdot z_{bu}/z_b + M'_d/z_b) / \cos(\alpha_b)$ = 553.82 kN, z_b = 534.8 mm, z_{bu} = 267.4 mm
$N_{b,c} = (N_d \cdot z_{bo}/z_b + M'_d/z_b) / \cos(\alpha_b)$ = 614.13 kN, z_b = 534.8 mm, z_{bo} = 267.4 mm

2.2. basic components

2.2.1. Gk 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: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 105.0$ mm, $l_{eff,cp} = 218.6$ mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 105.0$ mm

tension resistance of the T-stub flange:

in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 2.47$ 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

$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 241.04$ kN

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

$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 335.96$ kN

mode 3: bolt failure

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

tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 241.04$ kN

resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2}) = 360.0$ N/mm^2

tension resistance of welds: $F_{T,w,Rd} = 2^{1/2} \cdot f_{1w,d} \cdot a \cdot l_{eff} = 427.66$ kN ($\geq$ 241.04 kN, not decisive)

resistance and effective length of end-plate in bending (projection)

$F_{t,ep,Rd,1} = 241.04$ kN, $l_{eff,1} = 105.0$ mm

part of end-plate between beam flanges

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

here: number of bolt-rows n_b = 1

row 2

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

in mode 1: $\Sigma l_{eff,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 271.9$ mm, $l_{eff,cp} = 299.5$ mm

in mode 2: $\Sigma l_{eff,2} = l_{eff,2} = l_{eff,nc} = 271.9$ mm

tension resistance of the T-stub flange:

in mode 1+2: $M_{pl,Rd} = (0.25 \cdot \Sigma l_{eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 6.39$ 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

$F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 536.27$ kN

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

$F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 384.78$ kN

mode 3: bolt failure

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

tension resistance of the T-stub flange: $F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 384.78$ kN

resistance of a weld (req.1): $f_{1w,d} = f_u / (\beta_w \cdot \gamma_{M2}) = 360.0$ N/mm^2

tension resistance of welds: $F_{T,w,Rd} = 2^{1/2} \cdot f_{1w,d} \cdot a \cdot l_{eff} = 830.60$ kN ($\geq$ 384.78 kN, not decisive)

resistances and effective lengths of end-plate in bending (per bolt-row):

$F_{ep,Rd,2} = 384.78$ kN, $l_{eff,2} = 271.9$ mm

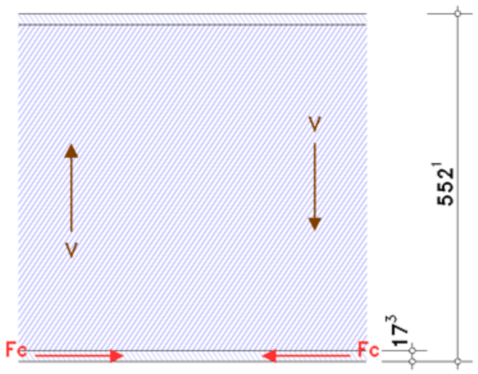
2.2.2. Gk 7: beam flange and web in compression

flange bottom: section class for $c/(\varepsilon \cdot t) = 4.39$: 1

web: section class for $\alpha = 0.52$ and $c/(\varepsilon \cdot t) = 42.13$: 1

section class of beam: 1

taking into account the moment-shear force-interaction $V_{Ed} = 116.7$ kN

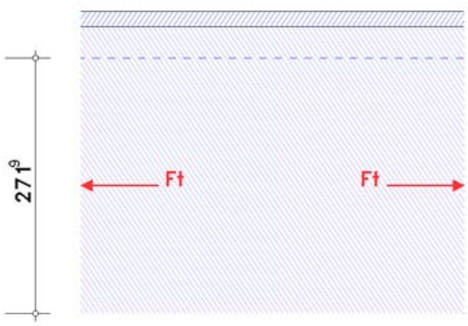


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

stress due to bending with shear force: $V_{Ed} = 116.7$ kN ≤ 492.5 kN $= V_{pl,Rd}/2$ $\Rightarrow$ no effect
resistance $M_{c,Rd} = M_{pl,Rd} = (W_{pl} \cdot f_y) / \gamma_{M0} = 642.25$ kNm, $W_{pl} = 2732.99$ cm^3
resistance of a flange (and web) with compression
$F_{c,f,Rd} = M_{c,Rd} / (h - t_f) = 1200.84$ kN

resistance of upper beam flange:
stress due to bending with shear force: $V_{Ed} = 116.7$ kN ≤ 492.5 kN $= V_{pl,Rd}/2$ $\Rightarrow$ no effect
resistance $M_{c,Rd} = M_{pl,Rd} = (W_{pl} \cdot f_y) / \gamma_{M0} = 642.25$ kNm, $W_{pl} = 2732.99$ cm^3
resistance of a flange (and web) with compression
$F_{c,f,Rd} = M_{c,Rd} / (h - t_f) = 1200.84$ kN

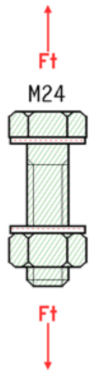
2.2.3. Gk 8: beam web in tension



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

each individual bolt-row:
row 2
effective width $b_{eff,t,wb} = 271.9$ mm (l_{eff} from bc 5)
resistance of a beam web in tension
$F_{t,wb,Rd} = b_{eff,t,wb} \cdot t_{wb} \cdot f_{y,wb} / \gamma_{M0} = 709.3$ kN

2.2.4. Gk 10: bolts in tension

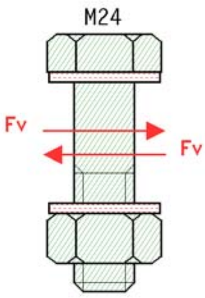


Only the essential sizes are sketched to scale.
The connection geometry is only hinted.

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 $B_{p,Rd} = (0.6 \cdot \pi \cdot d_m \cdot t_p \cdot f_u)) / \gamma_{M2} = 467.95$ kN, $t_p = 20.0$ 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

2.2.5. Gk 11: bolts in shear

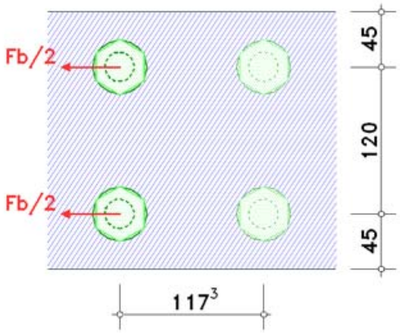
Only the essential sizes are sketched to scale.
The connection geometry is only hinted.



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

2.2.6. Gk 12: plate with bearing resistance

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



row 3
bolt 1: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 345.60$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bolt 2: bearing resistance $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d \cdot t) / \gamma_{M2} = 345.60$ kN, $k_1 = 2.50$, $\alpha_b = 1.00$
bearing resistance of 1x2 bolts: $\Sigma F_{b,Rd} = 691.20$ kN

2.3. connection capacity

2.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 593.5$ mm, $h_2 = 476.2$ mm

resistance per bolt-row
row 1: $F_{tr,Rd} = 241.0$ kN
row 2: $F_{tr,Rd} = 384.8$ kN
$\Sigma F_{tr,Rd} = 625.8$ kN
potential failure by basic component 5

resistance of flanges
$\Sigma F_{c,Rd}^* = 2401.7$ kN

moment resistance
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 326.3$ kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^* = 625.8$ kN
compression resistance
$N_{j,c,Rd} = \Sigma F_{c,Rd}^* = 2401.7$ kN

2.3.2. shear/bearing resistance

resistance per bolt-row
row 3: $F_{vr,Rd} = 434.3$ kN
$\Sigma F_{vr,Rd} = 434.3$ kN

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

2.3.3. total

$M_{j,Rd}$ = 326.3 kNm $N_{j,t,Rd}$ = 625.8 kN $N_{j,c,Rd}$ = 2401.7 kN $V_{j,Rd}$ = 434.3 kN

2.4. verifications

2.4.1. verification of the connection capacity by means of the component method

axial force: $N_{b,Ed} = |N_d \cdot \cos(\alpha) + V_d \cdot \sin(\alpha)| = 50.10$ kN $<$ 5%·$N_{pl,Rd}$ = 158.52 kN ⇒ moment resistance
internal moment: $M_{Ed} = M_d - N_d \cdot z_{bu} = 292.84$ kNm, z_{bu} = 265.7 mm
shear force: $V_{Ed} = |V_d| = 111.89$ kN

$M_{Ed}/M_{j,Rd} = 0.898 < 1$ ok

2.4.2. verification result

maximum utilization: max U = 0.898 $<$ 1 ok

2.5. rotational stiffness

stiffness coefficients
equivalent stiffness coefficient for 2 tension-bolt-rows:
1: k_5 = 11.01 mm, k_{10} = 8.62 mm ⇒ $k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 3.360$ mm
2: k_5 = 18.08 mm, k_{10} = 8.62 mm ⇒ $k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 4.413$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 7.680$ mm, $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 533.3$ mm
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 458668.5$ kNm/rad, $z = z_{eq} = 533.3$ mm, $\Sigma(1/k_i) = 0.130$ mm^{-1}
$|N_{b,Ed}| = 50.10$ kN $<$ 5%·$N_{pl,Rd}$ = 158.52 kN ok
$|M_{j,Ed}| = 292.84$ kNm $>$ 2/3 $M_{j,Rd}$ = 217.5 kNm ⇒ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 2.232$, $\Psi = 2.7$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 205493.9$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.082°$

3. final result

utilization/rotation of the connection

Lk	$S_{j,ini}$	S_j	φ_j	U_j	Gleichgewicht ΣH	ΣV	ΣM	
--	MNm/rad	MNm/rad	°		kN	kN	kNm	
1	458.7	205.5	0.082	0.898*	60.08	111.89	308.80	!!

$S_{j,ini}$: initial rotational stiffness; S_j: rotational stiffness; φ_j: rotation; U_j: utilization of the connection; tolerances of equilibrium 1 kN / 1 kNm
*) maximum utilization

maximum utilization: max U = 0.898 $<$ 1 ok
minimum rotational stiffness: min S_j = 205.5 MNm/rad, $S_{j,ini}$ = 458.7 MNm/rad, φ_j = 0.082°

verification succeeded