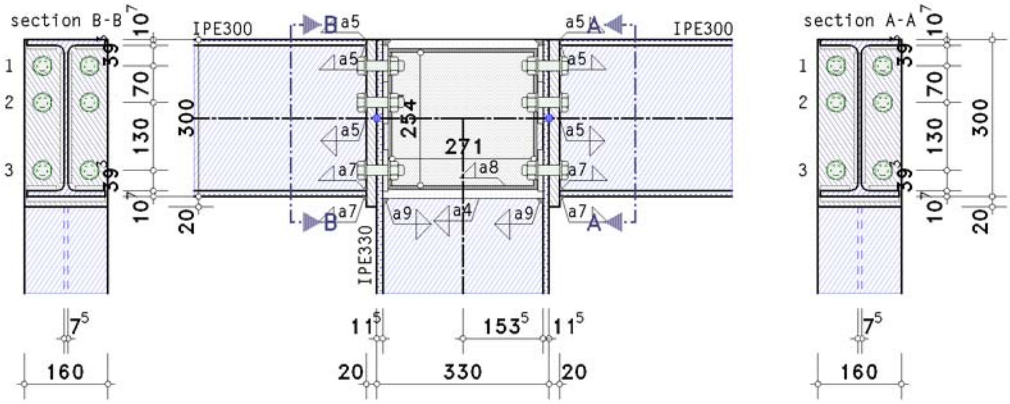
POS. 32: BEISPIEL BOLTED

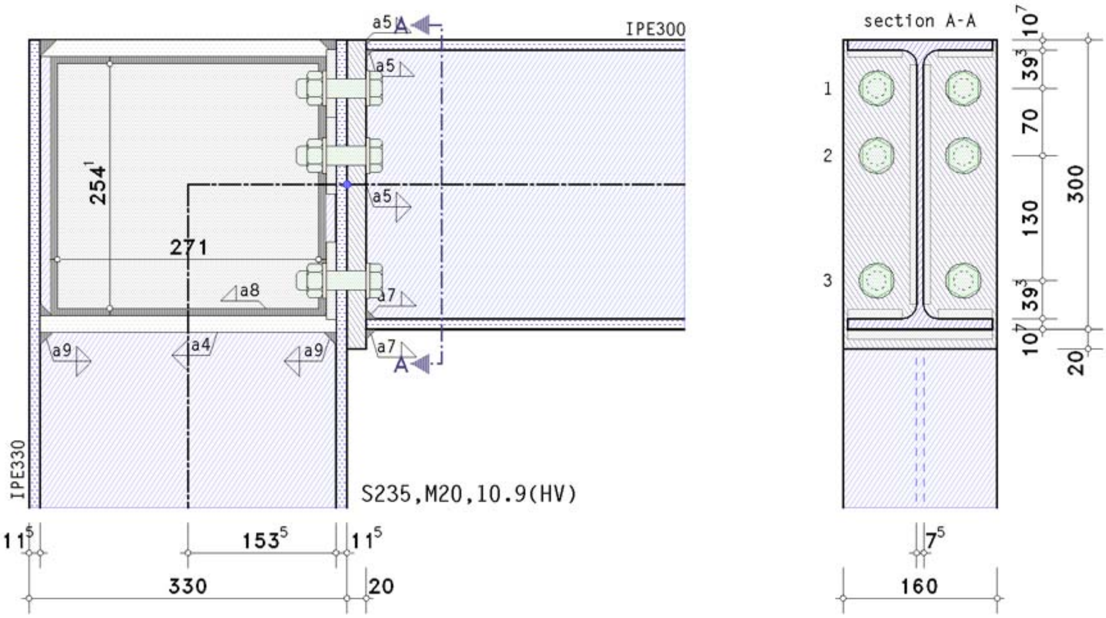
T-connection EC 3-1-8 (12.10), NA: Deutschland

1. input report

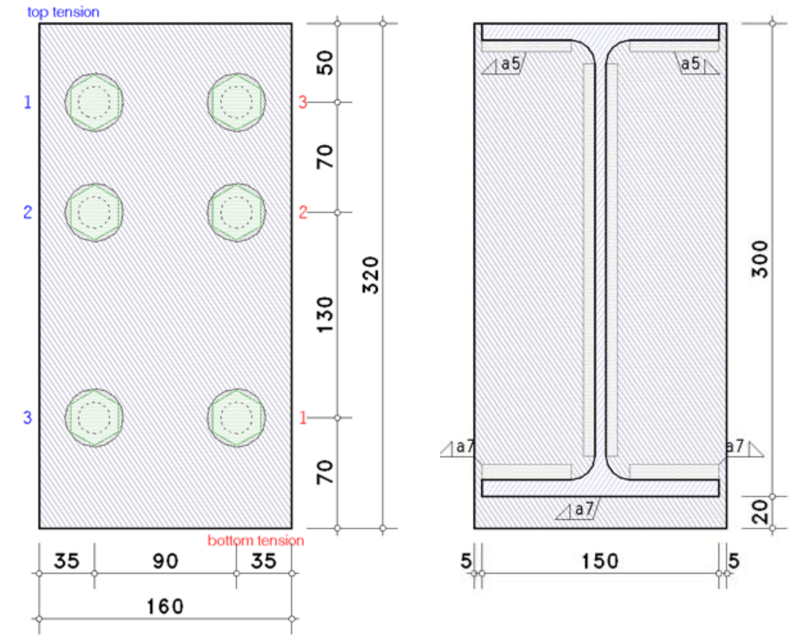


web stiffener (single-sided), t = 7.5 mm

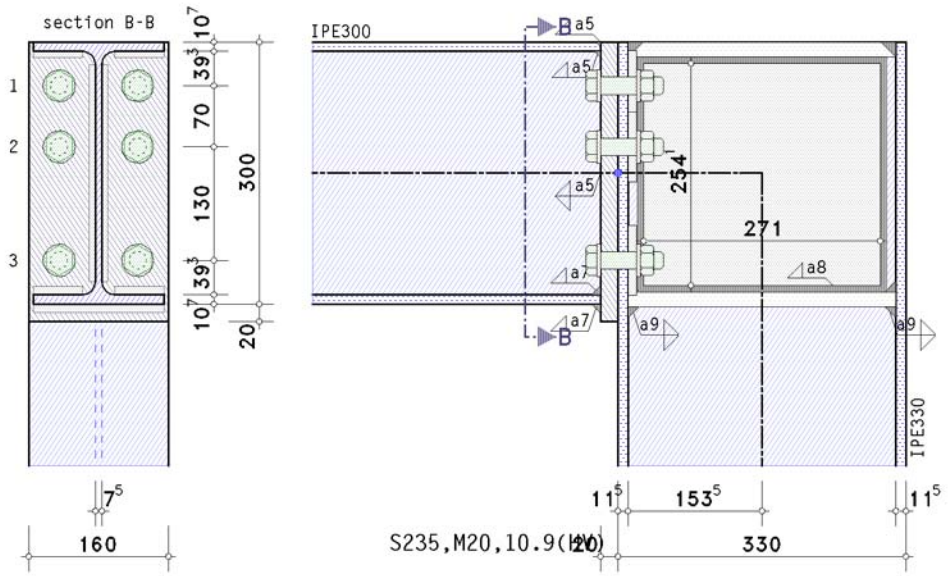
connection right



web stiffener (single-sided), t = 7.5 mm details (section A - A)

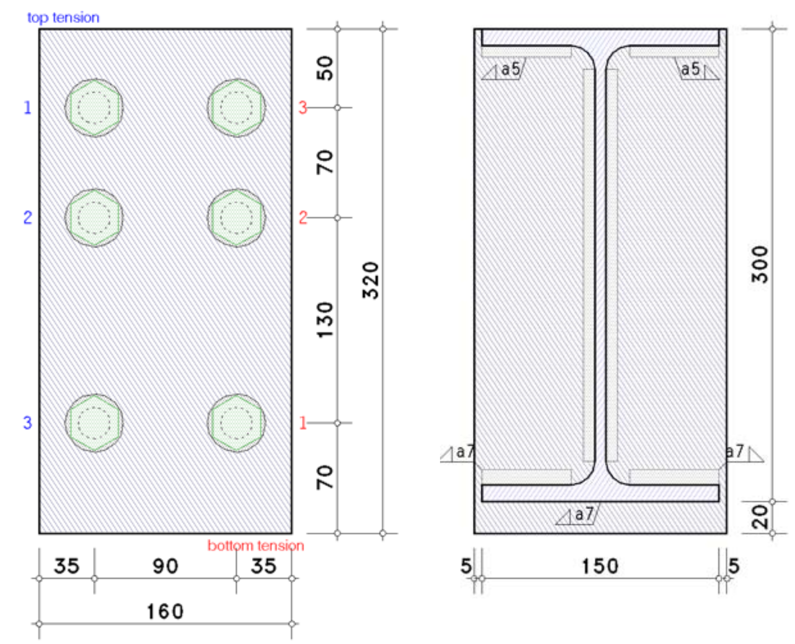


connection left



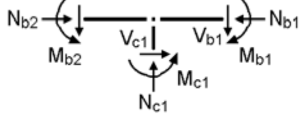
web stiffener (single-sided), t = 7.5 mm

details (section B - B)



According to EC 3-1-8, 5.3 in a double-sided beam-columnn-joint each joint is modelled separately.

steel grade
steel grade S235
column parameters
section IPE330
reinforcement of the section by 1 supplementary web plate(s):
thickness t_s = 7.5 mm, width b_s = 271.0 mm
weld thickness a_s = 7.5 mm
reinforcement of the section with transverse stiffeners (web stiffeners, d_{st} = 286.1 mm):
thickness t_{st} = 17.0 mm, width b_{st} = 76.3 mm, length l_{st} = 307.0 mm
recess at stiffeners c_{st} = 27.0 mm
welds $a_{st,f}$ = 9.0 mm, $a_{st,w}$ = 4.0 mm
double-sided beam-column joint, right
bolts
bolt class 10.9, bolt size M20
large wrench size (high strength bolt), preloaded (for info: preloading $F_{p,C}* = 0.7 \cdot f_{yb} \cdot A_s$ = 154.3 kN)
shear plane passes through the unthreaded portion of the bolt
flange reinforcement: thickness t_{bp} = 10.0 mm, width b_{bp} = 80.0 mm, length l_{bp} = 80.0 mm
beam parameters
section IPE300
verification parameters
bolted end-plate connection:
thickness t_p = 20.0 mm, width b_p = 160.0 mm, length l_p = 320.0 mm
projections $h_{p,o}$ = 0.0 mm, $h_{p,u}$ = 20.0 mm
bolts in connection:
3 bolt-rows with 2 bolts
all bolt-rows considered individually
all bolt-rows for shear transfer (rows 1-3)
bolt groups generated automatically, considering all groups reg. row 1
centre distance of the bolts to the lateral edge of the end-plate e_2 = 35.0 mm
centre distance of the first bolt-row to the upper edge of the end-plate (end row) e_o = 50.0 mm
centre distance of the last bolt-row to the bottom edge of the end-plate (end row) e_u = 70.0 mm
centre distance of the first bolt-row to the free edge of the column (end row) e_1' = 50.0 mm
centre distance of the bolt-rows from each other $p_{1\text{-}2}$ = 70.0 mm, $p_{2\text{-}3}$ = 130.0 mm
welds at the connection point:
beam flange top: fillet weld, weld thickness a = 5.0 mm
beam web: fillet weld, weld thickness a = 5.0 mm
beam flange bottom: fillet weld, weld thickness a = 7.0 mm
double-sided beam-column joint, left
bolts
bolt class 10.9, bolt size M20
large wrench size (high strength bolt), preloaded (for info: preloading $F_{p,C}* = 0.7 \cdot f_{yb} \cdot A_s$ = 154.3 kN)
shear plane passes through the unthreaded portion of the bolt
flange reinforcement: thickness t_{bp} = 10.0 mm, width b_{bp} = 80.0 mm, length l_{bp} = 80.0 mm
beam parameters
section IPE300
verification parameters
bolted end-plate connection:
thickness t_p = 20.0 mm, width b_p = 160.0 mm, length l_p = 320.0 mm
projections $h_{p,o}$ = 0.0 mm, $h_{p,u}$ = 20.0 mm
bolts in connection:
3 bolt-rows with 2 bolts
all bolt-rows considered individually
all bolt-rows for shear transfer (rows 1-3)
bolt groups generated automatically, considering all groups reg. row 1
centre distance of the bolts to the lateral edge of the end-plate e_2 = 35.0 mm
centre distance of the first bolt-row to the upper edge of the end-plate (end row) e_o = 50.0 mm
centre distance of the last bolt-row to the bottom edge of the end-plate (end row) e_u = 70.0 mm
centre distance of the first bolt-row to the free edge of the column (end row) e_1' = 50.0 mm
centre distance of the bolt-rows from each other $p_{1\text{-}2}$ = 70.0 mm, $p_{2\text{-}3}$ = 130.0 mm
welds at the connection point:
beam flange top: fillet weld, weld thickness a = 5.0 mm
beam web: fillet weld, weld thickness a = 5.0 mm
beam flange bottom: fillet weld, weld thickness a = 7.0 mm
internal forces and moments at the joint periphery perpendicular to the connection plane
Lk 1: N_{d1} = 300.00 kN M_{d1} = 80.00 kNm V_{d1} = 200.00 kN
Lk 2: N_{d1} = -140.00 kN M_{d1} = 80.00 kNm V_{d1} = 200.00 kN
Lk 3: M_{d1} = 80.00 kNm V_{d1} = 200.00 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 $\gamma_{M2} = 1.25$
prestressing of high strength bolts $\gamma_{M7} = 1.10$

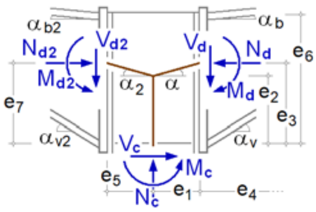
2. Lk 1

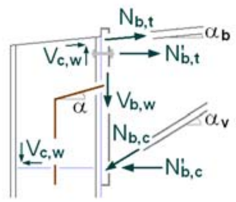
2.1. connection right

<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.

2.1.1. design values

⊥ zur connection plane   partial internal forces and moments





sign definition of EC3:   a positive axial force means <u>compression</u>, a positive bending moment produces tension at the <u>top</u>

slope angle: $\alpha_b = \alpha = \alpha_v = 0°$
slope angle: $\alpha_{b2} = \alpha_2 = \alpha_{v2} = 0°$
distance: $e_1 = 165.0$ mm, $e_3 = 144.6$ mm, $e_2 = 144.6$ mm, $e_5 = 165.0$ mm, $e_7 = 144.6$ mm, $e_6 = 286.1$ mm

internal forces and moments perpendicular to the connection planes
periphery beam (right)
$N_d = 300.00$ kN, $M_d = 80.00$ kNm, $V_d = 200.00$ kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 76.00$ kNm
$N_{b,t} = -N_d \cdot z_{bu}/z_b + M'_d/z_b = 112.70$ kN, $z_b = 289.3$ mm, $z_{bu} = 144.6$ mm
$N_{b,c} = N_d \cdot z_{bo}/z_b + M'_d/z_b = 412.70$ kN, $z_b = 289.3$ mm, $z_{bo} = 144.6$ mm

2.1.2. resistance of cross-section

plastic cross-sectional check for $N = -300.00$ kN, $M_y = -76.00$ kNm, $V_z = 200.00$ kN
elastic stresses: max $\sigma_x = 8.06$ kN/cm², min $\sigma_x = -19.21$ kN/cm², max $\tau = 10.59$ kN/cm²
valid normal/shear stress: zul $\sigma_{Rd} = 23.50$ kN/cm², zul $\tau_{Rd} = 13.57$ kN/cm²
top flange: resistance forces $N_{max,O} = 377.18$ kN, $N_{min,O} = -377.18$ kN
bottom flange: resistance forces $N_{max,U} = 377.18$ kN, $N_{min,U} = -377.18$ kN
web: shear force $V_S = 200.00$ kN, shear stress $\tau_S = 9.74$ kN/cm² $\Rightarrow$ $U_{\tau,S} = 0.718$
resistance forces $N_{max,S} = 336.15$ kN, $N_{min,S} = -336.15$ kN
main bending: axial force $N = -300.00$ kN, resistance forces $N_{max} = 1090.50$ kN, $N_{min} = -1090.50$ kN $\Rightarrow$ $U_N = 0.275$
moment $M_y = -76.00$ kNm, resistance moments $M_{y,max} = 114.06$ kNm, $M_{y,min} = -114.06$ kNm $\Rightarrow$ $U_{My} = 0.666$
total (possibly due to load increase): max $U = 0.830 < 1$ ok
utilizations: resistance $U_\sigma = 0.830 < 1$ ok, c/t-ratio $U_{c/t} = 0.394 < 1$ ok

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

2.1.3. connection capacity

transformation parameter: $\beta_j = 1.000$

2.1.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 244.6$ mm, $h_2 = 174.6$ mm, $h_3 = 44.6$ mm

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8
row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 234.9$ kN
row 3: $F_{tr,Rd} = 240.8$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (column)
decisive basic components: 3, 4
group 1
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 540.8$ kN $F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 453.3$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)

Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 301.5$ kN $\quad F_{tr,Rd} = 234.9$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 234.9$ kN

Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 214.0$ kN $\quad F_{tr,Rd} = 234.9$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (end-plate)

decisive basic components: 5, 8

group 1

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

Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 530.1$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 455.4$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)

Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 290.8$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 216.1$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

resistance per bolt-row (tension)

row 1: $F_{tr,Rd} = 239.3$ kN

row 2: $F_{tr,Rd} = 214.0$ kN

row 3: $F_{tr,Rd} = 240.8$ kN

$\Sigma F_{tr,Rd}^{*} = 694.1$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(7)

decisive basic components: 1, 2, 7

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

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 641.8$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 581.1$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 499.0$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (row 1)

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 402.5$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 341.8$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 259.7$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

row 3: $\Sigma F_{tr,Rd} = 453.3$ kN (rows 1 to 2)

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 188.5$ kN $\quad F_{tr,Rd} = 240.8$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 188.5$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 127.8$ kN $\quad F_{tr,Rd} = 188.5$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 127.8$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 45.7$ kN $\quad F_{tr,Rd} = 127.8$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 45.7$ kN

check acc. to EC 3-1-8, 6.2.7.2(9)

decisive basic component: 10

row 1: $F_{tx,Rd} = 239.3$ kN, $h_x = 244.6$ mm $\Rightarrow F_{tx,Rd} \le \lim F_{tx,Rd} = 335.2$ kN, no deduction

row 2: $F_{tx,Rd} = 214.0$ kN, $h_x = 174.6$ mm $\Rightarrow F_{tx,Rd} \le \lim F_{tx,Rd} = 335.2$ kN, no deduction

resistance per bolt-row (bending)

row 1: $F_{tr,Rd} = 239.3$ kN

row 2: $F_{tr,Rd} = 214.0$ kN

row 3: $F_{tr,Rd} = 45.7$ kN

$\Sigma F_{tr,Rd} = 499.0$ kN

potential failure by basic component 4, 7

resistance of flanges (compression)

$\Sigma F_{c,Rd}^{*} = 997.9$ kN

moment resistance **regarding the centre of compression**

$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 98.0$ kNm

tension resistance

$N_{j,t,Rd} = \Sigma F_{tr,Rd}^{*} = 694.1$ kN

compression resistance

$N_{j,c,Rd} = \Sigma F_{c,Rd}^{*} = 997.9$ kN

2.1.3.2. shear/bearing resistance

resistance per bolt-row

decisive basic components: 11, 12

row 1: $F_{vr,Rd} = 301.6$ kN

row 2: $F_{vr,Rd} = 268.5$ kN

row 3: $F_{vr,Rd} = 301.6$ kN

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

decisive basic component: 10

row 1: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 155.5$ kN $\quad$ with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.516$

row 2: $F_{vr,Rd} = f_{vt} \cdot 268.5$ kN $= 152.1$ kN $\quad$ with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.567$

row 3: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 273.7$ kN $\quad$ with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.908$

resistance per bolt-row

row 1: $F_{vr,Rd} = 155.5$ kN

row 2: $F_{vr,Rd} = 152.1$ kN

row 3: $F_{vr,Rd}$ = 273.7 kN
$\Sigma F_{vr,Rd}$ = 581.3 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 581.3 kN

2.1.3.3. shear resistance

shear resistance of end plate
end-plate: $V_{ep,Rd} = \tau_{Rd} \cdot t \cdot l_{eff}$ = 674.59 kN, τ_{Rd} = 135.7 N/mm², t = 20.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear strength: $f_{vw,d} = (f_u/3^{1/2}) / (\beta_w \cdot \gamma_{M2})$ = 207.8 N/mm², f_u = 360.0 N/mm², β_w = 0.80
welds: $F_{w,Rd} = 2 \cdot a \cdot l_{eff} \cdot f_{vw,d}$ = 516.71 kN, a = 5.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 516.71 kN
shear resistance of column web
decisive basic component: 1
$V_{wp,Rd}/\beta_j$ = 641.8 kN

2.1.3.4. total

$M_{j,Rd}$ = 98.0 kNm $N_{j,t,Rd}$ = 694.1 kN $N_{j,c,Rd}$ = 997.9 kN $V_{j,Rd}$ = 581.3 kN $V_{wp,Rd}/\beta_j$ = 641.8 kN $V_{ep,Rd}$ = 516.7 kN

2.1.4. verifications

calculation of internal lever arm z_{eq} s. rotational stiffness

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

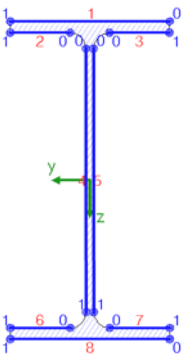
axial force: $N_{b,Ed} = |N_d|$ = 300.00 kN > $5\% \cdot N_{pl,Rd}$ = 63.23 kN ⇒ bending/comporession resistance
regarding beam axis with $N_{pl,Rd} = A_b \cdot f_{yb} / \gamma_{M0}$ = 1264.58 kN
axial force: $N_{Ed} = |N_d|$ = 300.00 kN
perpend. to connection plane
internal moment: $M_{Ed} = M_d$ = 80.00 kNm
perpend. to connection plane
shear force: $V_{Ed} = |V_d|$ = 200.00 kN
parallel to connection plane
shear force: $V_{c,w,Ed} = (M_{d1,w}-M_{d2,w})/z - (V_{c1}-V_{c2})/2$ = 413.99 kN, $M_{d1,w}$ = 82.3 kNm, $M_{d2,w}$ = 0.0 kNm, z = 198.8 mm
in column web

bending/comporession resistance
$N_{Ed}/N_{j,c,Rd} + M_{Ed}/M_{j,Rd}$ = 0.301 + 0.817 = 1.117 > 1 fault !!
shear/bearing resistance at 100% utilization of moment resistance
$V_{Ed}/V_{j,Rd}$ = 0.344 < 1 ok
shear resistance of column web
$V_{c,w,Ed}/(V_{wp,Rd}/\beta_j)$ = 0.645 < 1 ok
shear resistance of end plate
$V_{Ed}/V_{ep,Rd}$ = 0.387 < 1 ok

2.1.4.2. 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 = 5.0 mm	l_w = 150.0 mm
weld 2:	a_w = 5.0 mm	l_w = 56.5 mm
weld 3:	siehe weld 2	
weld 4:	a_w = 5.0 mm	l_w = 248.6 mm
weld 5:	siehe weld 4	
weld 6:	a_w = 7.0 mm	l_w = 56.5 mm
weld 7:	siehe weld 6	
weld 8:	a_w = 7.0 mm	l_w = 150.0 mm

design values refering to centroid of the section:
N_{Ed} = -300.00 kN, $M_{y,Ed}$ = -80.00 kNm, $V_{z,Ed}$ = 200.00 kN

cross-sectional properties refering to centroid of the line cross-section:
ΣA_w = 56.41 cm², $A_{w,z}$ = 24.86 cm², Σl_w = 102.3 cm
$I_{w,y}$ = 7855.63 cm⁴, $I_{w,z}$ = 673.03 cm⁴, $W_{w,t}$ = 53.81 cm³, Δz_w = 13.6 mm

stresses in weld edges:

weld 1, pt. 0: $\sigma_{w,x}$ = 113.38 N/mm²
weld 2, pt. 0: $\sigma_{w,x}$ = 102.48 N/mm²
weld 3, pt. 0: siehe weld 2
pt. 1: siehe weld 2
weld 4, pt. 0: $\sigma_{w,x}$ = 87.20 N/mm² $\tau_{w,z}$ = 80.45 N/mm²
pt. 1: $\sigma_{w,x}$ = -165.97 N/mm² $\tau_{w,z}$ = 80.45 N/mm²
weld 5, pt. 0: siehe weld 4
pt. 1: siehe weld 4
weld 6, pt. 0: $\sigma_{w,x}$ = -181.24 N/mm²
weld 7, pt. 0: siehe weld 6
pt. 1: siehe weld 6
weld 8, pt. 0: $\sigma_{w,x}$ = -192.14 N/mm²

verifications in weld edges:

verification of weld 1, pt. 0:

stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 113.4 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 5.67 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 5.67 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.545 < 1 ok

verification of weld 2, pt. 0:

stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 102.5 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 5.12 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 5.12 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.493 < 1 ok

verification of weld 4, pt. 0:

stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = (\sigma_{w,x}^2 + \tau_{w,z}^2)^{1/2}$ = 118.6 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 5.93 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 5.93 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.571 < 1 ok

verification of weld 4, pt. 1:

stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = (\sigma_{w,x}^2 + \tau_{w,z}^2)^{1/2}$ = 184.4 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 9.22 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 9.22 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.887 < 1 ok

verification of weld 6, pt. 0:

stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 181.2 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 12.69 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 14.55 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 7.0 mm
$F_{w,Ed}$ = 12.69 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U = 0.872 < 1 ok

verification of weld 8, pt. 0:

stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 192.1 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 13.45 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 14.55 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 7.0 mm
$F_{w,Ed}$ = 13.45 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U = 0.924 < 1 ok

Result:

weld 8, pt. 0: $\sigma_{w,x}$ = -192.14 N/mm²
Max: $F_{w,Ed}$ = 13.45 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U_w = 0.924 < 1 ok

2.1.4.3. verification of web stiffeners

$N_{R,t} = (-N_d \cdot z_{bu} + M_d) / z$ = 184.13 kN, $z = z_{eq}$ = 198.8 mm, z_{bu} = 144.6 mm
$N_{R,c} = (N_d \cdot z_{bo} + M_d) / z$ = 484.13 kN, $z = z_{eq}$ = 198.8 mm, z_{bo} = 54.1 mm

compression stiffener

$F_{c,Ed} = N_{R,c}$ = 484.13 kN
verification of the welds with the simplified method.

<u>dimensions, lever arms, forces per rib</u>

$b_R = b_{st}$ = 76.3 mm, $b_1 = b_R - r_R$ = 49.3 mm, $e_F = b_R - 0.5 \cdot b_1$ = 51.6 mm with r_R = 27.0 mm
$l_R = l_{st}$ = 307.0 mm, $l_1 = l_R - 2 \cdot r_R$ = 253.0 mm, $e_H = l_R$ = 307.0 mm, t_R = 17.0 mm
$F = 0.5 \cdot F_{c,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 176.3 kN, $H = F \cdot e_F/e_H$ = 29.6 kN
assumption: stiffeners do not buckle (verification method 'elastic-plastic' ⇒ max. section class 2)
c/t-ratio c/t = 4.49 ≤ 33.00 = 33·ε, $\varepsilon = (235/f_y)^{1/2}$ = 1.00 ⇒ section class 1 ≤ 2 ⇒ assumption succeeded !!

<u>cross-section at flange</u>

compression resistance $N_{c,Rd} = (A \cdot f_y) / \gamma_{M0}$ = 196.75 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 183.6 kN
F_{Ed} = 183.6 kN < F_{Rd} = 196.8 kN ⇒ U = 0.933 < 1 ok

cross-section at web

shear resistance V_{Rd} = 708.10 kN

design value: $F_{Ed} = F = 176.3$ kN

$F_{Ed} = 176.3$ kN < $F_{Rd} = 708.1$ kN ⇒ U = 0.249 < 1 ok

flange welds

fillet weld with a = 9.0 mm

weld thickness a = 9.0 mm > $a_{max} = 0.7 \cdot t_{min} = 8.0$ mm !!

weld thickness a = 9.0 mm > $a_{max} = 0.7 \cdot t_{min} = 8.0$ mm !!

resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a = 18.71$ kN/cm, $f_{vw,d} = 207.85$ N/mm², a = 9.0 mm

design value: $F_{Ed} = (F^2 + H^2)^{1/2} / (2 \cdot b_1) = 18.15$ kN/cm

0% decrease of stress by pressure contact

$F_{Ed} = 18.15$ kN/cm < $F_{Rd} = 18.71$ kN/cm ⇒ U = 0.970 < 1 ok

web welds

fillet weld with a = 4.0 mm

resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a = 8.31$ kN/cm, $f_{vw,d} = 207.85$ N/mm², a = 4.0 mm

design value: $F_{Ed} = F / (2 \cdot l_1) = 3.48$ kN/cm

0% decrease of stress by pressure contact

$F_{Ed} = 3.48$ kN/cm < $F_{Rd} = 8.31$ kN/cm ⇒ U = 0.419 < 1 ok

stiffener in tension

$F_{t,Ed} = N_{R,t} = 184.13$ kN

dimensions, lever arms, forces per rib

$b_R = b_{st} = 76.3$ mm, $b_1 = b_R - r_R = 49.3$ mm, $e_F = b_R - 0.5 \cdot b_1 = 51.6$ mm with $r_R = 27.0$ mm

$l_R = l_{st} = 307.0$ mm, $l_1 = l_R - 2 \cdot r_R = 253.0$ mm, $e_H = l_R = 307.0$ mm, $t_R = 17.0$ mm

$F = 0.5 \cdot F_{t,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f = 67.0$ kN, $H = F \cdot e_F/e_H = 11.3$ kN

cross-section at flange

tension resistance $N_{t,Rd}$ = 196.75 kN

design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2} = 69.8$ kN

$F_{Ed} = 69.8$ kN < $F_{Rd} = 196.8$ kN ⇒ U = 0.355 < 1 ok

cross-section at web

shear resistance V_{Rd} = 708.10 kN

design value: $F_{Ed} = F = 67.0$ kN

$F_{Ed} = 67.0$ kN < $F_{Rd} = 708.1$ kN ⇒ U = 0.095 < 1 ok

2.1.4.4. verification result

maximum utilization: max U = 1.117 > 1 fault !!

failure at verification of bending: U = 1.117

2.1.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 3 tension-bolt-rows:

effective stiffness coefficient for bolt-row 1:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 22.69$ mm, $l_{eff} = 144.5$ mm, $m = 35.8$ mm

$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.26$ mm, $b_{eff,t,wc} = 168.4$ mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 9.04$ mm, $l_{eff} = 127.8$ mm, $m = 26.9$ mm

$\Sigma(1/k_{i,1}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.624$ ⇒ $k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 1.603$ mm

effective stiffness coefficient for bolt-row 2:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 20.17$ mm, $l_{eff} = 128.5$ mm, $m = 35.8$ mm

$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 2.93$ mm, $b_{eff,t,wc} = 151.2$ mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 7.82$ mm, $l_{eff} = 110.6$ mm, $m = 26.9$ mm

$\Sigma(1/k_{i,2}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.682$ ⇒ $k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 1.467$ mm

effective stiffness coefficient for bolt-row 3:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 31.87$ mm, $l_{eff} = 203.0$ mm, $m = 35.8$ mm

$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.27$ mm, $b_{eff,t,wc} = 168.7$ mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 11.93$ mm, $l_{eff} = 168.7$ mm, $m = 26.9$ mm

$\Sigma(1/k_{i,3}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.584$ ⇒ $k_{eff,3} = 1 / \Sigma(1/k_{i,3}) = 1.713$ mm

equivalent internal lever arm: $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 198.8$ mm

$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 3.646$ mm

stiffness coefficient of basic component 1:

$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 9.77$ mm, $A_{vc} = 51.13$ cm², $\beta = 1.0$, $z = 198.8$ mm

stiffness coefficient of basic component 2:

$k_2 = \infty$ (stiffened)

sum of stiffness coefficients $\Sigma(1/k_i) = 1/k_1 + 1/k_2 + 1/k_{eq} = 0.377$

rotational stiffness

initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 22037.8$ kNm/rad, $z = z_{eq} = 198.8$ mm

internal moments at the connection point reg. centre of compression: $M_{j,Ed} = 36.61$ kNm, $M_{j,Rd} = 97.96$ kNm

axial force in the beam: $N_{b,Ed} = N_d = 300.00$ kN

$|N_{b,Ed}| = 300.00$ kN > $5\% \cdot N_{pl,Rd} = 63.23$ kN ⇒ rotational stiffness poss. inexact !!

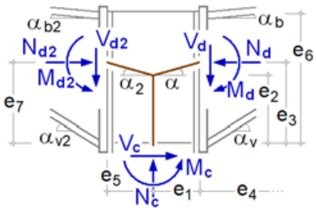
with $N_{pl,Rd} = A_b \cdot f_{yb} / \gamma_{M0} = 1264.58$ kN
$|M_{j,Ed}| = 36.61$ kNm $\leq$ 2/3 $M_{j,Rd} = 65.3$ kNm $\Rightarrow$ $\mu = 1$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 22037.8$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.095°$

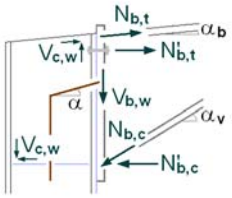
2.2. connection left

<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.

2.2.1. design values

⊥ zur connection plane   partial internal forces and moments





sign definition of EC3:   a positive axial force means <u>compression</u>, a positive bending moment produces tension at the <u>top</u>

slope angle: $\alpha_b = \alpha = \alpha_v = 0°$
slope angle: $\alpha_{b2} = \alpha_2 = \alpha_{v2} = 0°$
distance: $e_1 = 165.0$ mm, $e_3 = 144.6$ mm, $e_2 = 144.6$ mm, $e_5 = 165.0$ mm, $e_7 = 144.6$ mm, $e_6 = 286.1$ mm

internal forces and moments perpendicular to the connection planes
periphery beam (left)
$N_{d2} = 300.00$ kN, $M_{d2} = 80.00$ kNm, $V_{d2} = 200.00$ kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 0.00$ kNm

2.2.2. resistance of cross-section

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

2.2.3. connection capacity

transformation parameter: $\beta_j = 1.000$

2.2.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 244.6$ mm, $h_2 = 174.6$ mm, $h_3 = 44.6$ mm

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8
row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 234.9$ kN
row 3: $F_{tr,Rd} = 240.8$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (column)
decisive basic components: 3, 4
group 1
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 540.8$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 453.3$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 301.5$ kN $F_{tr,Rd} = 234.9$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 234.9$ kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 214.0$ kN $F_{tr,Rd} = 234.9$ kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (end-plate)
decisive basic components: 5, 8
group 1
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 530.1$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 455.4$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 290.8$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 216.1$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

resistance per bolt-row (tension)
row 1: $F_{tr,Rd}$ = 239.3 kN
row 2: $F_{tr,Rd}$ = 214.0 kN
row 3: $F_{tr,Rd}$ = 240.8 kN
$\Sigma F_{tr,Rd}^*$ = 694.1 kN

deductions acc. to EC 3-1-8, 6.2.7.2(7)
decisive basic components: 1, 2, 7
row 1: $\Sigma F_{tr,Rd}$ = 0.0 kN
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd}$ = 641.8 kN $F_{tr,Rd}$ = 239.3 kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 239.3 kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd}$ = 581.1 kN $F_{tr,Rd}$ = 239.3 kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 239.3 kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd}$ = 510.1 kN $F_{tr,Rd}$ = 239.3 kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 239.3 kN
row 2: $\Sigma F_{tr,Rd}$ = 239.3 kN (row 1)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd}$ = 402.5 kN $F_{tr,Rd}$ = 214.0 kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 214.0 kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd}$ = 341.8 kN $F_{tr,Rd}$ = 214.0 kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 214.0 kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd}$ = 270.8 kN $F_{tr,Rd}$ = 214.0 kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 214.0 kN
row 3: $\Sigma F_{tr,Rd}$ = 453.3 kN (rows 1 to 2)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd}$ = 188.5 kN $F_{tr,Rd}$ = 240.8 kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 188.5 kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd}$ = 127.8 kN $F_{tr,Rd}$ = 188.5 kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 127.8 kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd}$ = 56.8 kN $F_{tr,Rd}$ = 127.8 kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd}$ = 56.8 kN

check acc. to EC 3-1-8, 6.2.7.2(9)
decisive basic component: 10
row 1: $F_{tx,Rd}$ = 239.3 kN, h_x = 244.6 mm $\Rightarrow$ $F_{tx,Rd} \leq \lim F_{tx,Rd}$ = 335.2 kN, no deduction
row 2: $F_{tx,Rd}$ = 214.0 kN, h_x = 174.6 mm $\Rightarrow$ $F_{tx,Rd} \leq \lim F_{tx,Rd}$ = 335.2 kN, no deduction

resistance per bolt-row (bending)
row 1: $F_{tr,Rd}$ = 239.3 kN
row 2: $F_{tr,Rd}$ = 214.0 kN
row 3: $F_{tr,Rd}$ = 56.8 kN
$\Sigma F_{tr,Rd}$ = 510.1 kN
potential failure by basic component 4, 7

resistance of flanges (compression)
$\Sigma F_{c,Rd}^*$ = 1020.3 kN

moment resistance regarding the centre of compression
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 98.5 kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^*$ = 694.1 kN
compression resistance
$N_{j,c,Rd} = \Sigma F_{c,Rd}^*$ = 1020.3 kN

2.2.3.2. shear/bearing resistance

resistance per bolt-row
decisive basic components: 11, 12
row 1: $F_{vr,Rd}$ = 301.6 kN
row 2: $F_{vr,Rd}$ = 301.6 kN
row 3: $F_{vr,Rd}$ = 301.6 kN

deductions depending on tension force (at 100% utilization of moment resistance)
decisive basic component: 10
row 1: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN = 155.5 kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd})$ = 0.516
row 2: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN = 170.9 kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd})$ = 0.567
row 3: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN = 266.9 kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd})$ = 0.885

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 155.5 kN
row 2: $F_{vr,Rd}$ = 170.9 kN
row 3: $F_{vr,Rd}$ = 266.9 kN
$\Sigma F_{vr,Rd}$ = 593.3 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 593.3 kN

2.2.3.3. shear resistance

shear resistance of end plate
end-plate: $V_{ep,Rd} = \tau_{Rd} \cdot t \cdot l_{eff}$ = 674.59 kN, τ_{Rd} = 135.7 N/mm², t = 20.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear strength: $f_{vw,d} = (f_u/3^{1/2}) / (\beta_w \cdot \gamma_{M2})$ = 207.8 N/mm², f_u = 360.0 N/mm², β_w = 0.80
welds: $F_{w,Rd} = 2 \cdot a \cdot l_{eff} \cdot f_{vw,d}$ = 516.71 kN, a = 5.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 516.71 kN
shear resistance of column web
decisive basic component: 1

$V_{wp,Rd}/\beta_j$ = 641.8 kN

2.2.3.4. total

$M_{j,Rd}$ = 98.5 kNm $N_{j,t,Rd}$ = 694.1 kN $N_{j,c,Rd}$ = 1020.3 kN $V_{j,Rd}$ = 593.3 kN $V_{wp,Rd}/\beta_j$ = 641.8 kN $V_{ep,Rd}$ = 516.7 kN

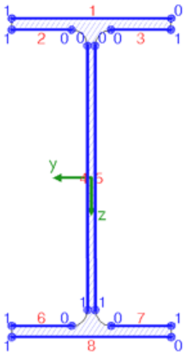
2.2.4. verifications

calculation of internal lever arm z_{eq} s. rotational stiffness

2.2.4.1. 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 = 5.0 mm	l_w = 150.0 mm
weld 2:	a_w = 5.0 mm	l_w = 56.5 mm
weld 3:	siehe weld 2	
weld 4:	a_w = 5.0 mm	l_w = 248.6 mm
weld 5:	siehe weld 4	
weld 6:	a_w = 7.0 mm	l_w = 56.5 mm
weld 7:	siehe weld 6	
weld 8:	a_w = 7.0 mm	l_w = 150.0 mm

design values refering to centroid of the section:

cross-sectional properties refering to centroid of the line cross-section:
ΣA_w = 56.41 cm², $A_{w,z}$ = 24.86 cm², Σl_w = 102.3 cm
$I_{w,y}$ = 7855.63 cm⁴, $I_{w,z}$ = 673.03 cm⁴, $W_{w,t}$ = 53.81 cm³, Δz_w = 13.6 mm

stresses in weld edges:

verifications in weld edges:

2.2.4.2. verification of web stiffeners

2.2.4.3. verification result

maximum utilization: max U = 0.000 < 1 **ok**

2.2.5. rotational stiffness

stiffness coefficients
equivalent stiffness coefficient for 3 tension-bolt-rows:
effective stiffness coefficient for bolt-row 1:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 22.69 mm, l_{eff} = 144.5 mm, m = 35.8 mm
$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 3.26 mm, $b_{eff,t,wc}$ = 168.4 mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 9.04 mm, l_{eff} = 127.8 mm, m = 26.9 mm
$\Sigma(1/k_{i,1}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.624 $\Rightarrow$ $k_{eff,1} = 1 / \Sigma(1/k_{i,1})$ = 1.603 mm
effective stiffness coefficient for bolt-row 2:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 20.17 mm, l_{eff} = 128.5 mm, m = 35.8 mm
$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 2.93 mm, $b_{eff,t,wc}$ = 151.2 mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 7.82 mm, l_{eff} = 110.6 mm, m = 26.9 mm
$\Sigma(1/k_{i,2}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.682 $\Rightarrow$ $k_{eff,2} = 1 / \Sigma(1/k_{i,2})$ = 1.467 mm
effective stiffness coefficient for bolt-row 3:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 31.87 mm, l_{eff} = 203.0 mm, m = 35.8 mm
$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 3.27 mm, $b_{eff,t,wc}$ = 168.7 mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 11.93 mm, l_{eff} = 168.7 mm, m = 26.9 mm
$\Sigma(1/k_{i,3}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.584 $\Rightarrow$ $k_{eff,3} = 1 / \Sigma(1/k_{i,3})$ = 1.713 mm
equivalent internal lever arm: $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r)$ = 198.8 mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq}$ = 3.646 mm
stiffness coefficient of basic component 1:
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z)$ = 9.77 mm, A_{vc} = 51.13 cm², β = 1.0, z = 198.8 mm
stiffness coefficient of basic component 2:
$k_2 = \infty$ (stiffened)

sum of stiffness coefficients $\Sigma(1/k_i) = 1/k_1 + 1/k_2 + 1/k_{eq} = 0.377$

rotational stiffness

initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 22037.8$ kNm/rad, $z = z_{eq} = 198.8$ mm

internal moments at the connection point reg. centre of compression: $M_{j,Ed} = 0.00$ kNm, $M_{j,Rd} = 98.46$ kNm

3. Lk 2

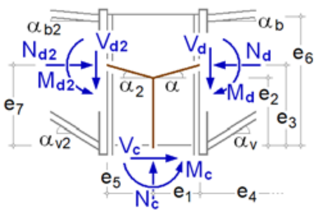
3.1. connection right

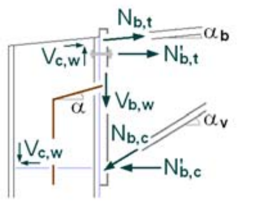
<u>notes</u>

connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.

3.1.1. design values

⊥ zur connection plane   partial internal forces and moments





sign definition of EC3: a positive axial force means <u>compression</u>, a positive bending moment produces tension at the <u>top</u>

slope angle: $\alpha_b = \alpha = \alpha_v = 0°$
slope angle: $\alpha_{b2} = \alpha_2 = \alpha_{v2} = 0°$
distance: $e_1 = 165.0$ mm, $e_3 = 144.6$ mm, $e_2 = 144.6$ mm, $e_5 = 165.0$ mm, $e_7 = 144.6$ mm, $e_6 = 286.1$ mm

internal forces and moments perpendicular to the connection planes

periphery beam (right)

$N_d = -140.00$ kN, $M_d = 80.00$ kNm, $V_d = 200.00$ kN

partial internal forces and moments

internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 76.00$ kNm

$N_{b,t} = -N_d \cdot z_{bu}/z_b + M'_d/z_b = 332.70$ kN, $z_b = 289.3$ mm, $z_{bu} = 144.6$ mm

$N_{b,c} = N_d \cdot z_{bo}/z_b + M'_d/z_b = 192.70$ kN, $z_b = 289.3$ mm, $z_{bo} = 144.6$ mm

3.1.2. resistance of cross-section

plastic cross-sectional check for $N = 140.00$ kN, $M_y = -76.00$ kNm, $V_z = 200.00$ kN
elastic stresses: max $\sigma_x = 16.24$ kN/cm², min $\sigma_x = -11.03$ kN/cm², max $\tau = 10.59$ kN/cm²
valid normal/shear stress: zul $\sigma_{Rd} = 23.50$ kN/cm², zul $\tau_{Rd} = 13.57$ kN/cm²
top flange: resistance forces $N_{max,O} = 377.18$ kN, $N_{min,O} = -377.18$ kN
bottom flange: resistance forces $N_{max,U} = 377.18$ kN, $N_{min,U} = -377.18$ kN
web: shear force $V_S = 200.00$ kN, shear stress $\tau_S = 9.74$ kN/cm² ⇒ $U_{\tau,S} = 0.718$
resistance forces $N_{max,S} = 336.15$ kN, $N_{min,S} = -336.15$ kN
main bending: axial force $N = 140.00$ kN, resistance forces $N_{max} = 1090.50$ kN, $N_{min} = -1090.50$ kN ⇒ $U_N = 0.128$
moment $M_y = -76.00$ kNm, resistance moments $M_{y,max} = 129.21$ kNm, $M_{y,min} = -129.21$ kNm ⇒ $U_{My} = 0.588$
total (possibly due to load increase): max $U = 0.749 < 1$ ok
utilizations: resistance $U_\sigma = 0.749 < 1$ ok, c/t-ratio $U_{c/t} = 0.257 < 1$ ok

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

3.1.3. connection capacity

transformation parameter: $\beta_j = 1.000$

3.1.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 244.6$ mm, $h_2 = 174.6$ mm, $h_3 = 44.6$ mm

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually

decisive basic components: 3, 4, 5, 8

row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 234.9$ kN
row 3: $F_{tr,Rd} = 240.8$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (column)

decisive basic components: 3, 4

group 1

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

Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 540.8$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 453.3$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 301.5$ kN $\quad F_{tr,Rd} = 234.9$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 234.9$ kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 214.0$ kN $\quad F_{tr,Rd} = 234.9$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (end-plate)
decisive basic components: 5, 8
group 1
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 530.1$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 455.4$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 290.8$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 216.1$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

resistance per bolt-row (tension)
row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 214.0$ kN
row 3: $F_{tr,Rd} = 240.8$ kN
$\Sigma F_{tr,Rd}^* = 694.1$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(7)
decisive basic components: 1, 2, 7
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 641.8$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 581.1$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 499.0$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (row 1)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 402.5$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 341.8$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 259.7$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN
row 3: $\Sigma F_{tr,Rd} = 453.3$ kN (rows 1 to 2)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 188.5$ kN $\quad F_{tr,Rd} = 240.8$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 188.5$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 127.8$ kN $\quad F_{tr,Rd} = 188.5$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 127.8$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 45.7$ kN $\quad F_{tr,Rd} = 127.8$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 45.7$ kN

check acc. to EC 3-1-8, 6.2.7.2(9)
decisive basic component: 10
row 1: $F_{tx,Rd} = 239.3$ kN, $h_x = 244.6$ mm $\Rightarrow F_{tx,Rd} \leq \lim F_{tx,Rd} = 335.2$ kN, no deduction
row 2: $F_{tx,Rd} = 214.0$ kN, $h_x = 174.6$ mm $\Rightarrow F_{tx,Rd} \leq \lim F_{tx,Rd} = 335.2$ kN, no deduction

resistance per bolt-row (bending)
row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 214.0$ kN
row 3: $F_{tr,Rd} = 45.7$ kN
$\Sigma F_{tr,Rd} = 499.0$ kN
potential failure by basic component 4, 7

resistance of flanges (compression)
$\Sigma F_{c,Rd}^* = 997.9$ kN

moment resistance regarding the centre of compression
$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 98.0$ kNm
tension resistance
$N_{j,t,Rd} = \Sigma F_{tr,Rd}^* = 694.1$ kN
compression resistance
$N_{j,c,Rd} = \Sigma F_{c,Rd}^* = 997.9$ kN

3.1.3.2. shear/bearing resistance

resistance per bolt-row
decisive basic components: 11, 12
row 1: $F_{vr,Rd} = 301.6$ kN
row 2: $F_{vr,Rd} = 268.5$ kN
row 3: $F_{vr,Rd} = 301.6$ kN

deductions depending on tension force (at 100% utilization of moment resistance)
decisive basic component: 10
row 1: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 155.5$ kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.516$
row 2: $F_{vr,Rd} = f_{vt} \cdot 268.5$ kN $= 152.1$ kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.567$
row 3: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 273.7$ kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.908$

resistance per bolt-row
row 1: $F_{vr,Rd} = 155.5$ kN

row 2: $F_{vr,Rd}$ = 152.1 kN
row 3: $F_{vr,Rd}$ = 273.7 kN
$\Sigma F_{vr,Rd}$ = 581.3 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 581.3 kN

3.1.3.3. shear resistance

shear resistance of end plate
end-plate: $V_{ep,Rd} = \tau_{Rd} \cdot t \cdot l_{eff}$ = 674.59 kN, τ_{Rd} = 135.7 N/mm², t = 20.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear strength: $f_{vw,d} = (f_u/3^{1/2}) / (\beta_w \cdot \gamma_{M2})$ = 207.8 N/mm², f_u = 360.0 N/mm², β_w = 0.80
welds: $F_{w,Rd} = 2 \cdot a \cdot l_{eff} \cdot f_{vw,d}$ = 516.71 kN, a = 5.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 516.71 kN
shear resistance of column web
decisive basic component: 1
$V_{wp,Rd}/\beta_j$ = 641.8 kN

3.1.3.4. total

$M_{j,Rd}$ = 98.0 kNm $N_{j,t,Rd}$ = 694.1 kN $N_{j,c,Rd}$ = 997.9 kN $V_{j,Rd}$ = 581.3 kN $V_{wp,Rd}/\beta_j$ = 641.8 kN $V_{ep,Rd}$ = 516.7 kN

3.1.4. verifications

calculation of internal lever arm z_{eq} s. rotational stiffness

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

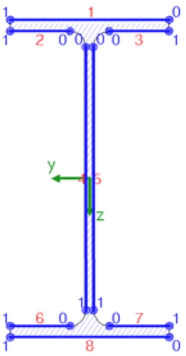
axial force: $N_{b,Ed} = |N_d|$ = 140.00 kN > 5%·$N_{pl,Rd}$ = 63.23 kN ⇒ bending/tension resistance
regarding beam axis with $N_{pl,Rd} = A_b \cdot f_{yb} / \gamma_{M0}$ = 1264.58 kN
axial force: $N_{Ed} = |N_d|$ = 140.00 kN
perpend. to connection plane
internal moment: $M_{Ed} = M_d$ = 80.00 kNm
perpend. to connection plane
shear force: $V_{Ed} = |V_d|$ = 200.00 kN
parallel to connection plane
shear force: $V_{c,w,Ed} = (M_{d1,w}-M_{d2,w})/z - (V_{c1}-V_{c2})/2$ = 413.99 kN, $M_{d1,w}$ = 82.3 kNm, $M_{d2,w}$ = 0.0 kNm, z = 198.8 mm
in column web

bending/tension resistance
$N_{Ed}/N_{j,t,Rd} + M_{Ed}/M_{j,Rd}$ = 0.202 + 0.817 = 1.018 > 1 fault !!
shear/bearing resistance at 100% utilization of moment resistance
$V_{Ed}/V_{j,Rd}$ = 0.344 < 1 ok
shear resistance of column web
$V_{c,w,Ed}/(V_{wp,Rd}/\beta_j)$ = 0.645 < 1 ok
shear resistance of end plate
$V_{Ed}/V_{ep,Rd}$ = 0.387 < 1 ok

3.1.4.2. 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 = 5.0 mm	l_w = 150.0 mm
weld 2:	a_w = 5.0 mm	l_w = 56.5 mm
weld 3:	siehe weld 2	
weld 4:	a_w = 5.0 mm	l_w = 248.6 mm
weld 5:	siehe weld 4	
weld 6:	a_w = 7.0 mm	l_w = 56.5 mm
weld 7:	siehe weld 6	
weld 8:	a_w = 7.0 mm	l_w = 150.0 mm

design values refering to centroid of the section:
N_{Ed} = 140.00 kN, $M_{y,Ed}$ = -80.00 kNm, $V_{z,Ed}$ = 200.00 kN

cross-sectional properties refering to centroid of the line cross-section:
ΣA_w = 56.41 cm², $A_{w,z}$ = 24.86 cm², Σl_w = 102.3 cm
$I_{w,y}$ = 7855.63 cm⁴, $I_{w,z}$ = 673.03 cm⁴, $W_{w,t}$ = 53.81 cm³, Δz_w = 13.6 mm

stresses in weld edges:

weld 1, pt. 0: $\sigma_{w,x}$ = 191.38 N/mm²
weld 2, pt. 0: $\sigma_{w,x}$ = 180.48 N/mm²
weld 3, pt. 0: siehe weld 2
pt. 1: siehe weld 2
weld 4, pt. 0: $\sigma_{w,x}$ = 165.21 N/mm² $\tau_{w,z}$ = 80.45 N/mm²
pt. 1: $\sigma_{w,x}$ = -87.96 N/mm² $\tau_{w,z}$ = 80.45 N/mm²
weld 5, pt. 0: siehe weld 4
pt. 1: siehe weld 4
weld 6, pt. 0: $\sigma_{w,x}$ = -103.24 N/mm²
weld 7, pt. 0: siehe weld 6
pt. 1: siehe weld 6
weld 8, pt. 0: $\sigma_{w,x}$ = -114.13 N/mm²

verifications in weld edges:

verification of weld 1, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 191.4 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 9.57 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 9.57 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.921 < 1 ok

verification of weld 2, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 180.5 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 9.02 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 9.02 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.868 < 1 ok

verification of weld 4, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = (\sigma_{w,x}^2 + \tau_{w,z}^2)^{1/2}$ = 183.8 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 9.19 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 9.19 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.884 < 1 ok

verification of weld 4, pt. 1:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = (\sigma_{w,x}^2 + \tau_{w,z}^2)^{1/2}$ = 119.2 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 5.96 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 5.96 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.574 < 1 ok

verification of weld 6, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 103.2 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 7.23 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 14.55 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 7.0 mm
$F_{w,Ed}$ = 7.23 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U = 0.497 < 1 ok

verification of weld 8, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 114.1 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 7.99 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 14.55 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 7.0 mm
$F_{w,Ed}$ = 7.99 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U = 0.549 < 1 ok

Result:
weld 1, pt. 0: $\sigma_{w,x}$ = 191.38 N/mm²
Max: $F_{w,Ed}$ = 9.57 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U_w = 0.921 < 1 ok

3.1.4.3. verification of web stiffeners

$N_{R,t} = (-N_d \cdot z_{bu} + M_d) / z$ = 504.28 kN, $z = z_{eq}$ = 198.8 mm, z_{bu} = 144.6 mm
$N_{R,c} = (N_d \cdot z_{bo} + M_d) / z$ = 364.28 kN, $z = z_{eq}$ = 198.8 mm, z_{bo} = 54.1 mm

compression stiffener

$F_{c,Ed} = N_{R,c}$ = 364.28 kN
verification of the welds with the simplified method.

<u>dimensions, lever arms, forces per rib</u>
$b_R = b_{st}$ = 76.3 mm, $b_1 = b_R - r_R$ = 49.3 mm, $e_F = b_R - 0.5 \cdot b_1$ = 51.6 mm with r_R = 27.0 mm
$l_R = l_{st}$ = 307.0 mm, $l_1 = l_R - 2 \cdot r_R$ = 253.0 mm, $e_H = l_R$ = 307.0 mm, t_R = 17.0 mm
$F = 0.5 \cdot F_{c,Ed} \cdot (b_f - 2 \cdot r \cdot t_w)/b_f$ = 132.6 kN, $H = F \cdot e_F/e_H$ = 22.3 kN
assumption: stiffeners do not buckle (verification method 'elastic-plastic' ⇒ max. section class 2)
c/t-ratio $c/t = 4.49 \leq 33.00 = 33 \cdot \varepsilon$, $\varepsilon = (235/f_y)^{1/2}$ = 1.00 ⇒ section class 1 ≤ 2 ⇒ assumption succeeded !!

<u>cross-section at flange</u>
compression resistance $N_{c,Rd} = (A \cdot f_y) / \gamma_{M0}$ = 196.75 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 138.1 kN

F_{Ed} = 138.1 kN < F_{Rd} = 196.8 kN ⇒ U = 0.702 < 1 ok

cross-section at web

shear resistance V_{Rd} = 708.10 kN

design value: F_{Ed} = F = 132.6 kN

F_{Ed} = 132.6 kN < F_{Rd} = 708.1 kN ⇒ U = 0.187 < 1 ok

flange welds

fillet weld with a = 9.0 mm

weld thickness a = 9.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 8.0 mm !!

weld thickness a = 9.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 8.0 mm !!

resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 18.71 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 9.0 mm

design value: $F_{Ed} = (F^2 + H^2)^{1/2} / (2 \cdot b_1)$ = 13.65 kN/cm

0% decrease of stress by pressure contact

F_{Ed} = 13.65 kN/cm < F_{Rd} = 18.71 kN/cm ⇒ U = 0.730 < 1 ok

web welds

fillet weld with a = 4.0 mm

resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 8.31 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 4.0 mm

design value: $F_{Ed} = F / (2 \cdot l_1)$ = 2.62 kN/cm

0% decrease of stress by pressure contact

F_{Ed} = 2.62 kN/cm < F_{Rd} = 8.31 kN/cm ⇒ U = 0.315 < 1 ok

stiffener in tension

$F_{t,Ed} = N_{R,t}$ = 504.28 kN

dimensions, lever arms, forces per rib

$b_R = b_{st}$ = 76.3 mm, $b_1 = b_R - r_R$ = 49.3 mm, $e_F = b_R - 0.5 \cdot b_1$ = 51.6 mm with r_R = 27.0 mm

$l_R = l_{st}$ = 307.0 mm, $l_1 = l_R - 2 \cdot r_R$ = 253.0 mm, $e_H = l_R$ = 307.0 mm, t_R = 17.0 mm

$F = 0.5 \cdot F_{t,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 183.6 kN, $H = F \cdot e_F/e_H$ = 30.9 kN

cross-section at flange

tension resistance $N_{t,Rd}$ = 196.75 kN

design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 191.2 kN

F_{Ed} = 191.2 kN < F_{Rd} = 196.8 kN ⇒ U = 0.972 < 1 ok

cross-section at web

shear resistance V_{Rd} = 708.10 kN

design value: F_{Ed} = F = 183.6 kN

F_{Ed} = 183.6 kN < F_{Rd} = 708.1 kN ⇒ U = 0.259 < 1 ok

3.1.4.4. verification result

maximum utilization: max U = 1.018 > 1 fault !!

failure at verification of bending: U = 1.018

3.1.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 3 tension-bolt-rows:

effective stiffness coefficient for bolt-row 1:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 22.69 mm, l_{eff} = 144.5 mm, m = 35.8 mm

$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 3.26 mm, $b_{eff,t,wc}$ = 168.4 mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 9.04 mm, l_{eff} = 127.8 mm, m = 26.9 mm

$\Sigma(1/k_{i,1}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.624 ⇒ $k_{eff,1} = 1 / \Sigma(1/k_{i,1})$ = 1.603 mm

effective stiffness coefficient for bolt-row 2:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 20.17 mm, l_{eff} = 128.5 mm, m = 35.8 mm

$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 2.93 mm, $b_{eff,t,wc}$ = 151.2 mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 7.82 mm, l_{eff} = 110.6 mm, m = 26.9 mm

$\Sigma(1/k_{i,2}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.682 ⇒ $k_{eff,2} = 1 / \Sigma(1/k_{i,2})$ = 1.467 mm

effective stiffness coefficient for bolt-row 3:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 31.87 mm, l_{eff} = 203.0 mm, m = 35.8 mm

$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 3.27 mm, $b_{eff,t,wc}$ = 168.7 mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 11.93 mm, l_{eff} = 168.7 mm, m = 26.9 mm

$\Sigma(1/k_{i,3}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.584 ⇒ $k_{eff,3} = 1 / \Sigma(1/k_{i,3})$ = 1.713 mm

equivalent internal lever arm: $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r)$ = 198.8 mm

$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq}$ = 3.646 mm

stiffness coefficient of basic component 1:

$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z)$ = 9.77 mm, A_{vc} = 51.13 cm², β = 1.0, z = 198.8 mm

stiffness coefficient of basic component 2:

$k_2 = \infty$ (stiffened)

sum of stiffness coefficients $\Sigma(1/k_i) = 1/k_1 + 1/k_2 + 1/k_{eq}$ = 0.377

rotational stiffness

initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i)$ = 22037.8 kNm/rad, $z = z_{eq}$ = 198.8 mm

internal moments at the connection point reg. centre of compression: $M_{j,Ed}$ = 100.25 kNm, $M_{j,Rd}$ = 97.96 kNm

axial force in the beam: $N_{b,Ed} = N_d$ = 140.00 kN

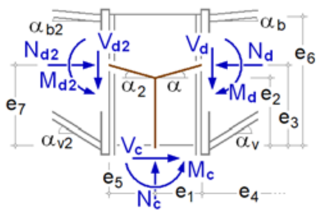
$|N_{b,Ed}| = 140.00$ kN $>$ $5\% \cdot N_{pl,Rd} = 63.23$ kN $\Rightarrow$ rotational stiffness poss. inexact !!
with $N_{pl,Rd} = A_b \cdot f_{yb} / \gamma_{M0} = 1264.58$ kN
$|M_{j,Ed}| = 100.25$ kNm $>$ 2/3 $M_{j,Rd} = 65.3$ kNm $\Rightarrow$ $\mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 3.181$, $\Psi = 2.7$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 6928.1$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.829°$

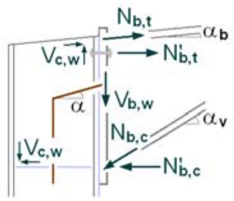
3.2. connection left

notes
connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.

3.2.1. design values

⊥ zur connection plane   partial internal forces and moments





sign definition of EC3: a positive axial force means compression, a positive bending moment produces tension at the top

slope angle: $\alpha_b = \alpha = \alpha_v = 0°$
slope angle: $\alpha_{b2} = \alpha_2 = \alpha_{v2} = 0°$
distance: $e_1 = 165.0$ mm, $e_3 = 144.6$ mm, $e_2 = 144.6$ mm, $e_5 = 165.0$ mm, $e_7 = 144.6$ mm, $e_6 = 286.1$ mm

internal forces and moments perpendicular to the connection planes
periphery beam (left)
$N_{d2} = -140.00$ kN, $M_{d2} = 80.00$ kNm, $V_{d2} = 200.00$ kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 0.00$ kNm

3.2.2. resistance of cross-section

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

3.2.3. connection capacity

transformation parameter: $\beta_j = 1.000$

3.2.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 244.6$ mm, $h_2 = 174.6$ mm, $h_3 = 44.6$ mm

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8
row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 234.9$ kN
row 3: $F_{tr,Rd} = 240.8$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (column)
decisive basic components: 3, 4
group 1
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 540.8$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 453.3$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 301.5$ kN $F_{tr,Rd} = 234.9$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 234.9$ kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 214.0$ kN $F_{tr,Rd} = 234.9$ kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (end-plate)
decisive basic components: 5, 8
group 1
row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 530.1$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 455.4$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN
row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 290.8$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 216.1$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

resistance per bolt-row (tension)

row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 214.0$ kN
row 3: $F_{tr,Rd} = 240.8$ kN
$\Sigma F_{tr,Rd}^{*} = 694.1$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(7)
decisive basic components: 1, 2, 7

row 1: $\Sigma F_{tr,Rd} = 0.0$ kN
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta j - \Sigma F_{tr,Rd} = 641.8$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 581.1$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 510.1$ kN $\quad F_{tr,Rd} = 239.3$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (row 1)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta j - \Sigma F_{tr,Rd} = 402.5$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 341.8$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 270.8$ kN $\quad F_{tr,Rd} = 214.0$ kN $< \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 214.0$ kN

row 3: $\Sigma F_{tr,Rd} = 453.3$ kN (rows 1 to 2)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta j - \Sigma F_{tr,Rd} = 188.5$ kN $\quad F_{tr,Rd} = 240.8$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 188.5$ kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 127.8$ kN $\quad F_{tr,Rd} = 188.5$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 127.8$ kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 56.8$ kN $\quad F_{tr,Rd} = 127.8$ kN $> \Delta F_{tr,Rd} \Rightarrow F_{tr,Rd} = 56.8$ kN

check acc. to EC 3-1-8, 6.2.7.2(9)
decisive basic component: 10

row 1: $F_{tx,Rd} = 239.3$ kN, $h_x = 244.6$ mm $\Rightarrow F_{tx,Rd} \leq \lim F_{tx,Rd} = 335.2$ kN, no deduction
row 2: $F_{tx,Rd} = 214.0$ kN, $h_x = 174.6$ mm $\Rightarrow F_{tx,Rd} \leq \lim F_{tx,Rd} = 335.2$ kN, no deduction

resistance per bolt-row (bending)

row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 214.0$ kN
row 3: $F_{tr,Rd} = 56.8$ kN
$\Sigma F_{tr,Rd} = 510.1$ kN
potential failure by basic component 4, 7

resistance of flanges (compression)

$\Sigma F_{c,Rd}^{*} = 1020.3$ kN

moment resistance regarding the centre of compression

$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 98.5$ kNm

tension resistance

$N_{j,t,Rd} = \Sigma F_{tr,Rd}^{*} = 694.1$ kN

compression resistance

$N_{j,c,Rd} = \Sigma F_{c,Rd}^{*} = 1020.3$ kN

3.2.3.2. shear/bearing resistance

resistance per bolt-row
decisive basic components: 11, 12

row 1: $F_{vr,Rd} = 301.6$ kN
row 2: $F_{vr,Rd} = 301.6$ kN
row 3: $F_{vr,Rd} = 301.6$ kN

deductions depending on tension force (at 100% utilization of moment resistance)
decisive basic component: 10

row 1: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 155.5$ kN $\quad$ with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.516$
row 2: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 170.9$ kN $\quad$ with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.567$
row 3: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 266.9$ kN $\quad$ with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.885$

resistance per bolt-row

row 1: $F_{vr,Rd} = 155.5$ kN
row 2: $F_{vr,Rd} = 170.9$ kN
row 3: $F_{vr,Rd} = 266.9$ kN
$\Sigma F_{vr,Rd} = 593.3$ kN

shear/bearing resistance

$V_{j,Rd} = \Sigma F_{vr,Rd} = 593.3$ kN

3.2.3.3. shear resistance

shear resistance of end plate

end-plate: $V_{ep,Rd} = \tau_{Rd} \cdot t \cdot l_{eff} = 674.59$ kN, $\tau_{Rd} = 135.7$ N/mm², $t = 20.0$ mm, $l_{eff} = d_w = 248.6$ mm

shear strength: $f_{vw,d} = (f_u/3^{1/2}) / (\beta_w \cdot \gamma_{M2}) = 207.8$ N/mm², $f_u = 360.0$ N/mm², $\beta_w = 0.80$

welds: $F_{w,Rd} = 2 \cdot a \cdot l_{eff} \cdot f_{vw,d} = 516.71$ kN, $a = 5.0$ mm, $l_{eff} = d_w = 248.6$ mm

shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd} = 516.71$ kN

shear resistance of column web

decisive basic component: 1

$V_{wp,Rd}/\beta_j = 641.8$ kN

3.2.3.4. total

$M_{j,Rd} = 98.5$ kNm $N_{j,t,Rd} = 694.1$ kN $N_{j,c,Rd} = 1020.3$ kN $V_{j,Rd} = 593.3$ kN $V_{wp,Rd}/\beta_j = 641.8$ kN $V_{ep,Rd} = 516.7$ kN

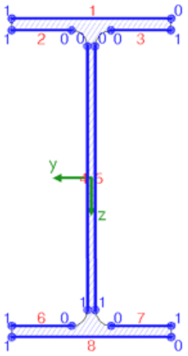
3.2.4. verifications

calculation of internal lever arm z_{eq} s. rotational stiffness

3.2.4.1. 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:	$a_w = 5.0$ mm	$l_w = 150.0$ mm
weld 2:	$a_w = 5.0$ mm	$l_w = 56.5$ mm
weld 3:	siehe weld 2	
weld 4:	$a_w = 5.0$ mm	$l_w = 248.6$ mm
weld 5:	siehe weld 4	
weld 6:	$a_w = 7.0$ mm	$l_w = 56.5$ mm
weld 7:	siehe weld 6	
weld 8:	$a_w = 7.0$ mm	$l_w = 150.0$ mm

design values refering to centroid of the section:

cross-sectional properties refering to centroid of the line cross-section:

$\Sigma A_w = 56.41$ cm², $A_{w,z} = 24.86$ cm², $\Sigma l_w = 102.3$ cm

$I_{w,y} = 7855.63$ cm⁴, $I_{w,z} = 673.03$ cm⁴, $W_{w,t} = 53.81$ cm³, $\Delta z_w = 13.6$ mm

stresses in weld edges:

verifications in weld edges:

3.2.4.2. verification of web stiffeners

3.2.4.3. verification result

maximum utilization: max $U = 0.000 < 1$ ok

3.2.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 3 tension-bolt-rows:

effective stiffness coefficient for bolt-row 1:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 22.69$ mm, $l_{eff} = 144.5$ mm, $m = 35.8$ mm

$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.26$ mm, $b_{eff,t,wc} = 168.4$ mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 9.04$ mm, $l_{eff} = 127.8$ mm, $m = 26.9$ mm

$\Sigma(1/k_{i,1}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.624 \Rightarrow k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 1.603$ mm

effective stiffness coefficient for bolt-row 2:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 20.17$ mm, $l_{eff} = 128.5$ mm, $m = 35.8$ mm

$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 2.93$ mm, $b_{eff,t,wc} = 151.2$ mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 7.82$ mm, $l_{eff} = 110.6$ mm, $m = 26.9$ mm

$\Sigma(1/k_{i,2}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.682 \Rightarrow k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 1.467$ mm

effective stiffness coefficient for bolt-row 3:

$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 31.87$ mm, $l_{eff} = 203.0$ mm, $m = 35.8$ mm

$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm

$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.27$ mm, $b_{eff,t,wc} = 168.7$ mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 11.93$ mm, $l_{eff} = 168.7$ mm, $m = 26.9$ mm
$\Sigma(1/k_{i,3}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.584 \Rightarrow k_{eff,3} = 1 / \Sigma(1/k_{i,3}) = 1.713$ mm
equivalent internal lever arm: $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 198.8$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 3.646$ mm
stiffness coefficient of basic component 1:
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 9.77$ mm, $A_{vc} = 51.13$ cm², $\beta = 1.0$, $z = 198.8$ mm
stiffness coefficient of basic component 2:
$k_2 = \infty$ (stiffened)
sum of stiffness coefficients $\Sigma(1/k_i) = 1/k_1 + 1/k_2 + 1/k_{eq} = 0.377$
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 22037.8$ kNm/rad, $z = z_{eq} = 198.8$ mm
internal moments at the connection point reg. centre of compression: $M_{j,Ed} = 0.00$ kNm, $M_{j,Rd} = 98.46$ kNm

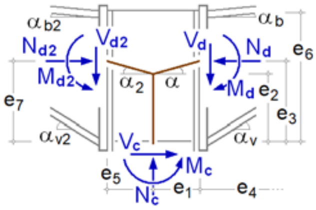
4. Lk 3

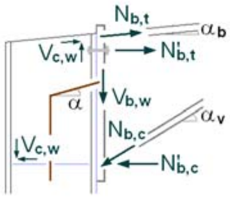
4.1. connection right

notes
connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.

4.1.1. design values

⊥ zur connection plane   partial internal forces and moments





sign definition of EC3: a positive axial force means compression, a positive bending moment produces tension at the top

slope angle: $\alpha_b = \alpha = \alpha_v = 0°$
slope angle: $\alpha_{b2} = \alpha_2 = \alpha_{v2} = 0°$
distance: $e_1 = 165.0$ mm, $e_3 = 144.6$ mm, $e_2 = 144.6$ mm, $e_5 = 165.0$ mm, $e_7 = 144.6$ mm, $e_6 = 286.1$ mm

internal forces and moments perpendicular to the connection planes
periphery beam (right)
$M_d = 80.00$ kNm, $V_d = 200.00$ kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 76.00$ kNm
$N_{b,t} = -N_d \cdot z_{bu}/z_b + M'_d/z_b = 262.70$ kN, $z_b = 289.3$ mm, $z_{bu} = 144.6$ mm
$N_{b,c} = N_d \cdot z_{bo}/z_b + M'_d/z_b = 262.70$ kN, $z_b = 289.3$ mm, $z_{bo} = 144.6$ mm

4.1.2. resistance of cross-section

plastic cross-sectional check for $M_y = -76.00$ kNm, $V_z = 200.00$ kN
elastic stresses: max $\sigma_x = 13.64$ kN/cm², min $\sigma_x = -13.64$ kN/cm², max $\tau = 10.59$ kN/cm²
valid normal/shear stress: zul $\sigma_{Rd} = 23.50$ kN/cm², zul $\tau_{Rd} = 13.57$ kN/cm²
top flange: resistance forces $N_{max,O} = 377.18$ kN, $N_{min,O} = -377.18$ kN
bottom flange: resistance forces $N_{max,U} = 377.18$ kN, $N_{min,U} = -377.18$ kN
web: shear force $V_S = 200.00$ kN, shear stress $\tau_S = 9.74$ kN/cm² $\Rightarrow U_{\tau,S} = 0.718$
resistance forces $N_{max,S} = 336.15$ kN, $N_{min,S} = -336.15$ kN
main bending: moment $M_y = -76.00$ kNm, resistance moments $M_{y,max} = 133.43$ kNm, $M_{y,min} = -133.43$ kNm $\Rightarrow U_{My} = 0.570$
total (possibly due to load increase): max $U = 0.719 < 1$ ok
utilizations: resistance $U_\sigma = 0.719 < 1$ ok, c/t-ratio $U_{c/t} = 0.287 < 1$ ok

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

4.1.3. connection capacity

transformation parameter: $\beta_j = 1.000$

4.1.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: h_1 = 244.6 mm, h_2 = 174.6 mm, h_3 = 44.6 mm

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8

row 1: $F_{tr,Rd}$ = 239.3 kN
row 2: $F_{tr,Rd}$ = 234.9 kN
row 3: $F_{tr,Rd}$ = 240.8 kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (column)
decisive basic components: 3, 4

group 1

row 1: $\Sigma F_{tr,Rd}$ = 0.0 kN
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd}$ = 540.8 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd}$ = 453.3 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
row 2: $\Sigma F_{tr,Rd}$ = 239.3 kN (due to row 1)
Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd}$ = 301.5 kN $F_{tr,Rd}$ = 234.9 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 234.9 kN
Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd}$ = 214.0 kN $F_{tr,Rd}$ = 234.9 kN > $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 214.0 kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (end-plate)
decisive basic components: 5, 8

group 1

row 1: $\Sigma F_{tr,Rd}$ = 0.0 kN
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd}$ = 530.1 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd}$ = 455.4 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
row 2: $\Sigma F_{tr,Rd}$ = 239.3 kN (due to row 1)
Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd}$ = 290.8 kN $F_{tr,Rd}$ = 214.0 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 214.0 kN
Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd}$ = 216.1 kN $F_{tr,Rd}$ = 214.0 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 214.0 kN

resistance per bolt-row (tension)

row 1: $F_{tr,Rd}$ = 239.3 kN
row 2: $F_{tr,Rd}$ = 214.0 kN
row 3: $F_{tr,Rd}$ = 240.8 kN
$\Sigma F_{tr,Rd}^*$ = 694.1 kN

deductions acc. to EC 3-1-8, 6.2.7.2(7)
decisive basic components: 1, 2, 7

row 1: $\Sigma F_{tr,Rd}$ = 0.0 kN
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd}$ = 641.8 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd}$ = 581.1 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd}$ = 499.0 kN $F_{tr,Rd}$ = 239.3 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 239.3 kN
row 2: $\Sigma F_{tr,Rd}$ = 239.3 kN (row 1)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd}$ = 402.5 kN $F_{tr,Rd}$ = 214.0 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 214.0 kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd}$ = 341.8 kN $F_{tr,Rd}$ = 214.0 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 214.0 kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd}$ = 259.7 kN $F_{tr,Rd}$ = 214.0 kN < $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 214.0 kN
row 3: $\Sigma F_{tr,Rd}$ = 453.3 kN (rows 1 to 2)
Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd}$ = 188.5 kN $F_{tr,Rd}$ = 240.8 kN > $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 188.5 kN
Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd}$ = 127.8 kN $F_{tr,Rd}$ = 188.5 kN > $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 127.8 kN
Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd}$ = 45.7 kN $F_{tr,Rd}$ = 127.8 kN > $\Delta F_{tr,Rd}$ ⇒ $F_{tr,Rd}$ = 45.7 kN

check acc. to EC 3-1-8, 6.2.7.2(9)
decisive basic component: 10

row 1: $F_{tx,Rd}$ = 239.3 kN, h_x = 244.6 mm ⇒ $F_{tx,Rd} \le \lim F_{tx,Rd}$ = 335.2 kN, no deduction
row 2: $F_{tx,Rd}$ = 214.0 kN, h_x = 174.6 mm ⇒ $F_{tx,Rd} \le \lim F_{tx,Rd}$ = 335.2 kN, no deduction

resistance per bolt-row (bending)

row 1: $F_{tr,Rd}$ = 239.3 kN
row 2: $F_{tr,Rd}$ = 214.0 kN
row 3: $F_{tr,Rd}$ = 45.7 kN
$\Sigma F_{tr,Rd}$ = 499.0 kN
potential failure by basic component 4, 7

resistance of flanges (compression)

$\Sigma F_{c,Rd}^*$ = 997.9 kN

moment resistance regarding the centre of compression

$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r)$ = 98.0 kNm

tension resistance

$N_{j,t,Rd} = \Sigma F_{tr,Rd}^*$ = 694.1 kN

compression resistance

$N_{j,c,Rd} = \Sigma F_{c,Rd}^*$ = 997.9 kN

4.1.3.2. shear/bearing resistance

resistance per bolt-row
decisive basic components: 11, 12
row 1: $F_{vr,Rd}$ = 301.6 kN
row 2: $F_{vr,Rd}$ = 268.5 kN
row 3: $F_{vr,Rd}$ = 301.6 kN

deductions depending on tension force (at 100% utilization of moment resistance)
decisive basic component: 10
row 1: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN = 155.5 kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.516$
row 2: $F_{vr,Rd} = f_{vt} \cdot 268.5$ kN = 152.1 kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.567$
row 3: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN = 273.7 kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.908$

resistance per bolt-row
row 1: $F_{vr,Rd}$ = 155.5 kN
row 2: $F_{vr,Rd}$ = 152.1 kN
row 3: $F_{vr,Rd}$ = 273.7 kN
$\Sigma F_{vr,Rd}$ = 581.3 kN

shear/bearing resistance
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 581.3 kN

4.1.3.3. shear resistance

shear resistance of end plate
end-plate: $V_{ep,Rd} = \tau_{Rd} \cdot t \cdot l_{eff}$ = 674.59 kN, τ_{Rd} = 135.7 N/mm², t = 20.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear strength: $f_{vw,d} = (f_u/3^{1/2}) / (\beta_w \cdot \gamma_{M2})$ = 207.8 N/mm², f_u = 360.0 N/mm², β_w = 0.80
welds: $F_{w,Rd} = 2 \cdot a \cdot l_{eff} \cdot f_{vw,d}$ = 516.71 kN, a = 5.0 mm, $l_{eff} = d_w$ = 248.6 mm
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd}$ = 516.71 kN
shear resistance of column web
decisive basic component: 1
$V_{wp,Rd}/\beta_j$ = 641.8 kN

4.1.3.4. total

$M_{j,Rd}$ = 98.0 kNm $N_{j,t,Rd}$ = 694.1 kN $N_{j,c,Rd}$ = 997.9 kN $V_{j,Rd}$ = 581.3 kN $V_{wp,Rd}/\beta_j$ = 641.8 kN $V_{ep,Rd}$ = 516.7 kN

4.1.4. verifications

calculation of internal lever arm z_{eq} s. rotational stiffness

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

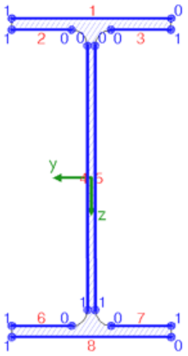
internal moment: $M_{Ed} = M_d$ = 80.00 kNm
perpend. to connection plane
shear force: $V_{Ed} = |V_d|$ = 200.00 kN
parallel to connection plane
shear force: $V_{c,w,Ed} = (M_{d1,w} - M_{d2,w})/z - (V_{c1} - V_{c2})/2$ = 413.99 kN, $M_{d1,w}$ = 82.3 kNm, $M_{d2,w}$ = 0.0 kNm, z = 198.8 mm
in column web

moment resistance
$M_{Ed}/M_{j,Rd} = 0.817 < 1$ ok
shear/bearing resistance at 100% utilization of moment resistance
$V_{Ed}/V_{j,Rd} = 0.344 < 1$ ok
shear/bearing resistance at 81.7% utilization of moment resistance
row 1: $F_{vr,Rd} = f_v \cdot 301.6$ kN = 182.3 kN with $f_v = 1 - 0.817 \cdot F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.604$
row 2: $F_{vr,Rd} = f_v \cdot 268.5$ kN = 173.5 kN with $f_v = 1 - 0.817 \cdot F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.646$
row 3: $F_{vr,Rd} = f_v \cdot 301.6$ kN = 278.8 kN with $f_v = 1 - 0.817 \cdot F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.925$
$V_{j,Rd} = \Sigma F_{vr,Rd}$ = 634.6 kN
$V_{Ed}/V_{j,Rd} = 0.315 < 1$ ok
shear resistance of column web
$V_{c,w,Ed}/(V_{wp,Rd}/\beta_j) = 0.645 < 1$ ok
shear resistance of end plate
$V_{Ed}/V_{ep,Rd} = 0.387 < 1$ ok

4.1.4.2. 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 = 5.0 mm l_w = 150.0 mm
weld 2: a_w = 5.0 mm l_w = 56.5 mm
weld 3: siehe weld 2
weld 4: a_w = 5.0 mm l_w = 248.6 mm
weld 5: siehe weld 4
weld 6: a_w = 7.0 mm l_w = 56.5 mm
weld 7: siehe weld 6
weld 8: a_w = 7.0 mm l_w = 150.0 mm

design values refering to centroid of the section:
$M_{y,Ed}$ = -80.00 kNm, $V_{z,Ed}$ = 200.00 kN

cross-sectional properties refering to centroid of the line cross-section:
ΣA_w = 56.41 cm², $A_{w,z}$ = 24.86 cm², Σl_w = 102.3 cm
$I_{w,y}$ = 7855.63 cm⁴, $I_{w,z}$ = 673.03 cm⁴, $W_{w,t}$ = 53.81 cm³, Δz_w = 13.6 mm

stresses in weld edges:

weld 1,	pt. 0:	$\sigma_{w,x}$ = 166.56 N/mm²	
weld 2,	pt. 0:	$\sigma_{w,x}$ = 155.66 N/mm²	
weld 3,	pt. 0:	siehe weld 2	
	pt. 1:	siehe weld 2	
weld 4,	pt. 0:	$\sigma_{w,x}$ = 140.39 N/mm²	$\tau_{w,z}$ = 80.45 N/mm²
	pt. 1:	$\sigma_{w,x}$ = -112.78 N/mm²	$\tau_{w,z}$ = 80.45 N/mm²
weld 5,	pt. 0:	siehe weld 4	
	pt. 1:	siehe weld 4	
weld 6,	pt. 0:	$\sigma_{w,x}$ = -128.06 N/mm²	
weld 7,	pt. 0:	siehe weld 6	
	pt. 1:	siehe weld 6	
weld 8,	pt. 0:	$\sigma_{w,x}$ = -138.95 N/mm²	

verifications in weld edges:

verification of weld 1, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 166.6 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 8.33 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 8.33 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.801 < 1 ok

verification of weld 2, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 155.7 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 7.78 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 7.78 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.749 < 1 ok

verification of weld 4, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = (\sigma_{w,x}^2 + \tau_{w,z}^2)^{1/2}$ = 161.8 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 8.09 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 8.09 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.778 < 1 ok

verification of weld 4, pt. 1:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = (\sigma_{w,x}^2 + \tau_{w,z}^2)^{1/2}$ = 138.5 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 6.93 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 10.39 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 5.0 mm
$F_{w,Ed}$ = 6.93 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U = 0.667 < 1 ok

verification of weld 6, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 128.1 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 8.96 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 14.55 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 7.0 mm
$F_{w,Ed}$ = 8.96 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U = 0.616 < 1 ok

verification of weld 8, pt. 0:
stresses on the design area of the weld (α = 45°):
$\sigma_{w,Ed} = \sigma_{w,x}$ = 139.0 N/mm²
resultant weld force $F_{w,Ed} = \sigma_{w,Ed} \cdot a$ = 9.73 kN/cm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 14.55 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 7.0 mm
$F_{w,Ed}$ = 9.73 kN/cm < $F_{w,Rd}$ = 14.55 kN/cm ⇒ U = 0.669 < 1 ok

Result:

weld 1, pt. 0: $\sigma_{w,x}$ = 166.56 N/mm²

Max: $F_{w,Ed}$ = 8.33 kN/cm < $F_{w,Rd}$ = 10.39 kN/cm ⇒ U_w = 0.801 < 1 ok

4.1.4.3. verification of web stiffeners

$N_{R,t} = (-N_d \cdot z_{bu} + M_d) / z$ = 402.42 kN, $z = z_{eq}$ = 198.8 mm, z_{bu} = 144.6 mm
$N_{R,c} = (N_d \cdot z_{bo} + M_d) / z$ = 402.42 kN, $z = z_{eq}$ = 198.8 mm, z_{bo} = 54.1 mm

compression stiffener

$F_{c,Ed} = N_{R,c}$ = 402.42 kN
verification of the welds with the simplified method.

dimensions, lever arms, forces per rib

$b_R = b_{st}$ = 76.3 mm, $b_1 = b_R - r_R$ = 49.3 mm, $e_F = b_R - 0.5 \cdot b_1$ = 51.6 mm with r_R = 27.0 mm
$l_R = l_{st}$ = 307.0 mm, $l_1 = l_R - 2 \cdot r_R$ = 253.0 mm, $e_H = l_R$ = 307.0 mm, t_R = 17.0 mm
$F = 0.5 \cdot F_{c,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 146.5 kN, $H = F \cdot e_F/e_H$ = 24.6 kN
assumption: stiffeners do not buckle (verification method 'elastic-plastic' ⇒ max. section class 2)
c/t-ratio $c/t = 4.49 \le 33.00 = 33 \cdot \varepsilon$, $\varepsilon = (235/f_y)^{1/2} = 1.00$ ⇒ section class $1 \le 2$ ⇒ assumption succeeded !!

cross-section at flange

compression resistance $N_{c,Rd} = (A \cdot f_y) / \gamma_{M0}$ = 196.75 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 152.6 kN
F_{Ed} = 152.6 kN < F_{Rd} = 196.8 kN ⇒ U = 0.776 < 1 ok

cross-section at web

shear resistance V_{Rd} = 708.10 kN
design value: $F_{Ed} = F$ = 146.5 kN
F_{Ed} = 146.5 kN < F_{Rd} = 708.1 kN ⇒ U = 0.207 < 1 ok

flange welds

fillet weld with a = 9.0 mm
weld thickness a = 9.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 8.0 mm !!
weld thickness a = 9.0 mm > $a_{max} = 0.7 \cdot t_{min}$ = 8.0 mm !!
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 18.71 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 9.0 mm
design value: $F_{Ed} = (F^2 + H^2)^{1/2} / (2 \cdot b_1)$ = 15.08 kN/cm
0% decrease of stress by pressure contact
F_{Ed} = 15.08 kN/cm < F_{Rd} = 18.71 kN/cm ⇒ U = 0.806 < 1 ok

web welds

fillet weld with a = 4.0 mm
resistance of a weld: $F_{w,Rd} = f_{vw,d} \cdot a$ = 8.31 kN/cm, $f_{vw,d}$ = 207.85 N/mm², a = 4.0 mm
design value: $F_{Ed} = F / (2 \cdot l_1)$ = 2.90 kN/cm
0% decrease of stress by pressure contact
F_{Ed} = 2.90 kN/cm < F_{Rd} = 8.31 kN/cm ⇒ U = 0.348 < 1 ok

stiffener in tension

$F_{t,Ed} = N_{R,t}$ = 402.42 kN

dimensions, lever arms, forces per rib

$b_R = b_{st}$ = 76.3 mm, $b_1 = b_R - r_R$ = 49.3 mm, $e_F = b_R - 0.5 \cdot b_1$ = 51.6 mm with r_R = 27.0 mm
$l_R = l_{st}$ = 307.0 mm, $l_1 = l_R - 2 \cdot r_R$ = 253.0 mm, $e_H = l_R$ = 307.0 mm, t_R = 17.0 mm
$F = 0.5 \cdot F_{t,Ed} \cdot (b_f - 2 \cdot r - t_w)/b_f$ = 146.5 kN, $H = F \cdot e_F/e_H$ = 24.6 kN

cross-section at flange

tension resistance $N_{t,Rd}$ = 196.75 kN
design value: $F_{Ed} = (F^2 + 3 \cdot H^2)^{1/2}$ = 152.6 kN
F_{Ed} = 152.6 kN < F_{Rd} = 196.8 kN ⇒ U = 0.776 < 1 ok

cross-section at web

shear resistance V_{Rd} = 708.10 kN
design value: $F_{Ed} = F$ = 146.5 kN
F_{Ed} = 146.5 kN < F_{Rd} = 708.1 kN ⇒ U = 0.207 < 1 ok

4.1.4.4. verification result

maximum utilization: max U = 0.817 < 1 ok

4.1.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 3 tension-bolt-rows:

effective stiffness coefficient for bolt-row 1:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 22.69 mm, l_{eff} = 144.5 mm, m = 35.8 mm
$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 3.26 mm, $b_{eff,t,wc}$ = 168.4 mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3$ = 9.04 mm, l_{eff} = 127.8 mm, m = 26.9 mm
$\Sigma(1/k_{i,1}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10}$ = 0.624 ⇒ $k_{eff,1} = 1 / \Sigma(1/k_{i,1})$ = 1.603 mm

effective stiffness coefficient for bolt-row 2:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3$ = 20.17 mm, l_{eff} = 128.5 mm, m = 35.8 mm
$k_{10} = 1.6 \cdot A_s / L_b$ = 6.15 mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2$ = 63.8 mm, t_{ges} = 41.5 mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c$ = 2.93 mm, $b_{eff,t,wc}$ = 151.2 mm

$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 7.82$ mm, $l_{eff} = 110.6$ mm, $m = 26.9$ mm
$\Sigma(1/k_{i,2}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.682 \Rightarrow k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 1.467$ mm
effective stiffness coefficient for bolt-row 3:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 31.87$ mm, $l_{eff} = 203.0$ mm, $m = 35.8$ mm
$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.27$ mm, $b_{eff,t,wc} = 168.7$ mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 11.93$ mm, $l_{eff} = 168.7$ mm, $m = 26.9$ mm
$\Sigma(1/k_{i,3}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.584 \Rightarrow k_{eff,3} = 1 / \Sigma(1/k_{i,3}) = 1.713$ mm
equivalent internal lever arm: $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 198.8$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 3.646$ mm

stiffness coefficient of basic component 1:
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 9.77$ mm, $A_{vc} = 51.13$ cm², $\beta = 1.0$, $z = 198.8$ mm
stiffness coefficient of basic component 2:
$k_2 = \infty$ (stiffened)
sum of stiffness coefficients $\Sigma(1/k_i) = 1/k_1 + 1/k_2 + 1/k_{eq} = 0.377$

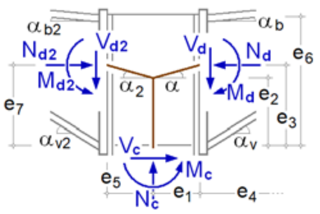
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 22037.8$ kNm/rad, $z = z_{eq} = 198.8$ mm
internal moments at the connection point reg. centre of compression: $M_{j,Ed} = 80.00$ kNm, $M_{j,Rd} = 97.96$ kNm
$|M_{j,Ed}| = 80.00$ kNm $>$ 2/3 $M_{j,Rd} = 65.3$ kNm $\Rightarrow \mu = ((1.5 \cdot M_{j,Ed}) / M_{j,Rd})^{\Psi} = 1.730$, $\Psi = 2.7$
rotational stiffness: $S_{j,Rd} = S_{j,ini} / \mu = 12741.2$ kNm/rad
rotation: $\varphi_{j,Ed} = M_{j,Ed} / S_{j,Rd} = 0.360°$

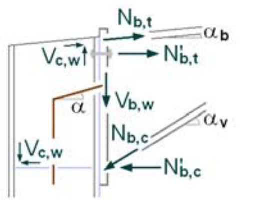
4.2. connection left

<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.

4.2.1. design values

⊥ zur connection plane   partial internal forces and moments





sign definition of EC3: a positive axial force means <u>compression</u>, a positive bending moment produces tension at the <u>top</u>

slope angle: $\alpha_b = \alpha = \alpha_v = 0°$
slope angle: $\alpha_{b2} = \alpha_2 = \alpha_{v2} = 0°$
distance: $e_1 = 165.0$ mm, $e_3 = 144.6$ mm, $e_2 = 144.6$ mm, $e_5 = 165.0$ mm, $e_7 = 144.6$ mm, $e_6 = 286.1$ mm

internal forces and moments perpendicular to the connection planes
periphery beam (left)
$M_{d2} = 80.00$ kNm, $V_{d2} = 200.00$ kN
partial internal forces and moments
internal forces and moments in the periphery end-plate-beam: $M'_d = M_d - V_d \cdot t_{ep} = 0.00$ kNm

4.2.2. resistance of cross-section

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

4.2.3. connection capacity

transformation parameter: $\beta_j = 1.000$

4.2.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 244.6$ mm, $h_2 = 174.6$ mm, $h_3 = 44.6$ mm

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 3, 4, 5, 8
row 1: $F_{tr,Rd} = 239.3$ kN
row 2: $F_{tr,Rd} = 234.9$ kN
row 3: $F_{tr,Rd} = 240.8$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (column)
decisive basic components: 3, 4

group 1

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

Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 540.8$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 453.3$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)

Gk 3: $\Delta F_{tr,Rd} = F_{t,wc,Rd} - \Sigma F_{tr,Rd} = 301.5$ kN $F_{tr,Rd} = 234.9$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 234.9$ kN

Gk 4: $\Delta F_{tr,Rd} = F_{t,fc,Rd} - \Sigma F_{tr,Rd} = 214.0$ kN $F_{tr,Rd} = 234.9$ kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(8) for bolt-rows as part of a group (end-plate)

decisive basic components: 5, 8

group 1

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

Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 530.1$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 455.4$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (due to row 1)

Gk 5: $\Delta F_{tr,Rd} = F_{t,ep,Rd} - \Sigma F_{tr,Rd} = 290.8$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

Gk 8: $\Delta F_{tr,Rd} = F_{t,wb,Rd} - \Sigma F_{tr,Rd} = 216.1$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

resistance per bolt-row (tension)

row 1: $F_{tr,Rd} = 239.3$ kN

row 2: $F_{tr,Rd} = 214.0$ kN

row 3: $F_{tr,Rd} = 240.8$ kN

$\Sigma F_{tr,Rd}^{*} = 694.1$ kN

deductions acc. to EC 3-1-8, 6.2.7.2(7)

decisive basic components: 1, 2, 7

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

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 641.8$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 581.1$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 510.1$ kN $F_{tr,Rd} = 239.3$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 239.3$ kN

row 2: $\Sigma F_{tr,Rd} = 239.3$ kN (row 1)

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 402.5$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 341.8$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 270.8$ kN $F_{tr,Rd} = 214.0$ kN $<$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 214.0$ kN

row 3: $\Sigma F_{tr,Rd} = 453.3$ kN (rows 1 to 2)

Gk 1: $\Delta F_{tr,Rd} = V_{wp,Rd}/\beta_j - \Sigma F_{tr,Rd} = 188.5$ kN $F_{tr,Rd} = 240.8$ kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 188.5$ kN

Gk 2: $\Delta F_{tr,Rd} = F_{c,w,Rd} - \Sigma F_{tr,Rd} = 127.8$ kN $F_{tr,Rd} = 188.5$ kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 127.8$ kN

Gk 7: $\Delta F_{tr,Rd} = F_{c,f,Rd} - \Sigma F_{tr,Rd} = 56.8$ kN $F_{tr,Rd} = 127.8$ kN $>$ $\Delta F_{tr,Rd}$ $\Rightarrow$ $F_{tr,Rd} = 56.8$ kN

check acc. to EC 3-1-8, 6.2.7.2(9)

decisive basic component: 10

row 1: $F_{tx,Rd} = 239.3$ kN, $h_x = 244.6$ mm $\Rightarrow$ $F_{tx,Rd} \leq \lim F_{tx,Rd} = 335.2$ kN, no deduction

row 2: $F_{tx,Rd} = 214.0$ kN, $h_x = 174.6$ mm $\Rightarrow$ $F_{tx,Rd} \leq \lim F_{tx,Rd} = 335.2$ kN, no deduction

resistance per bolt-row (bending)

row 1: $F_{tr,Rd} = 239.3$ kN

row 2: $F_{tr,Rd} = 214.0$ kN

row 3: $F_{tr,Rd} = 56.8$ kN

$\Sigma F_{tr,Rd} = 510.1$ kN

potential failure by basic component 4, 7

resistance of flanges (compression)

$\Sigma F_{c,Rd}^{*} = 1020.3$ kN

moment resistance regarding the centre of compression

$M_{j,Rd} = \Sigma(F_{tr,Rd} \cdot h_r) = 98.5$ kNm

tension resistance

$N_{j,t,Rd} = \Sigma F_{tr,Rd}^{*} = 694.1$ kN

compression resistance

$N_{j,c,Rd} = \Sigma F_{c,Rd}^{*} = 1020.3$ kN

4.2.3.2. shear/bearing resistance

resistance per bolt-row

decisive basic components: 11, 12

row 1: $F_{vr,Rd} = 301.6$ kN

row 2: $F_{vr,Rd} = 301.6$ kN

row 3: $F_{vr,Rd} = 301.6$ kN

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

decisive basic component: 10

row 1: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 155.5$ kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.516$

row 2: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 170.9$ kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.567$

row 3: $F_{vr,Rd} = f_{vt} \cdot 301.6$ kN $= 266.9$ kN with $f_{vt} = 1 - F_{tr,Rd} / (1.4 \cdot \Sigma F_{t,Rd}) = 0.885$

resistance per bolt-row

row 1: $F_{vr,Rd} = 155.5$ kN
row 2: $F_{vr,Rd} = 170.9$ kN
row 3: $F_{vr,Rd} = 266.9$ kN
$\Sigma F_{vr,Rd} = 593.3$ kN

shear/bearing resistance

$V_{j,Rd} = \Sigma F_{vr,Rd} = 593.3$ kN

4.2.3.3. shear resistance

shear resistance of end plate

end-plate: $V_{ep,Rd} = \tau_{Rd} \cdot t \cdot l_{eff} = 674.59$ kN, $\tau_{Rd} = 135.7$ N/mm², $t = 20.0$ mm, $l_{eff} = d_w = 248.6$ mm
shear strength: $f_{vw,d} = (f_u/3^{1/2}) / (\beta_w \cdot \gamma_{M2}) = 207.8$ N/mm², $f_u = 360.0$ N/mm², $\beta_w = 0.80$
welds: $F_{w,Rd} = 2 \cdot a \cdot l_{eff} \cdot f_{vw,d} = 516.71$ kN, $a = 5.0$ mm, $l_{eff} = d_w = 248.6$ mm
shear resistance of end plate: $V_{ep,Rd} = F_{w,Rd} = 516.71$ kN

shear resistance of column web

decisive basic component: 1
$V_{wp,Rd}/\beta_j = 641.8$ kN

4.2.3.4. total

$M_{j,Rd} = 98.5$ kNm $N_{j,t,Rd} = 694.1$ kN $N_{j,c,Rd} = 1020.3$ kN $V_{j,Rd} = 593.3$ kN $V_{wp,Rd}/\beta_j = 641.8$ kN $V_{ep,Rd} = 516.7$ kN

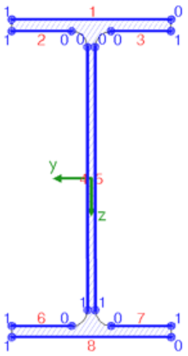
4.2.4. verifications

calculation of internal lever arm z_{eq} s. rotational stiffness

4.2.4.1. 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:	$a_w = 5.0$ mm	$l_w = 150.0$ mm
weld 2:	$a_w = 5.0$ mm	$l_w = 56.5$ mm
weld 3:	siehe weld 2	
weld 4:	$a_w = 5.0$ mm	$l_w = 248.6$ mm
weld 5:	siehe weld 4	
weld 6:	$a_w = 7.0$ mm	$l_w = 56.5$ mm
weld 7:	siehe weld 6	
weld 8:	$a_w = 7.0$ mm	$l_w = 150.0$ mm

design values refering to centroid of the section:

cross-sectional properties refering to centroid of the line cross-section:

$\Sigma A_w = 56.41$ cm², $A_{w,z} = 24.86$ cm², $\Sigma l_w = 102.3$ cm
$I_{w,y} = 7855.63$ cm⁴, $I_{w,z} = 673.03$ cm⁴, $W_{w,t} = 53.81$ cm³, $\Delta z_w = 13.6$ mm

stresses in weld edges:

verifications in weld edges:

4.2.4.2. verification of web stiffeners

4.2.4.3. verification result

maximum utilization: max $U = 0.000 < 1$ ok

4.2.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 3 tension-bolt-rows:
effective stiffness coefficient for bolt-row 1:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 22.69$ mm, $l_{eff} = 144.5$ mm, $m = 35.8$ mm
$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k + t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.26$ mm, $b_{eff,t,wc} = 168.4$ mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{fc}^3 / m^3 = 9.04$ mm, $l_{eff} = 127.8$ mm, $m = 26.9$ mm
$\Sigma(1/k_{i,1}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.624 \Rightarrow k_{eff,1} = 1 / \Sigma(1/k_{i,1}) = 1.603$ mm

effective stiffness coefficient for bolt-row 2:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 20.17$ mm, $l_{eff} = 128.5$ mm, $m = 35.8$ mm
$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 2.93$ mm, $b_{eff,t,wc} = 151.2$ mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 7.82$ mm, $l_{eff} = 110.6$ mm, $m = 26.9$ mm
$\Sigma(1/k_{i,2}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.682 \Rightarrow k_{eff,2} = 1 / \Sigma(1/k_{i,2}) = 1.467$ mm
effective stiffness coefficient for bolt-row 3:
$k_5 = 0.9 \cdot l_{eff} \cdot t_p^3 / m^3 = 31.87$ mm, $l_{eff} = 203.0$ mm, $m = 35.8$ mm
$k_{10} = 1.6 \cdot A_s / L_b = 6.15$ mm, $L_b = t_{ges} + 2 \cdot t_p + (t_k+t_m)/2 = 63.8$ mm, $t_{ges} = 41.5$ mm
$k_3 = 0.7 \cdot b_{eff,t,wc} \cdot t_{wc} / d_c = 3.27$ mm, $b_{eff,t,wc} = 168.7$ mm
$k_4 = 0.9 \cdot l_{eff} \cdot t_{tc}^3 / m^3 = 11.93$ mm, $l_{eff} = 168.7$ mm, $m = 26.9$ mm
$\Sigma(1/k_{i,3}) = 1/k_3 + 1/k_4 + 1/k_5 + 1/k_{10} = 0.584 \Rightarrow k_{eff,3} = 1 / \Sigma(1/k_{i,3}) = 1.713$ mm
equivalent internal lever arm: $z_{eq} = \Sigma(k_{eff,r} \cdot h_r^2) / \Sigma(k_{eff,r} \cdot h_r) = 198.8$ mm
$k_{eq} = \Sigma(k_{eff,r} \cdot h_r) / z_{eq} = 3.646$ mm
stiffness coefficient of basic component 1:
$k_1 = 0.38 \cdot A_{vc} / (\beta \cdot z) = 9.77$ mm, $A_{vc} = 51.13$ cm², $\beta = 1.0$, $z = 198.8$ mm
stiffness coefficient of basic component 2:
$k_2 = \infty$ (stiffened)
sum of stiffness coefficients $\Sigma(1/k_i) = 1/k_1 + 1/k_2 + 1/k_{eq} = 0.377$
rotational stiffness
initial rotational stiffness: $S_{j,ini} = (E \cdot z^2) / \Sigma(1/k_i) = 22037.8$ kNm/rad, $z = z_{eq} = 198.8$ mm
internal moments at the connection point reg. centre of compression: $M_{j,Ed} = 0.00$ kNm, $M_{j,Rd} = 98.46$ kNm

5. final result

utilization/rotation of the connection

Lk	right			left				equilibrium			
	$S_{j,ini}$	S_j	φ_j	$S_{j,ini}$	S_j	φ_j	U_j	ΣH	ΣV	ΣM	
--	MNm/rad	MNm/rad	°	MNm/rad	MNm/rad	°		kN	kN	kNm	
1	22.0	22.0	0.095	22.0	0.0	0	1.117*	300.00	200.00	69.61	!!
2	22.0	6.9	0.829	22.0	0.0	0	1.018!	140.00	200.00	133.25	!!
3	22.0	12.7	0.360	22.0	0.0	0	0.817	0.00	200.00	113.00	!!

$S_{j,ini}$: 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 [Lk 1]: max U = 1.117 > 1 fault !!
minimum rotational stiffness (right): min S_j = 6.9 MNm/rad, $S_{j,ini}$ = 22.0 MNm/rad, φ_j = 0.829°

resistance not ensured !!