1. input report

Steel grade
Steel grade S235

Bolts
Bolt class 10.9, bolt size M20

Large wrench size (high strength bolt), preloaded (for info: preloading $F_{p,c} = 0.7f_{yb}A_s = 154.3 \text{ kN}$)

Shear plane passes through the unthreaded portion of the bolt

Beam parameters
Section HE360A

Verification parameters
Bolted end-plate connection:
- Thickness $t_p = 25.0 \text{ mm}$, width $b_p = 300.0 \text{ mm}$, length $l_p = 440.0 \text{ mm}$
- Projections $h_{p,o} = 70.0 \text{ mm}$, $h_{p,u} = 20.0 \text{ mm}$

Bolts in connection:
- 3 bolt-rows with 4 bolts
d 1: 4 bolts, row 2: 4 bolts, row 3: 4 bolts
  of these 2 bolt-rows top in tension (rows 1-2)
  and 1 bolt-row for shear transfer top (row 3)
  of these 1 bolt-row bottom in tension (row 3)
  and 2 bolt-rows for shear transfer bottom (rows 2-3)
Calculation method (4 bolts per row) acc. to Wagenknecht, Stahlbau-Praxis acc. to EC 3, Bd.3
Centre distance between outer and inner bolt $w_2 = 70.0 \text{ mm}$
Centre distance of the bolts to the lateral edge of the end-plate $e_2 = 35.0 \text{ mm}$
Centre distance of the first bolt-row to the upper edge of the end-plate (end row) $e_u = 30.0 \text{ mm}$
Centre distance of the last bolt-row to the bottom edge of the end-plate (end row) $e_u = 80.0 \text{ mm}$
Centre distance of the bolt-rows from each other $p_{1-2} = 100.0 \text{ mm}$, $p_{2-3} = 230.0 \text{ mm}$
welds at the connection point:

- beam flange top: fillet weld, weld thickness $a = 9.0$ mm
- beam web: fillet weld, weld thickness $a = 4.0$ mm
- beam flange bottom: fillet weld, weld thickness $a = 9.0$ mm

**internal forces and moments at the joint periphery referring to the system axes**

Lk 1: $M_{b,Ed} = 320.00$ kNm, $V_{b,Ed} = 180.00$ kN
Lk 2: $M_{b,Ed} = -120.00$ kNm

**check of data**

**ok**

distances between bolt-rows at end-plate:

- horizontal: $e_2 = 35.0$ mm $\geq 1.2 \cdot d_0 = 26.4$ mm, $e_2 = 35.0$ mm $< 4t + 40$ mm = $140.0$ mm
- horizontal: $p_2 = 70.0$ mm $> 2.4 \cdot d_0 = 52.8$ mm, $p_2 = 70.0$ mm $< \min(14t, 200$ mm) = $200.0$ mm
- horizontal: $p_2 = 90.0$ mm $> 2.4 \cdot d_0 = 52.8$ mm, $p_2 = 90.0$ mm $< \min(14t, 200$ mm) = $200.0$ mm

- vertical: $e_1 = 30.0$ mm $> 1.2 \cdot d_0 = 26.4$ mm, $e_1 = 30.0$ mm $< 4t + 40$ mm = $140.0$ mm
- vertical: $p_1 = 100.0$ mm $> 2.2 \cdot d_0 = 48.4$ mm, $p_1 = 100.0$ mm $< \min(14t, 200$ mm) = $200.0$ mm
- vertical: $p_1 = 230.0$ mm $> 2.2 \cdot d_0 = 48.4$ mm, $p_1 = 230.0$ mm $< \min(14t, 200$ mm) = $200.0$ mm

**vertical:** $e_1 = 80.0$ mm $> 1.2 \cdot d_0 = 26.4$ mm, $e_1 = 80.0$ mm $< 4t + 40$ mm = $140.0$ mm

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

**notes**

no verification for cross-sections.

### 2. Lk 1

**notes**

connection is verified due to EC 3-1-8 regardless of preloading.

however, connections may be constructed with prestressed high strength bolts.

no consideration of bolt groups in joints with 4 bolts per row.

#### 2.1. design values

periphery connection $\perp$ zur connection plane

**partial internal forces and moments**

periphery-side

**partial internal forces and moments**

periphery-side

sign definition of EC3:

a positive axial force means compression, a positive bending moment produces tension at the top

slope angle: $\alpha_b = \alpha_y = \alpha_a = 0^\circ$

transformation joint values -> design values

$M_d = 320.00$ kNm, $V_d = 180.00$ kN

**internal forces and moments perpendicular to the connection planes**

periphery beam

$M_d = 320.00$ kNm, $V_d = 180.00$ kN

**partial internal forces and moments**

internal forces and moments in the periphery end-plate-beam: $M'_{d} = M_{d} - V_{d}a_{ep} = 315.50$ kNm

$N_{b,t} = -N_{a}z_{b}/z_{b} + M'd/z_{b} = 948.87$ kN, $z_{b} = 322.5$ mm, $z_{bu} = 166.3$ mm

$N_{b,c} = N_{a}z_{b}/z_{b} + M'd/z_{b} = 948.87$ kN, $z_{b} = 322.5$ mm, $z_{bo} = 166.3$ mm

### 2.2. basic components

beam splice w. end-plate: basic components: 5, 7, 8, 10, 11, 12

#### 2.2.1. Gk 5: end-plate in bending

Only the essential sizes are sketched to scale.

The connection geometry is only hinted.
extended part of end-plate  
in projecting part of end plate only one bolt-row (n_b - 1) is considered (4 bolts per row).  
distance centre-line of the bolt to beam flange m_1 = 29.8 mm  

**effective length of the T-stub flange (end-plate)**  
s_1 = 30.0 mm, m_2 = 29.8 mm, w_1 = 35.0 mm, w_2 = 70.0 mm, w_3 = 0.5 mm, w_4 = 90.0 mm with n_b = 300.0 mm, b_d = 300.0 mm  
end bolt-row outside tension flange of beam / of stiffener in tension  
al_{eff,1} = 2 = (\alpha \cdot m_1 + w_2) = 327.3 mm  
al_{eff,2} = \pi \cdot m_2 + 2 \cdot w_2 + w_1 = 327.3 mm  
al_{eff,3} = \pi \cdot m_2 + 2 \cdot (w_2+w_3) = 303.7 mm  
al_{eff,4} = 4 \cdot \pi \cdot m_2 = 374.7 mm  
al_{eff,sa} = \min(l_{eff,1}, l_{eff,2}, l_{eff,3}, l_{eff,4}) = 303.7 mm  
l_{eff,n,1} = 4 \cdot m_1 + 1.25 \cdot \alpha_1 + w_2 = 226.8 mm  
l_{eff,n,2} = 2 \cdot m_2 + 0.625 \cdot \alpha_1 + w_2 + 0.5 \cdot w_1 = 193.4 mm  
l_{eff,n,3} = 2 \cdot m_2 + 0.625 \cdot \alpha_1 + w_2 + w_3 = 183.4 mm  
l_{eff,n,4} = 8 \cdot m_2 + 2.5 \cdot \alpha_1 = 313.5 mm  
l_{eff,n,5} = w_2 + w_3 + 0.5 \cdot w_1 = 150.0 mm  
l_{eff,n,sa} = \min(l_{eff,n,1}, l_{eff,n,2}, l_{eff,n,3}, l_{eff,n,4}, l_{eff,n,5}) = 150.0 mm  
in mode 1: \gamma_{eff,1} = \min(l_{eff,1}, l_{eff,2}) = 150.0 mm  
in mode 2: \gamma_{eff,2} = \min(l_{eff,2}) = 150.0 mm  

**tension resistance of the T-stub flange**  
n = \min(5 \cdot e_{min}, 1.25 \cdot m) = 30.0 mm, \ e_{min} = 30.0 mm, m = 29.8 mm  
resisting plastic moments:  
in mode 1+2: \quad M_{pl,Rd} = (0.25 \cdot \gamma_{eff} \cdot t \cdot f_y) / \gamma_{M_0} = 5.51 \text{ kNm}, \quad t = 25.0 \text{ mm}, \quad f_y = 235.0 \text{ N/mm}^2, \quad \gamma_{M_0} = 1.00  
design value of tension resistance:  
tension resistance of one bolt: \quad F_{t,Rd} = (k_2 \cdot f_{ub,A_0}) / \gamma_{M_2} = 176.40 \text{ kN}, \quad k_2 = 0.90  
in mode 3: \quad \Sigma F_{t,Rd} = 4 \cdot n_b \cdot F_{t,Rd} = 705.60 \text{ kN}, \quad n_b = 4  
praying forces always appear at preloaded bolts!  
calculation with the standard method  
mode 1: complete yielding of the T-stub flange  
F_{t,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 738.87 \text{ kN}  
mode 2: bolt failure simultaneously with yielding of the T-stub flange  
F_{t,2,Rd} = (2 \cdot M_{pl,2,Rd} + n \cdot \Sigma F_{t,Rd}) / (m+n) = 503.03 \text{ kN}  
mode 3: bolt failure  
F_{t,3,Rd} = \Sigma F_{t,Rd} = 705.60 \text{ kN}, \quad F_{t,4,Rd} = 2 \cdot M_{pl,1,Rd} / m = 369.43 \text{ kN}  
tension resistance of the T-stub flange: \quad F_{t,Rd} = \min(F_{t,1,Rd}, F_{t,2,Rd}, F_{t,3,Rd}) = 503.03 \text{ kN}  
shear strength: \quad f_{w,m} = f_{w,0} / (1.33) = 207.8 \text{ N/mm}^2, \quad f_{w} = 360.0 \text{ N/mm}^2, \quad \gamma_{w} = 0.80  
tension resistance of welds: \quad F_{w,Rd} = 2 \cdot f_{w,d} \cdot a_{eff} = 561.18 \text{ kN} (\geq 538.03 \text{ kN}, \text{ not decisive})  

**resistance and effective length of end-plate in bending (projection)**  
F_{t,esp,Rd,1} = 538.03 \text{ kN}, \quad a_{eff,1} = 150.0 mm  

part of end-plate between beam flanges  
equivalent T-stub flange (each individual bolt-row):  
here: number of bolt-rows n_b - 1  

**row 2**  
(4 bolts per row)  
distance centre-line of the bolt to the stiffener m_2 = 32.3 mm  
distance centre-line of the bolt to the edge of flange e = 35.0 mm  
distance centre-line of the bolt to the stub web m = 35.5 mm  

**effective length of the T-stub flange (end-plate)**  
in end bolt-row outside tension flange of beam / of stiffener in tension  
al_{eff,1} = 2 = (\alpha \cdot m + w_2) = 445.8 mm  
al_{eff,2} = \pi \cdot m_2 + 2 \cdot w_2 + w_3 = 362.9 mm  
al_{eff,3} = \pi \cdot m_2 + 2 \cdot (w_2+w_3) = 321.4 mm  
al_{eff,si} = \min(l_{eff,1}, l_{eff,2}, l_{eff,si}) = 321.4 mm  
distance of inner bolt axis to the edge of flange e = 105.0 mm  
coefficient for stiffened column flanges and end-plates:  
input values: \lambda_1 = m / (m+e) = 0.253, \lambda_2 = m_2 / (m+e) = 0.230 \Rightarrow \alpha = 7.37 \text{ (s. figure 6.11)}  
al_{eff,nc,1} = \alpha \cdot m_1 = 261.4 mm  
al_{eff,nc,2} = 4 \cdot m_1 + 1.25 \cdot (w_2+w_3) = 273.1 mm  
al_{eff,nc,si} = \min(l_{eff,nc,1}, l_{eff,nc,2}) = 261.4 mm  
in mode 1: \quad \gamma_{eff,1} = \min(l_{eff,nc,1}, l_{eff,nc,si}) = 261.4 mm  
in mode 2: \quad \gamma_{eff,2} = \min(l_{eff,nc,2}) = 261.4 mm  

tension resistance of the T-stub flange  
m = 35.5 mm, \ n = \min(5 \cdot e_{min}, 1.25 \cdot m) = 44.3 mm  
\gamma_{M_0} = 1.00  
resisting plastic moments:  
in mode 1: \quad M_{pl,Rd} = (0.25 \cdot \gamma_{eff} \cdot t \cdot f_y) / \gamma_{M_0} = 9.60 \text{ kNm}, \quad t = 25.0 \text{ mm}, \quad f_y = 235.0 \text{ N/mm}^2, \quad \gamma_{M_0} = 1.00  
design value of tension resistance:  
tension resistance of one bolt: \quad F_{t,Rd} = (k_2 \cdot f_{ub,A_0}) / \gamma_{M_2} = 176.40 \text{ kN}, \quad k_2 = 0.90  
in mode 3: \quad \Sigma F_{t,Rd} = 4 \cdot n_b \cdot F_{t,Rd} = 705.60 \text{ kN}, \quad n_b = 4  
praying forces always appear at preloaded bolts!  
calculation with the standard method
mode 1: complete yielding of the T-stub flange
\[ F_{T,1,Rd} = (4 \cdot M_{pl,1,Rd}) / m = 1082.20 \text{ kN} \]

mode 2: bolt failure simultaneously with yielding of the T-stub flange
\[ F_{T,2,Rd} = (2 \cdot M_{pl,2,Rd} + (n_1 + n_2) \cdot 0.25 \cdot 2 \cdot F_{T,1,Rd} (3.6 - 1.6 \cdot n_1 / (n_1 + n_2))) / (m + n_1 + n_2) = 470.67 \text{ kN} \]

mode 3: bolt failure
\[ F_{T,3,Rd} = 0.9 \cdot F_{T,1,Rd} = 635.04 \text{ kN}, \quad F_{T,4,Rd} = (3.6 \cdot M_{pl,1,Rd}) / (1.8 \cdot m + 0.8 \cdot n_1) = 288.28 \text{ kN} \]

tension resistance of the T-stub flange: \[ F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 470.67 \text{ kN} \]
shear strength: \[ f_{w,d} = (f_y / 3^{1/2}) / (\sqrt{\beta_e \cdot \gamma_0}) = 207.8 \text{ N/mm}^2, \quad f_u = 360.0 \text{ N/mm}^2, \quad \beta_e = 0.80 \]
tension resistance of welds: \[ F_{T,w,Rd} = 2 \cdot f_{w,d} \cdot a \cdot l_{eff} = 434.62 \text{ kN}, \quad a = 4.0 \text{ mm}, \quad l_{eff} = 261.4 \text{ mm} \]
total loading capacity of the T-stub flange: \[ F_{T,Rd} = F_{T,w,Rd} = 434.62 \text{ kN} \]

resistances and effective lengths of end-plate in bending (per bolt-row):
\[ F_{ep,Rd,2} = 434.62 \text{ kN}, \quad l_{eff,2} = 261.4 \text{ mm} \]

### 2.2.2. Gk 7: beam flange and web in compression

section class of beam (c = 1.00):
- flange bottom: section class for c/(c+t) = 6.74 (outstand flange): 1
- web: section class for \( \alpha = 0.50 \) and c/(c+t) = 26.10 (internal compression parts, bending): 1
- total: section class: 1

taking into account the moment-shear force-interaction \( V_{Ed} = 180.0 \text{ kN} \)

stress due to bending with shear force
\[ V_{pl,Rd} = A_v \left( f_y / 3^{1/2} \right) / \gamma_0 = 664.2 \text{ kN}, \quad A_v = 48.96 \text{ cm}^2 \]
\[ V_{Ed} = 180.0 \text{ kN} \leq 332.1 \text{ kN} = V_{pl,Rd}/2 \Rightarrow \text{no effect on the moment resistance!} \]

stress for section class 1
- resistance \( M_{C,Rd} = M_{pl,Rd} = (W_{pl}/f_y) / \gamma_0 = 490.68 \text{ kNm}, \quad W_{pl} = 2088.00 \text{ cm}^2 \)

resistance of a flange (and web) with compression
\[ F_{c,t,Rd} = M_{C,Rd} / (h - t) = 1475.73 \text{ kN}, \quad (h - t) = 332.5 \text{ mm} \]

resistance of upper beam flange:
stress due to bending with shear force
\[ V_{pl,Rd} = A_v \left( f_y / 3^{1/2} \right) / \gamma_0 = 664.2 \text{ kN}, \quad A_v = 48.96 \text{ cm}^2 \]
\[ V_{Ed} = 180.0 \text{ kN} \leq 332.1 \text{ kN} = V_{pl,Rd}/2 \Rightarrow \text{no effect on the moment resistance!} \]

stress for section class 1
- resistance \( M_{C,Rd} = M_{pl,Rd} = (W_{pl}/f_y) / \gamma_0 = 490.68 \text{ kNm}, \quad W_{pl} = 2088.00 \text{ cm}^2 \)

resistance of a flange (and web) with compression
\[ F_{c,t,Rd} = M_{C,Rd} / (h - t) = 1475.73 \text{ kN}, \quad (h - t) = 332.5 \text{ mm} \]

### 2.2.3. Gk 8: beam web in tension

each individual bolt-row:
row 2
- effective width
  - effective width of the beam web in tension \( b_{eff,t,wb} = 261.4 \text{ mm} \) (left from bc 5)
  - resistance of a beam web in tension
    \[ F_{t,wb,Rd} = b_{eff,t,wb} f_{wb} / \gamma_0 = 614.2 \text{ kN}, \quad f_{wb} = 235.0 \text{ N/mm}^2 \]
2.2.4. Gk 10: bolts in tension

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

bolt category D:
tension resistance of one bolt: $F_{t,Rd} = (k_2 f_{ub} A_2) / \gamma_M = 176.40$ kN, $k_2 = 0.90$, $f_{ub} = 1000.0$ N/mm$^2$
p. sh. load capacity: $B_{p,Rd} = (0.6 \cdot d_m t_p f_u) / \gamma_M = 454.85$ kN, $d_m = 33.5$ mm, $t_p = 25.0$ mm, $f_u = 360.0$ N/mm$^2$
tension-punching shear load capacity for 4 bolts: $\Sigma F_{tp,Rd} = 4 \cdot \min(F_{t,Rd}, B_{p,Rd}) = 705.60$ kN

2.2.5. Gk 11: bolts in shear

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

bolt category A:
shear plane passes through the unthreaded portion of the bolt: $\alpha_V = 0.6$, $A = 3.14$ cm$^2$
shear resistance per shear plane: $F_{v,Rd} = \alpha_V f_{ub} A / \gamma_M = 150.80$ kN, $f_{ub} = 1000.0$ N/mm$^2$
shear resistance of 4 bolts (1-shear): $\Sigma F_{v,Rd} = 4 \cdot F_{v,Rd} = 603.19$ kN

2.2.6. Gk 12: plate with bearing resistance

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

row 3

bolt 1:
in direction of load transfer: $\alpha_d,i = p_1/(3 \cdot d_o)-1/4 = 3.23$ (inner bolt)
$\Rightarrow \alpha_b = 1.00$ (smallest value of $\alpha_d$ or $f_{ub}/f_u = 2.78$ or 1.0)
across to the direction of load transfer: $k_1,i = 1.4 \cdot p_b/d_o-1.7 = 2.75$ (inner bolt)
across to the direction of load transfer: $k_1,a = \min(2.8 \cdot e_p/d_o-1.7, 1.4 \cdot p_b/d_o-1.7) = 2.75$ (end bolt)
$\Rightarrow k_1 = 2.50$ (smallest value of $k_1$ or 2.5)
bearing resistance: $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d) / \gamma_M = 360.00$ kN, $f_u = 360.0$ N/mm$^2$, $t = 25.0$ mm, $d = 20.0$ mm

bolt 2:
in direction of load transfer: $\alpha_d,i = p_1/(3 \cdot d_o)-1/4 = 3.23$ (inner bolt)
$\Rightarrow \alpha_b = 1.00$ (smallest value of $\alpha_d$ or $f_{ub}/f_u = 2.78$ or 1.0)
across to the direction of load transfer: $k_1,i = 1.4 \cdot p_b/d_o-1.7 = 2.75$ (inner bolt)
$\Rightarrow k_1 = 2.50$ (smallest value of $k_1$ or 2.5)
bearing resistance: $F_{b,Rd} = (k_1 \cdot \alpha_b \cdot f_u \cdot d) / \gamma_M = 360.00$ kN, $f_u = 360.0$ N/mm$^2$, $t = 25.0$ mm, $d = 20.0$ mm

bolt 3:
in direction of load transfer: $\alpha_d,i = p_1/(3 \cdot d_o)-1/4 = 3.23$ (inner bolt)
$\Rightarrow \alpha_b = 1.00$ (smallest value of $\alpha_d$ or $f_{ub}/f_u = 2.78$ or 1.0)
across to the direction of load transfer: $k_1,i = 1.4 \cdot p_b/d_o-1.7 = 2.75$ (inner bolt)
$\Rightarrow k_1 = 2.50$ (smallest value of $k_1$ or 2.5)
bearing resistance: \( F_{br, Rd} = (k_r \cdot \alpha_f \cdot f_u \cdot d \cdot t) / \gamma_M2 = 360.00 \text{ kN} \), \( f_u = 360.0 \text{ N/mm}^2 \), \( t = 25.0 \text{ mm} \), \( d = 20.0 \text{ mm} \),

bolt 4.
in direction of load transfer: \( \alpha_{d, i} = p_i / (3 \cdot d_0) - 1/4 = 3.23 \) (inner bolt)
\( \Rightarrow \alpha = 1.00 \) (smallest value of \( \alpha \) or \( f_{ub} / f_u = 2.78 \) or 1.0)

across to the direction of load transfer: \( k_{1, i} = 1.4 \cdot p_2 / d_0 - 1.7 = 2.75 \) (inner bolt)
across to the direction of load transfer: \( k_{1, a} = \min(2.8 \cdot e_0 / d_0 - 1.7, 1.4 \cdot p_2 / d_0 - 1.7) = 2.75 \) (end bolt)
\( \Rightarrow k_1 = 2.50 \) (smallest value of \( k_1 \) or 2.5)
bearing resistance: \( F_{br, Rd} = (k_1 \cdot \alpha_f \cdot f_u \cdot d \cdot t) / \gamma_M2 = 360.00 \text{ kN} \), \( f_u = 360.0 \text{ N/mm}^2 \), \( t = 25.0 \text{ mm} \), \( d = 20.0 \text{ mm} \)
bearing resistance of 1x4 bolts: \( \Sigma F_{br, Rd} = 1440.00 \text{ kN} \)

2.3. connection capacity

2.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: \( h_1 = 381.3 \text{ mm} \), \( h_2 = 281.3 \text{ mm} \)

resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
decisive basic components: 6, 8
row 1: \( F_{tr, Rd} = 538.0 \text{ kN} \)
row 2: \( F_{tr, Rd} = 434.6 \text{ kN} \)

resistance per bolt-row (tension)
row 1: \( F_{tr, Rd} = 538.0 \text{ kN} \)
row 2: \( F_{tr, Rd} = 434.6 \text{ kN} \)
\( \Sigma F_{tr, Rd}^* = 972.6 \text{ kN} \)

deductions acc. to EC 3-1-8, 6.2.7.2(7)
decisive basic component: 7
row 1: \( \Sigma F_{tr, Rd} = 0.0 \text{ kN} \)
Gk 7: \( \Sigma F_{tr, Rd} = F_{ct, Rd} \cdot \Sigma F_{tr, Rd} = 1475.7 \text{ kN} F_{tr, Rd} = 538.0 \text{ kN} \) \( \land \) \( \Sigma F_{tr, Rd} = 538.0 \text{ kN} \) \( \Rightarrow \) \( F_{tr, Rd} = 538.0 \text{ kN} \)
row 2: \( \Sigma F_{tr, Rd} = 538.0 \text{ kN} \) (row 1)
Gk 7: \( \Sigma F_{tr, Rd} = F_{ct, Rd} \cdot \Sigma F_{tr, Rd} = 937.7 \text{ kN} F_{tr, Rd} = 434.6 \text{ kN} \) \( \land \) \( \Sigma F_{tr, Rd} = 434.6 \text{ kN} \) \( \Rightarrow \) \( F_{tr, Rd} = 434.6 \text{ kN} \)

check acc. to EC 3-1-8, 6.2.7.2(9)
decisive basic component: 10
row 1: \( F_{tx, Rd} = 538.0 \text{ kN} \), \( h_x = 381.3 \text{ mm} \) \( \Rightarrow \) \( F_{tx, Rd} \leq \lim F_{tx, Rd} = 670.3 \text{ kN} \), no deduction

resistance per bolt-row (bending)
row 1: \( F_{tr, Rd} = 538.0 \text{ kN} \)
row 2: \( F_{tr, Rd} = 434.6 \text{ kN} \)
\( \Sigma F_{tr, Rd} = 972.6 \text{ kN} \)

potential failure by basic component 5

resistance of flanges (compression)
\( \Sigma F_{c, Rd}^* = 2951.5 \text{ kN} \)

moment resistance regarding the centre of compression
\( M_{l, Rd} = \Sigma (F_{tr, Rd} \cdot t_1) = 327.4 \text{ kNm} \)

tension resistance
\( N_{l, Rd} = \Sigma F_{tr, Rd}^* = 972.6 \text{ kN} \)
compression resistance
\( N_{c, Rd} = \Sigma F_{c, Rd}^* = 2951.5 \text{ kN} \)

2.3.2. shear/bearing resistance

resistance per bolt-row
decisive basic components: 11, 12
row 3: \( F_{vr, Rd} = 603.2 \text{ kN} \)

deductions depending on tension force (at 100% utilization of moment resistance)
decisive basic component: 10
row 3: \( F_{vr, Rd} = f_{vt} \cdot 603.2 \text{ kN} = 603.2 \text{ kN} \) with \( f_{vt} = 1 \) - \( F_{tr, Rd} / (1.4 \cdot \Sigma F_{tr, Rd}) = 1.000 \)

resistance per bolt-row
row 3: \( F_{vr, Rd} = 603.2 \text{ kN} \)
\( \Sigma F_{vr, Rd} = 603.2 \text{ kN} \)

shear/bearing resistance
\( V_{vl, Rd} = \Sigma F_{vr, Rd} = 603.2 \text{ kN} \)
2.3.3. total
$M_{L,Rd} = 327.4 \text{ kNm}$  $N_{L,Rd} = 972.6 \text{ kN}$  $N_{L,Z,Rd} = 2951.5 \text{ kN}$  $V_{L,Rd} = 603.2 \text{ kN}$

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

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

internal moment:  $M_{Ed} = M_d = 320.00 \text{ kNm}$
perpendicular to connection plane
shear force:  $V_{Ed} = |V_d| = 180.00 \text{ kN}$
parallel to connection plane

moment resistance
$M_{Ed}/M_{L,Rd} = 0.978 < 1 \text{ ok}$
shear/bearing resistance at 100% utilization of moment resistance
$V_{Ed}/V_{L,Rd} = 0.298 < 1 \text{ ok}$

2.4.2. 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
welds 6, 7: beam flange in compression inner
weld 4: NA-DE: plate thickness $t_{max} \geq 3 \text{ mm}$; weld thickness $a = 4.0 \text{ mm} < a_{min} = t_{max}^{1/2} - 0.5 = 4.50 \text{ mm}$
weld 5: NA-DE: plate thickness $t_{max} \geq 3 \text{ mm}$; weld thickness $a = 4.0 \text{ mm} < a_{min} = t_{max}^{1/2} - 0.5 = 4.50 \text{ mm}$
calculation section:

\[ aw = 9.0 \text{ mm} \quad lw = 300.0 \text{ mm} \]
\[ aw = 9.0 \text{ mm} \quad lw = 118.0 \text{ mm} \]
\[ aw = 4.0 \text{ mm} \quad lw = 281.0 \text{ mm} \]
\[ aw = 9.0 \text{ mm} \quad lw = 118.0 \text{ mm} \]
\[ aw = 9.0 \text{ mm} \quad lw = 300.0 \text{ mm} \]

design values referring to centroid of the section:
$M_{y,Ed} = -320.00 \text{ kNm}$, $V_{z,Ed} = 180.00 \text{ kN}$

cross-sectional properties referring to centroid of the line cross-section:
$\Sigma A_w = 117.36 \text{ cm}^2$, $A_{w,z} = 20.68 \text{ cm}^2$, $\Sigma I_w = 159.4 \text{ cm}^4$
$lw, y = 82650.50 \text{ cm}^4$, $lw, z = 8065.90 \text{ cm}^4$, $W_{w,1} = 114.21 \text{ cm}^3$, $\Delta z_w = 0.0 \text{ mm}$

distribution of internal forces and moments:
\[ N_w = 535.02 \text{ kN} \]
\[ N_w = 189.40 \text{ kN} \]
\[ N_w = -535.02 \text{ kN} \]

from conventional distribution of shear force:  $V_{z,w} = 180.00 \text{ kN}$

stresses in weld edges:
\[ \sigma_{w,x} = 198.16 \text{ N/mm}^2 \]
\[ \sigma_{w,x} = 178.34 \text{ N/mm}^2 \]
\[ \tau_{w,z} = 86.21 \text{ N/mm}^2 \]
\[ \sigma_{w,x} = -178.34 \text{ N/mm}^2 \]
\[ \tau_{w,z} = 86.21 \text{ N/mm}^2 \]

verifications in weld edges:
verification of weld 1, pt. 0:
- stresses on the design area of the weld \( \alpha = 45^\circ \):
  \[ \sigma_{W,Ed} = \sigma_{W,X} = 198.2 \, \text{N/mm}^2 \]
resultant weld force \( F_{W,Ed} = \sigma_{W,Ed} \cdot a = 17.83 \, \text{kN/cm} \)
resistance of a weld: \( F_{W,Rd} = f_{W,d} \cdot a = 18.71 \, \text{kN/cm} \), \( f_{W,d} = 207.85 \, \text{N/mm}^2 \), \( a = 9.0 \, \text{mm} \)
\[ F_{W,Ed} = 17.83 \, \text{kN/cm} < F_{W,Rd} = 18.71 \, \text{kN/cm} \Rightarrow U = 0.953 < 1 \ \text{ok} \]
verification of weld 2, pt. 0:
- stresses on the design area of the weld \( \alpha = 45^\circ \):
  \[ \sigma_{W,Ed} = \sigma_{W,X} = 178.3 \, \text{N/mm}^2 \]
resultant weld force \( F_{W,Ed} = \sigma_{W,Ed} \cdot a = 16.05 \, \text{kN/cm} \)
resistance of a weld: \( F_{W,Rd} = f_{W,d} \cdot a = 18.71 \, \text{kN/cm} \), \( f_{W,d} = 207.85 \, \text{N/mm}^2 \), \( a = 9.0 \, \text{mm} \)
\[ F_{W,Ed} = 16.05 \, \text{kN/cm} < F_{W,Rd} = 18.71 \, \text{kN/cm} \Rightarrow U = 0.858 < 1 \ \text{ok} \]
verification of weld 4, pt. 0:
- stresses on the design area of the weld \( \alpha = 45^\circ \):
  \[ \sigma_{W,Ed} = \left( \sigma_{W,X}^2 + t_{w,d}^2 \right)^{1/2} = 171.1 \, \text{N/mm}^2 \]
resultant weld force \( F_{W,Ed} = \sigma_{W,Ed} \cdot a = 6.84 \, \text{kN/cm} \)
resistance of a weld: \( F_{W,Rd} = f_{W,d} \cdot a = 8.31 \, \text{kN/cm} \), \( f_{W,d} = 207.85 \, \text{N/mm}^2 \), \( a = 4.0 \, \text{mm} \)
\[ F_{W,Ed} = 6.84 \, \text{kN/cm} < F_{W,Rd} = 8.31 \, \text{kN/cm} \Rightarrow U = 0.823 < 1 \ \text{ok} \]
verification of weld 4, pt. 1:
- stresses on the design area of the weld \( \alpha = 45^\circ \):
  \[ \sigma_{W,Ed} = \left( \sigma_{W,X}^2 + t_{w,d}^2 \right)^{1/2} = 171.1 \, \text{N/mm}^2 \]
resultant weld force \( F_{W,Ed} = \sigma_{W,Ed} \cdot a = 6.84 \, \text{kN/cm} \)
resistance of a weld: \( F_{W,Rd} = f_{W,d} \cdot a = 8.31 \, \text{kN/cm} \), \( f_{W,d} = 207.85 \, \text{N/mm}^2 \), \( a = 4.0 \, \text{mm} \)
\[ F_{W,Ed} = 6.84 \, \text{kN/cm} < F_{W,Rd} = 8.31 \, \text{kN/cm} \Rightarrow U = 0.823 < 1 \ \text{ok} \]
verification of weld 6, pt. 0:
- stresses on the design area of the weld \( \alpha = 45^\circ \):
  \[ \sigma_{W,Ed} = \sigma_{W,X} = 178.3 \, \text{N/mm}^2 \]
resultant weld force \( F_{W,Ed} = \sigma_{W,Ed} \cdot a = 16.05 \, \text{kN/cm} \)
resistance of a weld: \( F_{W,Rd} = f_{W,d} \cdot a = 18.71 \, \text{kN/cm} \), \( f_{W,d} = 207.85 \, \text{N/mm}^2 \), \( a = 9.0 \, \text{mm} \)
\[ F_{W,Ed} = 16.05 \, \text{kN/cm} < F_{W,Rd} = 18.71 \, \text{kN/cm} \Rightarrow U = 0.858 < 1 \ \text{ok} \]
verification of weld 8, pt. 0:
- stresses on the design area of the weld \( \alpha = 45^\circ \):
  \[ \sigma_{W,Ed} = \sigma_{W,X} = 198.2 \, \text{N/mm}^2 \]
resultant weld force \( F_{W,Ed} = \sigma_{W,Ed} \cdot a = 17.83 \, \text{kN/cm} \)
resistance of a weld: \( F_{W,Rd} = f_{W,d} \cdot a = 18.71 \, \text{kN/cm} \), \( f_{W,d} = 207.85 \, \text{N/mm}^2 \), \( a = 9.0 \, \text{mm} \)
\[ F_{W,Ed} = 17.83 \, \text{kN/cm} < F_{W,Rd} = 18.71 \, \text{kN/cm} \Rightarrow U = 0.953 < 1 \ \text{ok} \]

Result:
- weld 1, pt. 0: \[ \sigma_{W,X} = 198.16 \, \text{N/mm}^2 \]
  \[ \text{Max: } F_{W,Ed} = 17.83 \, \text{kN/cm} < F_{W,Rd} = 18.71 \, \text{kN/cm} \Rightarrow U = 0.953 < 1 \ \text{ok} \]

2.4.3. verification result
- maximum utilization: \( \text{max } U = 0.978 < 1 \ \text{ok} \)

2.5. rotational stiffness

stiffness coefficients
- equivalent stiffness coefficient for 2 tension-bolt-rows:
  effective stiffness coefficient for bolt-row 1 (4 bolts):
  \[ k_5 = 0.9 \frac{f_{tp}}{m^2} / \text{m}^2 = 79.57 \, \text{mm}, \quad l_{tp} = 150.0 \, \text{mm}, \quad m = 29.8 \, \text{mm} \]
  \[ k_1 = 1.6 A_s / L_s = 5.43 \, \text{mm}, \quad L_s = l_{ges} + 2 \times l_b + (l_k+l_m)/2 = 72.3 \, \text{mm}, \quad l_{ges} = 50.0 \, \text{mm} \]
  \[ \Sigma(1/k_1) = 1/k_1 + 1/k_s + 1/(2 	imes k_0) = 0.117 \Rightarrow k_{eff,1} = 1 / (\Sigma(1/k_1)) = 8.526 \, \text{mm} \]
  effective stiffness coefficient for bolt-row 2 (4 bolts):
  \[ k_5 = 0.9 \frac{f_{tp}}{m^2} / \text{m}^2 = 82.34 \, \text{mm}, \quad l_{tp} = 261.4 \, \text{mm}, \quad m = 35.5 \, \text{mm} \]
  \[ k_1 = 1.6 A_s / L_s = 5.43 \, \text{mm}, \quad L_s = l_{ges} + 2 \times l_b + (l_k+l_m)/2 = 72.3 \, \text{mm}, \quad l_{ges} = 50.0 \, \text{mm} \]
  \[ \Sigma(1/k_1) = 1/k_1 + 1/k_s + 1/(2 	imes k_0) = 0.116 \Rightarrow k_{eff,2} = 1 / (\Sigma(1/k_1)) = 8.588 \, \text{mm} \]
- equivalent internal lever arm:
  \[ z_{eq} = \Sigma(k_{eff,r} \cdot h_r) / \Sigma(k_{eff,r} \cdot h_r) = 339.6 \, \text{mm} \]
sum of stiffness coefficients \( \Sigma(1/k) = 1/k_{eq} = 0.060 \)

rotational stiffness
- initial rotational stiffness:
  \[ S_{j,ini} = (E \cdot z^2) / \Sigma(1/k) = 402890.9 \, \text{kNm/rad}, \quad z = z_{eq} = 339.6 \, \text{mm} \]
- internal moment at the connection point:
  \[ M_{j,Ed} = M_{Ed} = 320.0 \, \text{kNm} \]
  \[ M_{j,Rd} = 320.0 \, \text{kNm} > 2 \times 320.0 \, \text{kNm} \Rightarrow \mu = (1.5 \times M_{j,Ed}) / M_{j,Rd} = 2.810, \quad \Psi = 2.7 \]
- rotational stiffness:
  \[ S_{j,Rd} = S_{j,ini} / \mu = 143352.4 \, \text{kNm/rad} \]
rotation:
  \[ \varphi_{Ed} = M_{j,Ed} / S_{j,Rd} = 0.128 \]
3. Lk 2

notes
connection is verified due to EC 3-1-8 regardless of preloading.
however, connections may be constructed with prestressed high strength bolts.
no consideration of bolt groups in joints with 4 bolts per row.

3.1. design values

periphery connection ⊥ zur connection plane
periphery connection-sided ⊥ to 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: \( \beta_b = \alpha_v = \alpha = 0^\circ \)

transformation joint values -> design values
\[ M_d = -120.00 \text{ kNm} \]

internal forces and moments perpendicular to the connection planes

periphery beam
\[ M_d = -120.00 \text{ kNm} \]

negative internal moment \( M_d \Rightarrow \) mirrored model
\[ M_d = 120.00 \text{ kNm} \]

partial internal forces and moments referring to the mirrored model

internal forces and moments in the periphery end-plate-beam: \( M_d = M_d \cdot V_d \text{tep} = 120.00 \text{ kNm} \)

\[ N_{d,1} = -N_d \cdot z_u/z_b + M_d'z_b = 360.90 \text{ kN}, z_b = 332.5 \text{ mm}, z_{bu} = 166.3 \text{ mm} \]

\[ N_{d,2} = N_d \cdot z_b/z_b + M_d'z_b = 360.90 \text{ kN}, z_b = 332.5 \text{ mm}, z_{bo} = 166.3 \text{ mm} \]

bending: bolt-rows below centre of compression are ignored !!

3.2. basic components

beam splice w. end-plate: basic components: 5, 7, 8, 10, 11, 12

3.2.1. Gk 5: end-plate in bending

connections with 4 bolts per bolt-row are not treated in EC 3-1-8.
verification according to Wagenknecht, Stahlbau Praxis nach EC 3, Bd.3.

part of end-plate between beam flanges

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

here: number of bolt-rows \( n_0 = 1 \)
distance centre-line of the bolt to the stiffener \( m_2 = 32.3 \text{ mm} \)
distance centre-line of the bolt to the edge of flange \( e = 35.0 \text{ mm} \)
distance centre-line of the bolt to the stub web \( m = 35.5 \text{ mm} \)

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

inner bolt-row outside tension flange of beam / of stiffener in tension

\[ \text{left,op.1} = 4 \cdot \pi \cdot m = 445.8 \text{ mm} \]
\[ \text{left,op.2} = 2 \cdot (\pi \cdot m + w_2) = 362.9 \text{ mm} \]
\[ \text{left,op.3} = \pi \cdot m + 2 \cdot (w_2 + w_3) = 321.4 \text{ mm} \]
\[ \text{left,op.1} = \min(\text{left,op.1}, \text{left,op.2}, \text{left,op.3}) = 321.4 \text{ mm} \]
distance of inner bolt axis to the edge of flange \( e = 105.0 \text{ mm} \)

coefficient for stiffened column flanges and end-plates:

input values \( \lambda_1 = m / (m + e) = 0.253, \lambda_2 = m_2 / (m + e) = 0.230 \Rightarrow \alpha = 7.37 \) (s. figure 6.11)

\[ \text{left,nc.1} = \alpha \cdot m = 261.4 \text{ mm} \]
\[ \text{left,nc.2} = 4 \cdot m + 1.25 \cdot (w_2 + w_3) = 273.1 \text{ mm} \]
tension resistance of the T-stub flange

\[ m = 35.5 \text{ mm}, \quad n = \min(w + \varepsilon_{\text{min}}, 1.25m) = 44.3 \text{ mm} \]
\[ n_1 = w = 70.0 \text{ mm}, \quad n_2 = \min(\varepsilon_{\text{min}}, 1.25m + n_1) = 35.0 \text{ mm}, \quad \varepsilon_{\text{min}} = 35.0 \text{ mm} \]

resisting plastic moments:

- in mode 1: \[ M_{\text{pl,Rd}} = \left(0.25 \cdot \left(3.6 - 1.6 \cdot n_1/(n_1 + n_2)\right)\right) / (m + n_1 + n_2) = 470.67 \text{ kN} \]
- in mode 3: \[ F_{\text{T,Rd}} = \left(2 \cdot M_{\text{pl,Rd}} + \gamma_{\text{M}}\right) / (1.8m + 0.8n_1) = 288.28 \text{ kN} \]

shear strength: \[ f_{\text{w,d}} = \frac{f_u}{\sqrt{3}} \]

resistance of the T-stub flange: \[ F_{\text{T,Rd}} = \min(F_{\text{T,1,Rd}}, F_{\text{T,2,Rd}}, F_{\text{T,3,Rd}}) = 470.67 \text{ kN} \]

total loading capacity of the T-stub flange: \[ F_{\text{T,Rd}} = 470.67 \text{ kN} \]

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

- \[ F_{\text{ep,Rd,1}} = 434.62 \text{ kN}, \quad \text{left} = 261.4 \text{ mm} \]

3.2.2. Gk 7: beam flange and web in compression

section class of beam (\( c = 1.00 \)):

- flange bottom: section class for \( c/c-t = 6.74 \) (outstand flange): 1
- web: section class for \( a = 0.50 \) and \( c/c-t = 26.10 \) (internal compression parts, bending): 1
- total: section class: 1

\[ \text{stress for section class 1} \]

resistance \[ M_{\text{c,Rd}} = M_{\text{pl,Rd}} = (W_{\text{pl}} f_y) / \gamma_{\text{M}} = 490.68 \text{ kNm}, \quad W_{\text{pl}} = 2088.00 \text{ cm}^3 \]

resistance of a flange (and web) with compression:

\[ F_{\text{c,t,Rd}} = M_{\text{c,Rd}} / (h - t_t) = 1475.73 \text{ kN}, \quad (h - t_t) = 332.5 \text{ mm} \]

resistance of upper beam flange:

3.2.3. Gk 8: beam web in tension

\[ \text{stress for section class 1} \]

resistance \[ M_{\text{c,Rd}} = W_{\text{pl}} f_y / \gamma_{\text{M}} = 490.68 \text{ kNm}, \quad W_{\text{pl}} = 2088.00 \text{ cm}^3 \]

resistance of a flange (and web) with compression:

\[ F_{\text{c,t,Rd}} = M_{\text{c,Rd}} / (h - t_t) = 1475.73 \text{ kN}, \quad (h - t_t) = 332.5 \text{ mm} \]

each individual bolt-row:

effective width
effective width of the beam web in tension $b_{eff,t,wb} = 261.4$ mm (left from bc 5)

resistance of a beam web in tension

$F_{w,b,Rd} = b_{eff,t,wb} f_{y,wb} / \gamma_{M0} = 614.2$ kN, $f_{y,wb} = 235.0$ N/mm²

3.2.4. Gk 10: bolts in tension

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

bolt category D:
tension resistance of one bolt: $F_{t,Rd} = (K_2 f_{ub} A_2) / \gamma_{M2} = 176.40$ kN, $K_2 = 0.90$, $f_{ub} = 1000.0$ N/mm²
p. sh. load capacity: $B_{p,Rd} = (0.6 + d_m t_p f_u) / \gamma_{M2} = 454.85$ kN, $d_m = 33.5$ mm, $t_p = 25.0$ mm, $f_u = 360.0$ N/mm²
tension-punching shear load capacity for 4 bolts: $\Sigma F_{p,Rd} = 4 \cdot \min(F_{t,Rd}, B_{p,Rd}) = 705.60$ kN

3.2.5. Gk 11: bolts in shear

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

bolt category A:
shear plane passes through the unthreaded portion of the bolt: $\alpha_y = 0.6$, $A = 3.14$ cm²
shear resistance per shear plane: $F_{v,Rd} = \alpha_y f_{ub} A / \gamma_{M2} = 150.80$ kN, $f_{ub} = 1000.0$ N/mm²
shear resistance of 4 bolts (1-shear): $\Sigma F_{v,Rd} = 4 \cdot F_{v,Rd} = 603.19$ kN

3.2.6. Gk 12: plate with bearing resistance

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

row 2

bolt 1:
in direction of load transfer: $\alpha_b = 1.00$
across to the direction of load transfer: $K_1,i = 1.4 - p_d / d - 0.75$ (inner bolt)
across to the direction of load transfer: $K_1,a = \min(2.8 - p_d / d - 0.75, 1.4 - p_d / d - 0.75) = 2.75$ (end bolt)
$\Rightarrow K_1 = 2.50$ (smallest value of $K_1$ or 2.5)
bearing resistance: $F_{b,Rd} = (K_1 \cdot \alpha_b f_u d t) / \gamma_{M2} = 360.00$ kN, $f_u = 360.0$ N/mm², $t = 25.0$ mm, $d = 20.0$ mm

bolt 2:
in direction of load transfer: $\alpha_b = 1.00$
across to the direction of load transfer: $K_1,i = 1.4 - p_d / d - 0.75$ (inner bolt)
$\Rightarrow K_1 = 2.50$ (smallest value of $K_1$ or 2.5)
bearing resistance: $F_{b,Rd} = (K_1 \cdot \alpha_b f_u d t) / \gamma_{M2} = 360.00$ kN, $f_u = 360.0$ N/mm², $t = 25.0$ mm, $d = 20.0$ mm

bolt 3:
in direction of load transfer: $\alpha_b = 1.00$
across to the direction of load transfer: $K_1,i = 1.4 - p_d / d - 0.75$ (inner bolt)
\[ k_1 = 2.50 \text{ (smallest value of } k_1 \text{ or } 2.5) \]

bearing resistance: \( F_{b,Rd} = \left( k_1 - \alpha_B - f_u d t \right) / \gamma_M \)\( = 360.00 \text{ kN}, f_u = 360.0 \text{ N/mm}^2, t = 25.0 \text{ mm}, d = 20.0 \text{ mm} \)

bolt 4:
- in direction of load transfer: \( \alpha_B = 1.00 \)
- across to the direction of load transfer: \( k_{1,i} = 1.4 \cdot p_2/ d_0 - 1.7 = 2.75 \) (inner bolt)
- across to the direction of load transfer: \( k_{1,a} = \text{min}(2.8 \cdot d_0/ d - 1.7, 1.4 \cdot p_2/ d_0 - 1.7) = 2.75 \) (end bolt)

\[ k_1 = 2.50 \text{ (smallest value of } k_1 \text{ or } 2.5) \]

bearing resistance: \( F_{b,Rd} = \left( k_1 - \alpha_B - f_u d t \right) / \gamma_M \)\( = 360.00 \text{ kN}, f_u = 360.0 \text{ N/mm}^2, t = 25.0 \text{ mm}, d = 20.0 \text{ mm} \)

bearing resistance of 1x4 bolts: \( \sum F_{b,Rd} = 1440.00 \text{ kN} \)

row 3

bolt 1:
- in direction of load transfer: \( \alpha_B = 1.00 \)
- across to the direction of load transfer: \( k_{1,i} = 1.4 \cdot p_2/ d_0 - 1.7 = 2.75 \) (inner bolt)
- across to the direction of load transfer: \( k_{1,a} = \text{min}(2.8 \cdot d_0/ d - 1.7, 1.4 \cdot p_2/ d_0 - 1.7) = 2.75 \) (end bolt)

\[ k_1 = 2.50 \text{ (smallest value of } k_1 \text{ or } 2.5) \]

bearing resistance: \( F_{b,Rd} = \left( k_1 - \alpha_B - f_u d t \right) / \gamma_M \)\( = 360.00 \text{ kN}, f_u = 360.0 \text{ N/mm}^2, t = 25.0 \text{ mm}, d = 20.0 \text{ mm} \)

bolt 2:
- in direction of load transfer: \( \alpha_B = 1.00 \)
- across to the direction of load transfer: \( k_{1,i} = 1.4 \cdot p_2/ d_0 - 1.7 = 2.75 \) (inner bolt)

\[ k_1 = 2.50 \text{ (smallest value of } k_1 \text{ or } 2.5) \]

bearing resistance: \( F_{b,Rd} = \left( k_1 - \alpha_B - f_u d t \right) / \gamma_M \)\( = 360.00 \text{ kN}, f_u = 360.0 \text{ N/mm}^2, t = 25.0 \text{ mm}, d = 20.0 \text{ mm} \)

bolt 3:
- in direction of load transfer: \( \alpha_B = 1.00 \)
- across to the direction of load transfer: \( k_{1,i} = 1.4 \cdot p_2/ d_0 - 1.7 = 2.75 \) (inner bolt)

\[ k_1 = 2.50 \text{ (smallest value of } k_1 \text{ or } 2.5) \]

bearing resistance: \( F_{b,Rd} = \left( k_1 - \alpha_B - f_u d t \right) / \gamma_M \)\( = 360.00 \text{ kN}, f_u = 360.0 \text{ N/mm}^2, t = 25.0 \text{ mm}, d = 20.0 \text{ mm} \)

bolt 4:
- in direction of load transfer: \( \alpha_B = 1.00 \)
- across to the direction of load transfer: \( k_{1,i} = 1.4 \cdot p_2/ d_0 - 1.7 = 2.75 \) (inner bolt)
- across to the direction of load transfer: \( k_{1,a} = \text{min}(2.8 \cdot d_0/ d - 1.7, 1.4 \cdot p_2/ d_0 - 1.7) = 2.75 \) (end bolt)

\[ k_1 = 2.50 \text{ (smallest value of } k_1 \text{ or } 2.5) \]

bearing resistance: \( F_{b,Rd} = \left( k_1 - \alpha_B - f_u d t \right) / \gamma_M \)\( = 360.00 \text{ kN}, f_u = 360.0 \text{ N/mm}^2, t = 25.0 \text{ mm}, d = 20.0 \text{ mm} \)

bearing resistance of 1x4 bolts: \( \sum F_{b,Rd} = 1440.00 \text{ kN} \)

bearing resistance (2 rows)
\[ \sum F_{b,Rd,2} = 1440.00 \text{ kN} \]
\[ \sum F_{b,Rd,3} = 1440.00 \text{ kN} \]

3.3. connection capacity

3.3.1. moment resistance

distance of tension-bolt-row from centre of compression: \( h_1 = 281.3 \text{ mm} \)

calculate resistance acc. to EC 3-1-8, 6.2.7.2(6) for bolts rows considered individually
decisive basic components: 6, 8

row 1: \( F_{tr,Rd} = 434.6 \text{ kN} \)

resistance per bolt-row (tension)
row 1: \( F_{tr,Rd} = 434.6 \text{ kN} \)
\[ \sum F_{tr,Rd} = 434.6 \text{ kN} \]

deductions acc. to EC 3-1-8, 6.2.7.2(7)
decisive basic component: 7
row 1: \( \Delta F_{tr,Rd} = 0.0 \text{ kN} \)

Gk 7: \( \Delta F_{tr,Rd} = F_{ct,Rd} - \sum F_{tr,Rd} = 1475.7 \text{ kN} \)

resistance per bolt-row (bending)
row 1: \( F_{tr,Rd} = 434.6 \text{ kN} \)
\[ \sum F_{tr,Rd} = 434.6 \text{ kN} \]

potential failure by basic component 5

resistance of flanges (compression)
\[ \sum F_{c,Rd} = 2951.5 \text{ kN} \]

moment resistance regarding the centre of compression
\[ M_{b,Rd} = \sum (F_{tr,Rd} \cdot h) = 122.2 \text{ kNm} \]

tension resistance
\[ N_{tr,Rd} = \sum F_{tr,Rd} = 434.6 \text{ kN} \]

compression resistance
\[ N_{c,Rd} = \sum F_{c,Rd} = 2951.5 \text{ kN} \]
3.3.2. shear/bearing resistance

**resistance per bolt-row**

decisive basic component: 11, 12

row 2: \( F_{\text{v}, \text{Rd}} = 603.2 \text{ kN} \)

row 3: \( F_{\text{v}, \text{Rd}} = 603.2 \text{ kN} \)

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

decisive basic component: 10

row 2: \( F_{\text{v}, \text{Rd}} = f_{\text{v}} \cdot 603.2 \text{ kN} = 603.2 \text{ kN} \)

\[ \text{with } f_{\text{v}} = 1 - \frac{F_{\text{t}, \text{Rd}}}{(1.4 \cdot F_{\text{t}, \text{Rd}})} = 1.000 \]

row 3: \( F_{\text{v}, \text{Rd}} = f_{\text{v}} \cdot 603.2 \text{ kN} = 603.2 \text{ kN} \)

\[ \text{with } f_{\text{v}} = 1 - \frac{F_{\text{t}, \text{Rd}}}{(1.4 \cdot F_{\text{t}, \text{Rd}})} = 1.000 \]

**resistance per bolt-row**

row 2: \( F_{\text{v}, \text{Rd}} = 603.2 \text{ kN} \)

row 3: \( F_{\text{v}, \text{Rd}} = 603.2 \text{ kN} \)

\[ \Sigma F_{\text{v}, \text{Rd}} = 1206.4 \text{ kN} \]

**shear/bearing resistance**

\[ V_{\text{f}, \text{Rd}} = \Sigma F_{\text{v}, \text{Rd}} = 1206.4 \text{ kN} \]

3.3.3. total

\( M_{\text{l}, \text{Rd}} = 122.2 \text{ kNm} \)

\( N_{\text{p}, \text{L}, \text{Rd}} = 434.6 \text{ kN} \)

\( N_{\text{p}, \text{C}, \text{Rd}} = 2951.5 \text{ kN} \)

\( V_{\text{L}, \text{Rd}} = 1206.4 \text{ kN} \)

3.4. verifications

calculation of internal lever arm \( z_{\text{eq}} \) s. rotational stiffness

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

internal moment: \( M_{\text{Ed}} = M_{\text{d}} = 120.00 \text{ kNm} \)

perpendicular to connection plane

**moment resistance**

\[ M_{\text{Ed}}/M_{\text{l}, \text{Rd}} = 0.982 < 1 \text{ ok} \]

3.4.2. verification of welds at beam section

**weld 1:** beam flange in tension outer

**weld 2:** beam flange in compression outer

**welds 3, 4:** beam flange in tension inner

**welds 5, 6:** beam web double-sided

**weld 7:** beam web single-sided

weld 4: NA-DE: plate thickness \( t_{\text{max}} \geq 3 \text{ mm} \): weld thickness \( a = 4.0 \text{ mm} \) \(< \Delta a_{\min} = l_{\text{max}}^{1/2} - 0.5 = 4.50 \text{ mm} \)

weld 5: NA-DE: plate thickness \( t_{\text{max}} \geq 3 \text{ mm} \): weld thickness \( a = 4.0 \text{ mm} \) \(< \Delta a_{\min} = l_{\text{max}}^{1/2} - 0.5 = 4.50 \text{ mm} \)

**calculation section:**

\[ \begin{align*}
\text{weld 1: } & a_{\text{w}} = 9.0 \text{ mm} & l_{\text{w}} = 300.0 \text{ mm} \\
\text{weld 2: } & a_{\text{w}} = 9.0 \text{ mm} & l_{\text{w}} = 118.0 \text{ mm} \\
\text{weld 3: } & \text{siehe weld 2} & \\
\text{weld 4: } & a_{\text{w}} = 4.0 \text{ mm} & l_{\text{w}} = 261.0 \text{ mm} \\
\text{weld 5: } & \text{siehe weld 4} & \\
\text{weld 6: } & a_{\text{w}} = 9.0 \text{ mm} & l_{\text{w}} = 118.0 \text{ mm} \\
\text{weld 7: } & \text{siehe weld 6} & \\
\text{weld 8: } & a_{\text{w}} = 9.0 \text{ mm} & l_{\text{w}} = 300.0 \text{ mm} \\
\end{align*} \]

design values refering to centroid of the section:

\( M_{Y, \text{Ed}} = -120.00 \text{ kNm} \)

**cross-sectional properties referring to centroid of the line cross-section:**

\[ \begin{align*}
\Sigma A_{\text{w}} &= 117.36 \text{ cm}^2, & A_{\text{w}, \text{z}} &= 20.88 \text{ cm}^2, & \Sigma I_{\text{w}} &= 159.4 \text{ cm}^4 \\
l_{\text{w}, \text{y}} &= 28260.50 \text{ cm}^4, & l_{\text{w}, \text{z}} &= 8065.90 \text{ cm}^4, & W_{y, \text{t}} &= 114.21 \text{ cm}^3, & \Delta X_{\text{w}} &= 0.0 \text{ mm} \\
\end{align*} \]

distribution of internal forces and moments:

weld 1: \( N_{\text{w}} = 200.63 \text{ kN} \)

weld 2: \( N_{\text{w}} = 71.02 \text{ kN} \)

weld 3: \( \text{siehe weld 2} \)

weld 4: \( M_{y, \text{w}} = -2.52 \text{ kNm} \)

weld 5: \( \text{siehe weld 4} \)

weld 6: \( N_{\text{w}} = -71.02 \text{ kN} \)

weld 7: \( \text{siehe weld 6} \)

weld 8: \( N_{\text{w}} = -200.63 \text{ kN} \)

**stresses in weld edges:**
weld 1, pt. 0: $\sigma_{W,x} = 74.31 \text{ N/mm}^2$
weld 2, pt. 0: $\sigma_{W,x} = 68.88 \text{ N/mm}^2$
weld 3, pt. 0: siehe weld 2
pt. 1: siehe weld 2
weld 4, pt. 0: $\sigma_{W,x} = 55.41 \text{ N/mm}^2$
pt. 1: $\sigma_{W,x} = 55.41 \text{ N/mm}^2$
weld 5, pt. 0: siehe weld 4
pt. 1: siehe weld 4
weld 6, pt. 0: $\sigma_{W,x} = 66.88 \text{ N/mm}^2$
weld 7, pt. 0: siehe weld 6
pt. 1: siehe weld 6
weld 8, pt. 0: $\sigma_{W,x} = 74.31 \text{ N/mm}^2$

verifications in weld edges:

verification of weld 1, pt. 0:

stresses on the design area of the weld ($\alpha = 45^\circ$):

$\sigma_{W,Ed} = \sigma_{W,x} = 74.3 \text{ N/mm}^2$
resultant weld force $F_{W,Ed} = \sigma_{W,Ed} a = 6.69 \text{ kN/cm}$
resistance of a weld: $F_{W,Rd} = f_{W,d} a = 18.71 \text{ kN/cm}$, $f_{W,d} = 207.85 \text{ N/mm}^2$, $a = 9.0 \text{ mm}$ $F_{W,Ed} = 6.69 \text{ kN/cm} < F_{W,Rd} = 18.71 \text{ kN/cm} \Rightarrow U = 0.358 < 1 \text{ ok}$

verification of weld 2, pt. 0:

stresses on the design area of the weld ($\alpha = 45^\circ$):

$\sigma_{W,Ed} = \sigma_{W,x} = 66.9 \text{ N/mm}^2$
resultant weld force $F_{W,Ed} = \sigma_{W,Ed} a = 6.22 \text{ kN/cm}$
resistance of a weld: $F_{W,Rd} = f_{W,d} a = 8.31 \text{ kN/cm}$, $f_{W,d} = 207.85 \text{ N/mm}^2$, $a = 4.0 \text{ mm}$ $F_{W,Ed} = 6.22 \text{ kN/cm} < F_{W,Rd} = 8.31 \text{ kN/cm} \Rightarrow U = 0.267 < 1 \text{ ok}$

verification of weld 4, pt. 0:

stresses on the design area of the weld ($\alpha = 45^\circ$):

$\sigma_{W,Ed} = \sigma_{W,x} = 55.4 \text{ N/mm}^2$
resultant weld force $F_{W,Ed} = \sigma_{W,Ed} a = 2.22 \text{ kN/cm}$
resistance of a weld: $F_{W,Rd} = f_{W,d} a = 8.31 \text{ kN/cm}$, $f_{W,d} = 207.85 \text{ N/mm}^2$, $a = 4.0 \text{ mm}$ $F_{W,Ed} = 2.22 \text{ kN/cm} < F_{W,Rd} = 8.31 \text{ kN/cm} \Rightarrow U = 0.267 < 1 \text{ ok}$

verification of weld 6, pt. 0:

stresses on the design area of the weld ($\alpha = 45^\circ$):

$\sigma_{W,Ed} = \sigma_{W,x} = 66.9 \text{ N/mm}^2$
resultant weld force $F_{W,Ed} = \sigma_{W,Ed} a = 6.02 \text{ kN/cm}$
resistance of a weld: $F_{W,Rd} = f_{W,d} a = 18.71 \text{ kN/cm}$, $f_{W,d} = 207.85 \text{ N/mm}^2$, $a = 9.0 \text{ mm}$ $F_{W,Ed} = 6.02 \text{ kN/cm} < F_{W,Rd} = 18.71 \text{ kN/cm} \Rightarrow U = 0.322 < 1 \text{ ok}$

verification of weld 8, pt. 0:

stresses on the design area of the weld ($\alpha = 45^\circ$):

$\sigma_{W,Ed} = \sigma_{W,x} = 74.3 \text{ N/mm}^2$
resultant weld force $F_{W,Ed} = \sigma_{W,Ed} a = 6.69 \text{ kN/cm}$
resistance of a weld: $F_{W,Rd} = f_{W,d} a = 18.71 \text{ kN/cm}$, $f_{W,d} = 207.85 \text{ N/mm}^2$, $a = 9.0 \text{ mm}$ $F_{W,Ed} = 6.69 \text{ kN/cm} < F_{W,Rd} = 18.71 \text{ kN/cm} \Rightarrow U = 0.358 < 1 \text{ ok}$

Result:

weld 1, pt. 0: $\sigma_{W,x} = 74.31 \text{ N/mm}^2$
Max: $F_{W,Ed} = 6.69 \text{ kN/cm} < F_{W,Rd} = 18.71 \text{ kN/cm} \Rightarrow U_w = 0.358 < 1 \text{ ok}$

3.4.3. verification result

maximum utilization: max $U = 0.982 < 1 \text{ ok}$

3.5. rotational stiffness

stiffness coefficients

stiffness coefficient of basic component 5:

$k_5 = 0.9 \text{ taf} \cdot t^3 / m^3 = 82.34 \text{ mm}$, $l_{\text{eff}} = 261.4 \text{ mm}$, $m = 35.5 \text{ mm}$ (bolt row 1)

stiffness coefficient of basic component 10:

$k_{10} = 1.6 A_s / L_b = 5.43 \text{ mm}$, $L_b = l_{ges} + 2 l_p + (l_k+1)m/2 = 72.3 \text{ mm}$, $l_{ges} = 50.0 \text{ mm}$

sum of stiffness coefficients $\Sigma (1/k_i) = 1/k_s + 1/k_5 + 1/(2k_{10}) = 0.116$

rotational stiffness

initial rotational stiffness: $S_{ij,ini} = (E \cdot t^2) / \Sigma (1/k_i) = 142652.2 \text{ kNm/rd}$, $z = 281.3 \text{ mm}$

internal moment at the connection point: $M_{ij,Ed} = M_{Ed} = 120.00 \text{ kNm}$

$|M_{ij,Ed} = 120.00 \text{ kNm} > 2/3 M_{j,Ed} = 81.5 \text{ kNm} \Rightarrow \mu = ((1.5 \cdot M_{ij,Ed}) / M_{j,Ed})^{\Psi} = 2.843$, $\Psi = 2.7$

rotational stiffness: $S_{ij,Ed} = S_{ij,ini} / \mu = 50174.7 \text{ kNm/rd}$
4. final result

utilization/rotation of the connection

<table>
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<tr>
<th>Lk</th>
<th>$S_{j,\text{inf}}$</th>
<th>$S_j$</th>
<th>$\varphi_j$</th>
<th>$U_j$</th>
<th>$\Sigma H$</th>
<th>$\Sigma V$</th>
<th>$\Sigma M$</th>
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<td>°</td>
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<td>kN</td>
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<td>0.00</td>
<td>0.00</td>
<td>120.00</td>
</tr>
</tbody>
</table>

$S_{j,\text{inf}}$: initial rotational stiffness; $S_j$: rotational stiffness; $\varphi_j$: rotation; $U_j$: utilization of the connection; tolerances of equilibrium 1 kN / 1 MNm

*) maximum utilization

maximum utilization [Lk 2]: \[ \text{max } U = 0.982 < 1 \text{ ok} \]

minimum rotational stiffness: \[ \text{min } S_j = 50.2 \text{ MNm/rad}, \text{ } S_{j,\text{ini}} = 142.7 \text{ MNm/rad}, \text{ } \varphi_j = 0.137^\circ \]

verification succeeded