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

1. input report

![Diagram of beam splice]

**steel grade**
steel grade S235

**bolts**
bolt class 10.9, bolt size M24
large wrench size (high strength bolt), preloaded (for info: preloading $F_{P,C^*} = 0.7\cdot f_{yB}\cdot A_b = 222.4$ kN)
shear plane passes through the unthreaded portion of the bolt

**beam parameters**
section IPE550
slope angle of section about the horizontal axis $\alpha_b = -5.00^\circ$

**verification parameters**
bolted end-plate connection:
thickness $t_p = 20.0$ mm, width $b_p = 210.0$ mm, length $l_p = 682.1$ mm
projections $h_{p,o} = 20.0 \text{ mm}$, $h_{p,u} = 110.0 \text{ mm}$
bolts in connection:
3 bolt-rows with 2 bolts
of these 1 bolt-row top in tension (row 1)
and 2 bolt-rows for shear transfer top (rows 2-3)
of these 2 bolt-rows bottom in tension (rows 2-3)
and 1 bolt-row for shear transfer bottom (row 3)
centre distance of the bolts to the lateral edge of the end-plate $e_2 = 45.0 \text{ mm}$
centre distance of the first bolt-row to the upper edge of the end-plate (end row) $e_0 = 87.3 \text{ mm}$
centre distance of the last bolt-row to the bottom edge of the end-plate (end row) $e_o = 60.0 \text{ mm}$
centre distance of the bolt-rows from each other $p_{1-2} = 417.5 \text{ mm}$, $p_{2-3} = 117.3 \text{ mm}$
welds at the connection point:
beam flange top: fillet weld, weld thickness $a = 8.0 \text{ mm}$, angle $\varphi = 95^\circ$
beam web: fillet weld, weld thickness $a = 6.0 \text{ mm}$
beam flange bottom: fillet weld, weld thickness $a = 8.0 \text{ mm}$, angle $\varphi = 85^\circ$

**Internal forces and moments in the intersection point of system axes**

$Lk\, 1: \text{Ek \,3 (bzgl. right frame corner)}$

\[
N_{j,b,Ed} = -50.10 \text{ kN} \quad M_{j,b,Ed} = 308.80 \text{ kNm} \quad V_{j,b,Ed} = 116.70 \text{ kN}
\]

**Partial safety factors for material**
resistance of cross-sections $\gamma_M = 1.00$
resistance of members in stability failure $\gamma_M = 1.10$
resistance of bolts, welds, plates in bearing $\gamma_M = 1.25$
presstressing of high strength bolts $\gamma_M = 1.10$

**Check of data**
ok
distances between bolt-rows at end-plate
horizontal: $e_2 = 45.0 \text{ mm} > 1.2 \cdot d_0 = 31.2 \text{ mm}$, $e_2 = 45.0 \text{ mm} < 4 \cdot t + 40 \text{ mm} = 120.0 \text{ mm}$
horizontal: $p_2 = 120.0 \text{ mm} > 2.4 \cdot d_0 = 62.4 \text{ mm}$, $p_2 = 120.0 \text{ mm} < \min(14t, 200 \text{ mm}) = 200.0 \text{ mm}$
vertical: $e_1 = 87.3 \text{ mm} > 1.2 \cdot d_0 = 31.2 \text{ mm}$, $e_1 = 87.3 \text{ mm} < 4 \cdot t + 40 \text{ mm} = 120.0 \text{ mm}$
vertical: $p_1 = 417.5 \text{ mm} > 2.2 \cdot d_0 = 57.2 \text{ mm}$, $p_1 = 417.5 \text{ mm} > \min(14t, 200 \text{ mm}) = 200.0 \text{ mm}$
vertical: $p_1 = 117.3 \text{ mm} > 2.2 \cdot d_0 = 57.2 \text{ mm}$, $p_1 = 117.3 \text{ mm} < \min(14t, 200 \text{ mm}) = 200.0 \text{ mm}$
vertical: $e_1 = 60.0 \text{ mm} > 1.2 \cdot d_0 = 31.2 \text{ mm}$, $e_1 = 60.0 \text{ mm} < 4 \cdot t + 40 \text{ mm} = 120.0 \text{ mm}$
maximum values for spacings and edge distances should be in order to avoid local buckling and to prevent corrosion.

**Notes**
no verification for cross-sections.
no verification for welds within the connection.

2. **Lk\, 1: \text{Ek \,3 (bzgl. right frame corner)}**

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

2.1. **Design values**

\begin{align*}
\text{Knotenschlittgrößen} & \quad \text{periphery connection} & \quad \text{zur connection plane} & \quad \text{partial internal forces and moments} \\
\text{intersectional forces and} & \quad \text{periphery connection-aligned} & \quad \text{perpendicular to the connection planes} & \quad \text{partial internal forces and moments} \\
\text{moments} & \quad \text{perpendicular to the connection plane} & \quad \text{periphery end-plate-beam:} \quad M'_{d} = M_{d} + N_{b,\text{top}} \tan(\alpha) & \quad \text{periphery end-plate-beam:} \quad M'_{d} = M_{d} + N_{b,\text{top}} \tan(\alpha) \cdot \cos(\alpha_{b}) + M'_{d} \cos(\alpha_{b}) \\
\end{align*}

\[
\begin{aligned}
\text{slope angle: } & \quad \alpha_{b} = \alpha_{v} = -5.00^\circ \\
\text{internal forces and moments perpendicular to the connection planes} & \quad N_{a} = 60.08 \text{ kN} \quad M_{d} = -308.80 \text{ kNm} \quad V_{d} = 111.89 \text{ kN} \\
\text{negative internal moment } & \quad M_{d} = 308.80 \text{ kNm} \quad V_{d} = -111.89 \text{ kN} \\
\text{partial internal forces and moments referring to the mirrored model} & \quad N_{b,\text{top}} = \cos(\frac{z_{d}}{2b} + \frac{M'_{d}z_{b}}{C(\alpha_{b})}) \cdot \cos(\alpha_{b}) \cdot \cos(\alpha_{b}) = 553.82 \text{ kN} \quad z_{b} = 534.8 \text{ mm} \quad z_{b} = 267.4 \text{ mm} \\
\text{internal forces and moments in the periphery end-plate-beam:} & \quad M'_{d} = M_{d} + N_{b,\text{top}} \tan(\alpha) \cdot \cos(\alpha_{b}) = 553.82 \text{ kN} \quad z_{b} = 534.8 \text{ mm} \quad z_{b} = 267.4 \text{ mm} \\
\end{aligned}
\]
2.2. basic components

2.2.1. Gk 5: end-plate in bending

extended part of end-plate

in the extended part of the end-plate only one bolt-row is considered \( (n_b - 1) \).

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

in mode 1: \( \xi_{l,1} = l_{eff,1} = \min(\xi_{l,nc}, l_{eff,cp}) = 105.0 \text{ mm}, \ l_{eff,cp} = 218.6 \text{ mm} \)

in mode 2: \( \xi_{l,2} = l_{eff,2} = l_{eff,nc} = 105.0 \text{ mm} \)

tension resistance of the T-stub flange:

in mode 1+2: \( M_{pl,Rd} = (0.25 \cdot \xi_{l,eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 2.47 \text{ kNm} \)

in mode 3: \( \Sigma F_{l,Rd} = 2 \cdot n_b \cdot F_{l,Rd} = 508.32 \text{ kN} \)

mode 1: complete yielding of the T-stub flange

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

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

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

mode 3: bolt failure

\( F_{T,3,Rd} = \Sigma F_{l,Rd} = 508.32 \text{ kN} \)

tension resistance of the T-stub flange:

\( F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 241.04 \text{ kN} \)

resistance of a weld (req.1):

\( f_{w,d} = f_u / (\gamma_w \gamma_{M2}) = 360.0 \text{ N/mm}^2 \)

tension resistance of welds:

\( F_{T,w,Rd} = 2^{1/2} \cdot f_{w,d} \cdot a \cdot l_{eff} = 427.66 \text{ kN} \) (\( \geq 241.04 \text{ kN}, \text{ not decisive} \))

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

\( F_{T,ep,Rd,1} = 241.04 \text{ kN}, \ l_{eff,1} = 105.0 \text{ mm} \)

part of end-plate between beam flanges

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

here: number of bolt-rows \( n_b - 1 \)

row 2

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

in mode 1: \( \xi_{l,1} = l_{eff,1} = \min(l_{eff,nc}, l_{eff,cp}) = 271.9 \text{ mm}, \ l_{eff,cp} = 299.5 \text{ mm} \)

in mode 2: \( \xi_{l,2} = l_{eff,2} = l_{eff,nc} = 271.9 \text{ mm} \)

tension resistance of the T-stub flange:

in mode 1+2: \( M_{pl,Rd} = (0.25 \cdot \xi_{l,eff} \cdot t_f^2 \cdot f_y) / \gamma_{M0} = 6.39 \text{ kNm} \)

in mode 3: \( \Sigma F_{l,Rd} = 2 \cdot n_b \cdot F_{l,Rd} = 508.32 \text{ kN} \)

mode 1: complete yielding of the T-stub flange

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

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

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

mode 3: bolt failure

\( F_{T,3,Rd} = \Sigma F_{l,Rd} = 508.32 \text{ kN} \)

tension resistance of the T-stub flange:

\( F_{T,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd}) = 384.78 \text{ kN} \)

resistance of a weld (req.1):

\( f_{w,d} = f_u / (\gamma_w \gamma_{M2}) = 360.0 \text{ N/mm}^2 \)

tension resistance of welds:

\( F_{T,w,Rd} = 2^{1/2} \cdot f_{w,d} \cdot a \cdot l_{eff} = 830.60 \text{ kN} \) (\( \geq 384.78 \text{ kN}, \text{ not decisive} \))

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

\( F_{ep,Rd,2} = 384.78 \text{ kN}, \ l_{eff,2} = 271.9 \text{ mm} \)

2.2.2. Gk 7: beam flange and web in compression

flange bottom: section class for \( \alpha (b/t) = 4.39: 1 \)

web: section class for \( \alpha = 0.52 \) and \( \alpha (b/t) = 42.13: 1 \)

section class of beam: 1

taking into account the moment-shear force-interaction \( V_{Ed} = 116.7 \text{ kN} \)
stress due to bending with shear force: \( V_{Ed} = 116.7 \, \text{kN} \leq 492.5 \, \text{kN} = V_{pl,Rd}^2 \) => no effect
resistance \( M_{c, Rd} = M_{pl, Rd} = (W_{pl} f_y) / \gamma_{M0} = 642.25 \, \text{kNm} \), \( W_{pl} = 2732.99 \, \text{cm}^3 \)
resistance of a flange (and web) with compression
\( F_{c, t, Rd} = M_{c, Rd} / (h - t) = 1200.84 \, \text{kN} \)

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

2.2.3. Gk 8: beam web in tension

Each individual bolt-row:
row 2
- effective width \( b_{eff, wb} = 271.9 \, \text{mm} \) (left from bc 5)
resistance of a beam web in tension
\( F_{t, wb, Rd} = b_{eff, wb} f_{wb} f_y / \gamma_{M0} = 709.3 \, \text{kN} \)

2.2.4. Gk 10: bolts in tension

tension resistance of one bolt \( F_{t, Rd} = (k_2 f_{wb} A_w) / \gamma_{M2} = 254.16 \, \text{kN} \), \( k_2 = 0.90 \)
punching shear load capacity \( B_{p, Rd} = (0.6 \pi d_m f_u) / \gamma_{M2} = 467.95 \, \text{kN} \), \( d_m = 20.0 \, \text{mm} \)
tension-punching shear load capacity for 2 bolts: \( \Sigma F_{t, Rd} = 2 \min(F_{t, Rd}, B_{p, Rd}) = 508.32 \, \text{kN} \)

2.2.5. Gk 11: bolts in shear
shear resistance per shear plane $F_{V, Rd} = \alpha_V \cdot f_{ub} \cdot A / \gamma M_2 = 217.15 \text{ kN}$, $\alpha_V = 0.60$

shear resistance of 2 bolts (1-shear): $\sum F_{V, Rd} = 2 \cdot F_{V, Rd} = 434.29 \text{ kN}$

2.2.6. Gk 12: plate with bearing resistance

row 3
- bolt 1: bearing resistance $F_{b, Rd} = (k_1 \cdot \alpha_B \cdot f_{ub} \cdot d \cdot t) / \gamma M_2 = 345.60 \text{ kN}$, $k_1 = 2.50$, $\alpha_B = 1.00$
- bolt 2: bearing resistance $F_{b, Rd} = (k_1 \cdot \alpha_B \cdot f_{ub} \cdot d \cdot t) / \gamma M_2 = 345.60 \text{ kN}$, $k_1 = 2.50$, $\alpha_B = 1.00$

bearing resistance of 1x2 bolts: $\sum F_{b, Rd} = 691.20 \text{ kN}$

2.3. connection capacity

2.3.1. moment resistance

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

resistance per bolt-row
- row 1: $F_{tr, Rd} = 241.0 \text{ kN}$
- row 2: $F_{tr, Rd} = 384.8 \text{ kN}$
  $\sum F_{tr, Rd} = 625.8 \text{ kN}$

potential failure by basic component 5

resistance of flanges
$\sum F_{c, Rd} = 2401.7 \text{ kN}$

moment resistance
$M_{b, Rd} = \sum (F_{tr, Rd} \cdot h) = 326.3 \text{ kNm}$

tension resistance
$N_{t, Rd} = \sum F_{tr, Rd} = 625.8 \text{ kN}$

compression resistance
$N_{c, Rd} = \sum F_{c, Rd} = 2401.7 \text{ kN}$

2.3.2. shear/bearing resistance

resistance per bolt-row
- row 3: $F_{V, Rd} = 434.3 \text{ kN}$
  $\sum F_{V, Rd} = 434.3 \text{ kN}$

shear/bearing resistance
$V_{b, Rd} = \sum F_{V, Rd} = 434.3 \text{ kN}$
2.3.3. total
\( M_{L,Rd} = 326.3 \text{ kNm} \quad N_{L,Rd} = 625.8 \text{ kN} \quad N_{J,Rd} = 2401.7 \text{ kN} \quad V_{J,Rd} = 434.3 \text{ kN} \)

2.4. verifications

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

axial force: \( N_{Ed,ax} = |N_{Ed,ax}| = 50.10 \text{ kN} \quad \Rightarrow 5\% N_{Ed,ax} = 158.52 \text{ kN} \Rightarrow \) moment resistance

internal moment: \( M_{Ed} = M_d \quad N_{Ed,2bu} = 292.84 \text{ kNm} \quad z_{bu} = 285.7 \text{ mm} \)

shear force: \( V_{Ed} = |V_{Ed}| = 111.89 \text{ kN} \)

\( M_{Ed}/M_{L,Rd} = 0.898 < 1 \quad \text{ok} \)

2.4.2. verification result

maximum utilization: \( \max U = 0.898 < 1 \quad \text{ok} \)

2.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 2 tension-bolt-rows:

1: \( k_s = 11.01 \text{ mm} \quad k_{10} = 8.62 \text{ mm} \Rightarrow k_{eff,1} = 1 / \Sigma(1/k_s) = 3.360 \text{ mm} \)

2: \( k_s = 18.08 \text{ mm} \quad k_{10} = 8.62 \text{ mm} \Rightarrow k_{eff,2} = 1 / \Sigma(1/k_s) = 4.413 \text{ mm} \)

\( k_{eq} = |k_{eff,1}r_1| / z_{eq} = 7.680 \text{ mm} \quad z_{eq} = \Sigma(k_{eff,1}r_1^2) / \Sigma(k_{eff,1}r_1) = 533.3 \text{ mm} \)

rotational stiffness

initial rotational stiffness: \( S_{J,ini} = (Ez)^2 / \Sigma(1/k_s) = 458666.5 \text{ kNm/rad} \quad z = z_{eq} = 533.3 \text{ mm} \quad \Sigma(1/k_s) = 0.130 \text{ mm}^{-1} \)

\( |N_{Ed,ax}| = 50.10 \text{ kN} \quad \Rightarrow 5\% N_{Ed,ax} = 158.52 \text{ kN} \quad \text{ok} \)

\( |M_{Ed}| = 292.84 \text{ kNm} > 2/3 M_{L,Rd} = 217.5 \text{ kNm} \Rightarrow \mu = ((1.5M_{Ed}) / M_{L,Rd})^{0.5} = 2.232 \quad \Psi = 2.7 \)

rotational stiffness: \( S_{J,Rd} = S_{J,ini} / \mu = 205493.9 \text{ kNm/rad} \)

rotation: \( \varphi_{Ed} = M_{Ed} / S_{J,Rd} = 0.082^\circ \)

3. final result

utilization/rotation of the connection

<table>
<thead>
<tr>
<th>( L_k )</th>
<th>( S_{J,ini} )</th>
<th>( S_J )</th>
<th>( \varphi_J )</th>
<th>( U_J )</th>
<th>Gleichgewicht</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>458.7</td>
<td>205.5</td>
<td>0.082</td>
<td>0.898*</td>
<td>60.08</td>
</tr>
</tbody>
</table>

\( S_{J,ini} \): initial rotational stiffness; \( S_J \): rotational stiffness; \( \varphi_J \): rotation; \( U_J \): utilization of the connection; tolerances of equilibrium 1 kN / 1 kNm

* maximum utilization

maximum utilization: \( \max U = 0.898 < 1 \quad \text{ok} \)

minimum rotational stiffness: \( \min S_J = 205.5 \text{ MNm/rad} \quad S_{J,ini} = 458.7 \text{ MNm/rad} \quad \varphi_J = 0.082^\circ \)

verification succeeded