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

1. input report

bolts
bolt class 10.9, bolt size M24
large wrench size (high strength bolt), preloaded (for info: preloading \( F_p, C^* = 0.7 \cdot f_y \cdot A_s = 222.4 \text{ kN} \))
shear plane passes through the unthreaded portion of the bolt

beam parameters
section HE400A, steel grade S355
verification parameters
bolted end-plate connection:
thickness \( t_p = 20.0 \text{ mm} \), width \( b_p = 320.0 \text{ mm} \), length \( l_p = 495.0 \text{ mm} \), steel grade S235
projections \( h_{p,o} = 85.0 \text{ mm} \), \( h_{p,u} = 20.0 \text{ mm} \)
bolts in connection:
3 bolt-rows with 4 bolts
  row 1: 4 bolts, row 2: 4 bolts, row 3: 4 bolts
  of these 2 bolt-rows top in tension (rows 1-2)
  and 2 bolt-rows for shear transfer top (rows 2-3)
  of these 1 bolt-row bottom in tension (row 3)
  and 1 bolt-row for shear transfer bottom (row 3)
calculation method (4 bolts per row) acc. to B. Schmidt, Dissertation, TU Dortmund
  centre distance between outer and inner bolt \( w_2 = 65.0 \text{ mm} \)
  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) \( e_0 = 35.0 \text{ mm} \)
  centre distance of the last bolt-row to the bottom edge of the end-plate (end row) \( e_u = 90.0 \text{ mm} \)
  centre distance of the bolt-rows from each other \( p_{1-2} = 120.0 \text{ mm} \), \( p_{2-3} = 250.0 \text{ mm} \)
welds at the connection point:
beam flange top: fillet weld, weld thickness $a = 13.0$ mm
beam web: fillet weld, weld thickness $a = 6.0$ mm
beam flange bottom: fillet weld, weld thickness $a = 13.0$ mm

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

Lk 1: $M_{b, Ed} = 460.00$ kNm

**Partial safety factors for material**

resistance of cross-sections $\gamma_{M0} = 1.00$
resistance of members in stability failure $\gamma_{M1} = 1.10$
resistance of bolts, welds, plates in bearing $\gamma_{M2} = 1.25$
prestressing of high strength bolts $\gamma_{M7} = 1.10$

**Check of data**

ok

**Distances between bolt-rows at end-plate**

- horizontal: $e_2 = 35.0$ mm $> 1.2 \times d_0 = 31.2$ mm, $e_2 = 35.0$ mm $< 4 \times 40$ mm = 120.0 mm
- horizontal: $p_2 = 65.0$ mm $> 2.4 \times d_0 = 62.4$ mm, $p_2 = 65.0$ mm $< \min(14d, 200)$ mm = 200.0 mm
- horizontal: $p_2 = 120.0$ mm $> 2.4 \times d_0 = 62.4$ mm, $p_2 = 120.0$ mm $< \min(14d, 200)$ mm = 200.0 mm
- vertical: $e_1 = 35.0$ mm $> 1.2 \times d_0 = 31.2$ mm, $e_1 = 35.0$ mm $< 4 \times 40$ mm = 120.0 mm
- vertical: $p_1 = 120.0$ mm $> 2.2 \times d_0 = 57.2$ mm, $p_1 = 120.0$ mm $< \min(14d, 200)$ mm = 200.0 mm
- vertical: $p_1 = 250.0$ mm $> 2.2 \times d_0 = 57.2$ mm, $p_1 = 250.0$ mm $> \min(14d, 200)$ mm = 200.0 mm
- vertical: $e_1 = 90.0$ mm $> 1.2 \times d_0 = 31.2$ mm, $e_1 = 90.0$ mm $< 4 \times 40$ mm = 120.0 mm

**Notes**

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

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 L zur Connection Plane**

**Partial Internal forces and moments**

**Slope angle:** $\alpha_b = \alpha_v = \alpha = 0°$

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

- Periphery beam $M_0 = 460.00$ kNm
- Partial internal forces and moments
- Internal forces and moments in the periphery end-plate-beam: $M_d = M_0 \cdot V_{d-ep} = 460.00$ kNm
- $N_{b,t} = N_d \cdot z_{bu} / z_b + M_d / z_b = 1239.89$ kN, $z_b = 371.0$ mm, $z_{bu} = 185.5$ mm
- $N_{b,c} = N_d \cdot z_{bol} / z_b + M_d / z_b = 1239.89$ kN, $z_b = 371.0$ mm, $z_{bo} = 185.5$ mm

2.2. Basic components

2.2.1. Gk 5: End-plate in bending

**Notes**

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

IH4-connection: connections with 4 bolts per bolt-row are not treated in EC 3-1-8.
Verification according to B. Schmidt, Dissertation, TU Dortmund.
extended part of end-plate
in projecting part of end plate only one bolt-row (nB = 1) is considered (4 bolts per row).
effective length of the T-stub flange (end-plate):
in mode 1: \( \delta_{\text{eff,1}} = \text{left,1} = \min(\text{left,nc, left,cp}) = 160.0 \text{ mm, } \text{left,cp} = 190.4 \text{ mm} \)
in mode 2: \( \delta_{\text{eff,2}} = \text{left,2} = \text{left,nc} = 160.0 \text{ mm} \)
tension resistance of the T-stub flange:
in mode 1 + 2: \( \mathcal{M}_{\text{pl,Rd}} = (0.25 \delta_{\text{eff,1}} f_t^2 f_y) / Y_{\text{MO}} = 3.76 \text{ kNm} \)
in mode 3: \( \mathcal{Sigma}_{\text{Rd}} = 4 \text{nB} \mathcal{F}_{\text{Tr, Rd}} = 1016.64 \text{ kN} \)
mode 1: complete yielding of the T-stub flange
\( \mathcal{F}_{\text{Tr,1,Rd}} = (\mathcal{M}_{\text{pl1,Rd}} (4+0.0196n)) / (m - ((m+n) e') / (2-n)) = 734.70 \text{ kN} \)
mode 2: bolt failure simultaneously with yielding of the T-stub flange
\( \mathcal{F}_{\text{Tr,2,Rd}} = (2 \mathcal{M}_{\text{pl2,Rd}} + n \mathcal{Sigma}_{\text{Rd}}) / (m+n) = 613.19 \text{ kN} \)
mode 3: bolt failure
\( \mathcal{F}_{\text{Tr,3,Rd}} = \delta_{\text{eff,1}} = 1016.64 \text{ kN} \)
tension resistance of the T-stub flange: \( \mathcal{F}_{\text{Tr,Rd}} = \min(\mathcal{F}_{\text{Tr,1,Rd}}, \mathcal{F}_{\text{Tr,2,Rd}}, \mathcal{F}_{\text{Tr,3,Rd}}) = 613.19 \text{ kN} \)
tension resistance of beam flange: max \( \mathcal{F}_{\text{Tr,Rd}} = (A F_{\text{Tr,yst}}) / Y_{\text{MO}} = 2025.50 \text{ kN} > \mathcal{F}_{\text{Tr,Rd}} \text{ ok} \)
resistance of a weld (req.1): \( f_{\text{w,d}} = f_u / (0.6 + 2.0 Y_{\text{MO}}) = 320.0 \text{ N/mm}^2 \)
tension resistance of welds: \( \mathcal{F}_{\text{Tr,w,Rd}} = 2^{1/2} f_{\text{w,d}} \delta_{\text{left}} = 941.30 \text{ kN} \) \( \geq 613.19 \text{ kN} \), not decisive
resistance and effective length of end-plate in bending (projection)
\( \mathcal{F}_{\text{ep,Rd,1}} = 613.19 \text{ kN, } \delta_{\text{left}} = 160.0 \text{ mm} \)
part of end-plate between beam flanges
equivalent T-stub flange (each individual bolt-row):
row 2 (4 bolts per row)
effective length of the T-stub flange (end-plate):
in mode 1: \( \delta_{\text{eff,1}} = \text{left,1} = \min(\text{left,nc, left,cp}) = 349.9 \text{ mm, } \text{left,cp} = 349.9 \text{ mm} \)
in mode 2: \( \delta_{\text{eff,2}} = \text{left,2} = \text{left,nc} = 362.5 \text{ mm} \)
tension resistance of the T-stub flange:
in mode 1: \( \mathcal{M}_{\text{pl1,Rd}} = (0.25 \delta_{\text{eff,1}} f_t^2 f_y) / Y_{\text{MO}} = 8.22 \text{ kNm} \)
in mode 2: \( \mathcal{M}_{\text{pl2,Rd}} = (0.25 \delta_{\text{eff,2}} f_t^2 f_y) / Y_{\text{MO}} = 8.52 \text{ kNm} \)
in mode 3: \( \mathcal{Sigma}_{\text{Rd}} = 4 \text{nB} \mathcal{F}_{\text{Tr, Rd}} = 1016.64 \text{ kN} \)
mode 1: complete yielding of the T-stub flange
\( \mathcal{F}_{\text{Tr,1,Rd}} = (\mathcal{M}_{\text{pl1,Rd}} (4+0.0196n)) / (m - ((m+n) e') / (2-n)) = 1159.91 \text{ kN} \)
\( \mathcal{F}_{\text{Tr,1,Rd}} = (\mathcal{M}_{\text{pl1,Rd}} (4+0.0196n)) / (m - ((m+n) e') / (2-n)) = 181.57 \text{ kN} \)
\( \mathcal{F}_{\text{Tr,1,Rd}} = \mathcal{F}_{\text{Tr,1,Rd}} + \mathcal{F}_{\text{Tr,1,Rd}} = 1341.48 \text{ kN} \)
mode 2: bolt failure simultaneously with yielding of the T-stub flange
\( \mathcal{F}_{\text{Tr,2,Rd}} = (2 \mathcal{M}_{\text{pl2,Rd}} + n \mathcal{Sigma}_{\text{Rd}}) / (m+n) = 347.07 \text{ kN} \)
\( \mathcal{F}_{\text{Tr,2,Rd}} = (2 \mathcal{M}_{\text{pl2,Rd}} + n \mathcal{Sigma}_{\text{Rd}}) / (m+n) = 391.91 \text{ kN} \)
\( \mathcal{F}_{\text{Tr,2,Rd}} = \mathcal{F}_{\text{Tr,2,Rd}} + \mathcal{F}_{\text{Tr,2,Rd}} = 738.97 \text{ kN} \)
mode 3: bolt failure
\( \mathcal{F}_{\text{Tr,3,Rd}} = \delta_{\text{eff,1}} = 1016.64 \text{ kN} \)
tension resistance of the T-stub flange: \( \mathcal{F}_{\text{Tr,Rd}} = \min(\mathcal{F}_{\text{Tr,1,Rd}}, \mathcal{F}_{\text{Tr,2,Rd}}, \mathcal{F}_{\text{Tr,3,Rd}}) = 738.97 \text{ kN} \)
resistance of a weld (req.1): \( f_{\text{w,d}} = f_u / (0.6 + 2.0 Y_{\text{MO}}) = 320.0 \text{ N/mm}^2 \)
tension resistance of welds: \( \mathcal{F}_{\text{Tr,w,Rd}} = 2^{1/2} f_{\text{w,d}} \delta_{\text{left}} = 950.06 \text{ kN} \) \( \geq 738.97 \text{ kN} \), not decisive
resistances and effective lengths of end-plate in bending (per bolt-row):
\( \mathcal{F}_{\text{ep,Rd,2}} = 738.97 \text{ kN, } \delta_{\text{left,2}} = 349.9 \text{ mm} \)

2.2.7 Gk 7: beam flange and web in compression
flange bottom: section class for \( a/(c-t) = 7.60; 1 \)
web: section class for \( \alpha = 0.50 \) and \( a/(c-t) = 33.30; 1 \)
section class of beam: 1

resistance \( M_c,Rd = M_{pl,Rd} = (W_{pl} f_y) / Y_{\text{MO}} = 909.51 \text{ kNm, } W_{pl} = 2562.00 \text{ cm}^3 \)
resistance of a flange (and web) with compression
\( F_{c,frad} = M_{c,Rd} / (h - t) = 2451.51 \text{ kN} \)
resistance of upper beam flange:
resistance \( M_c,Rd = M_{pl,Rd} = (W_{pl} f_y) / Y_{\text{MO}} = 909.51 \text{ kNm, } W_{pl} = 2562.00 \text{ cm}^3 \)
resistance of a flange (and web) with compression
2.2.3. Gk 8: beam web in tension

Each individual bolt-row:
row 2

effective width \( b_{\text{eff,wb}} = 349.9 \text{ mm} \) (left from bc 5)

resistance of a beam web in tension
\( F_{t,\text{wb,Rd}} = b_{\text{eff,wb}} f_{\text{y,wb}} / \gamma_{M0} = 1366.3 \text{ kN} \)

2.2.4. Gk 10: bolts in tension

Tension resistance of one bolt \( F_{t,Rd} = (k_2 f_{\text{ub}, A_2}) / \gamma_{M2} = 254.16 \text{ kN} \), \( k_2 = 0.90 \)

Punching shear load capacity \( B_{p,Rd} = (0.6 \pi d f_{p}) / \gamma_{M2} = 467.95 \text{ kN} \), \( f_p = 20.0 \text{ mm} \)

Tension/punching shear load capacity for 4 bolts: \( \Sigma F_{\text{p,Rd}} = 4 \cdot \min(F_{t,Rd}, B_{p,Rd}) = 1016.64 \text{ kN} \)

2.3. Connection capacity

2.3.1. Moment resistance

distance of tension-bolt-rows from centre of compression: \( h_1 = 430.5 \text{ mm} \), \( h_2 = 310.5 \text{ mm} \)

Resistance per bolt-row
row 1: \( F_{t,Rd} = 613.2 \text{ kN} \)
row 2: \( F_{t,Rd} = 739.0 \text{ kN} \)
\( \Sigma F_{t,Rd} = 1352.2 \text{ kN} \)

Potential failure by basic component 5

Resistance of flanges
\( \Sigma F_{c,Rd}^* = 4903.0 \text{ kN} \)

Moment resistance
\( M_{j,Rd} = \Sigma (F_{t,Rd} h) = 493.4 \text{ kNm} \)

Tension resistance
\( N_{t,Rd} = \Sigma F_{t,Rd} = 1352.2 \text{ kN} \)

Compression resistance
\( N_{c,Rd} = \Sigma F_{c,Rd} = 4903.0 \text{ kN} \)

2.4. Verifications

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

Internal moment: \( M_{Ed} = M_d = 460.00 \text{ kNm} \)

\( M_{Ed}/M_{j,Rd} = 0.932 < 1 \text{ ok} \)
2.4.2. verification result

maximum utilization: \( \max U = 0.932 < 1 \) ok

2.5. rotational stiffness

stiffness coefficients

equivalent stiffness coefficient for 2 tension-bolt-rows:
1: \( k_s = 26.21 \text{ mm}, \ k_{10} = 8.62 \text{ mm} \Rightarrow k_{\text{eff},1} = 1 / \Sigma(1/k_i,1) = 7.446 \text{ mm} \)
2: \( k_s = 4.44 \text{ mm}, \ k_{10} = 8.62 \text{ mm} \Rightarrow k_{\text{eff},2} = 1 / \Sigma(1/k_i,2) = 7.904 \text{ mm} \)
\( k_{\text{eq}} = \Sigma (k_{\text{eff},r} / z_{\text{eq}}) / z_{\text{eq}} = 14.954 \text{ mm}, \ z_{\text{eq}} = \Sigma (k_{\text{eff},r} / z_{\text{eq}}) = 788.5 \text{ mm} \)

rotational stiffness

initial rotational stiffness: \( S_{\text{ini}} = (E \cdot z^2) / \Sigma(1/k_i) = 449820.1 \text{ kNm/rad}, \ z = z_{\text{eq}} = 788.5 \text{ mm}, \ \Sigma(1/k_i) = 0.067 \text{ mm}^{-1} \)

\( |M_{\text{Ed}}| = 460.00 \text{ kNm} > 2/3 M_{\text{L,Rd}} = 329.0 \text{ kNm} \Rightarrow \mu = ((1,5 \cdot M_{\text{Ed}}) / M_{\text{L,Rd}})^\Psi = 2.473, \ \Psi = 2.7 \)

rotational stiffness: \( S_{\text{L,Rd}} = S_{\text{ini}} / \mu = 181908.5 \text{ kNm/rad} \)

rotation: \( \varphi_{\text{Ed}} = M_{\text{Ed}} / S_{\text{L,Rd}} = 0.145^\circ \)

3. final result

utilization/rotation of the connection

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
L_k & S_{\text{ini}} & S_{\text{L}} & \varphi & U_j & \Sigma H & \Sigma V & \Sigma M \\
\hline
\text{--} & \text{MNM/rad} & \text{MNM/rad} & ^\circ & \text{N} & \text{kN} & \text{kN} & \text{kNm} \\
\hline
1 & 449.8 & 181.9 & 0.145 & 0.932 & 0.00 & 0.00 & 460.00 & \text{!!} \\
\hline
\end{array}
\]

\( S_{\text{ini}} \): initial rotational stiffness; \( S_{\text{L}} \): rotational stiffness; \( \varphi \): rotation; \( U_j \): utilization of the connection; tolerances of equilibrium: 1 kN / 1 kNm

maximum utilization: \( \max U = 0.932 < 1 \) ok

minimum rotational stiffness: \( \min S_{\text{L}} = 181.9 \text{ MNm/rad}, \ S_{\text{ini}} = 449.8 \text{ MNm/rad}, \ \varphi = 0.145^\circ \)

verification succeeded