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 $F_{P,C^*} = 0.7 f_{yB} A_s = 154.3 \, \text{kN}$)
shear plane passes through the unthreaded portion of the bolt

**beam parameters**
section IPE400
slope angle of section about the horizontal axis $\omega_b = -2.00^\circ$

**verification parameters**
bolted end-plate connection:
thickness $t_p = 20.0 \, \text{mm}$, width $b_p = 180.0 \, \text{mm}$, length $l_p = 480.0 \, \text{mm}$
projections $h_{p,o} = 10.0 \, \text{mm}$, $h_{p,u} = 69.8 \, \text{mm}$
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 e₂ = 45.0 mm
centre distance of the first bolt-row to the upper edge of the end-plate (end row) e₀ = 90.0 mm
centre distance of the last bolt-row to the bottom edge of the end-plate (end row) e₃ = 30.0 mm
centre distance of the bolt-rows from each other p₁,₂ = 270.0 mm, p₂,₃ = 90.0 mm
welds at the connection point:
beam flange top: fillet weld, weld thickness a = 6.0 mm, angle ϕ = 92°
beam web: fillet weld, weld thickness a = 3.0 mm
beam flange bottom: fillet weld, weld thickness a = 6.0 mm, angle ϕ = 88°

internal forces and moments in the intersection point of system axes
Lk 1: N₁,b,Ed = -30.10 kN, M₁,b,Ed = 184.50 kNm, V₁,b,Ed = 0.80 kN

partial safety factors for material
resistance of cross-sections γ₀ = 1.00
resistance of members in stability failure γₐ = 1.10
resistance of bolts, welds, plates in bearing γ₁ = 1.25
prestress factors of high strength bolts γₗ = 1.10

check of data
ok
distances between bolt-rows at end-plate
horizontal: e₂ = 45.0 mm > 1.2d₀ = 26.4 mm,
e₂ = 45.0 mm > 41 + 40 mm = 120.0 mm
horizontal: p₂ = 90.0 mm > 2.4d₀ = 52.8 mm,
p₂ = 90.0 mm > min(141, 200 mm) = 200.0 mm
vertical: e₁ = 90.0 mm > 1.2d₀ = 26.4 mm,
e₁ = 90.0 mm < 41 + 40 mm = 120.0 mm
vertical: p₁ = 270.0 mm > 2.2d₀ = 48.4 mm,
p₁ = 270.0 mm > min(141, 200 mm) = 200.0 mm
vertical: p₁ = 90.0 mm > 2.2d₀ = 48.4 mm,
p₁ = 90.0 mm > min(141, 200 mm) = 200.0 mm
vertical: e₁ = 30.0 mm > 1.2d₀ = 26.4 mm,
e₁ = 30.0 mm < 41 + 40 mm = 120.0 mm
maximum values for spacings and edge distances should be in order to avoid local buckling and to prevent corrosion.

notes
there are several basic components selected which perhaps do not ensure the total loading capacity of the joint.
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.

2.1. design values

Knotenschnittgrößen

\[
\begin{align*}
M_{1,b} & = 30.10 \text{kN} \\
M_{1,b,Ed} & = 184.50 \text{kNm} \\
V_{1,b,Ed} & = 0.80 \text{kN}
\end{align*}
\]

sign definition of statics:
⇒ transformation to EC3:
a positive axial force means tension,
a positive bending moment produces tension at the bottom
a positive axial force means compression,
a positive bending moment produces tension at the top

slope angle:
α₉₀ = α₉₀ = α = -2.00°

transformation sign convention of statics ⇒ ec3-cos
\[
N_{b,Ed} = 30.10 \text{kN},
M_{b,Ed} = 184.50 \text{kNm},
V_{b,Ed} = 0.80 \text{kN}
\]
transformation node values ⇒ joint values
\[
N_b, Ed = 30.10 \text{kN},
M_b, Ed = 184.50 \text{kNm},
V_b, Ed = 0.80 \text{kN}
\]
transformation joint values ⇒ design values
\[
N_d = 30.11 \text{kN},
M_d = 184.50 \text{kNm},
V_d = -0.25 \text{kN}
\]

internal forces and moments perpendicular to the connection planes
periphery beam
\[
N_d = 30.11 \text{kN},
M_d = 184.50 \text{kNm},
V_d = -0.25 \text{kN}
\]
negative internal moment \(M_d\) ⇒ mirrored model \((\alpha_9 = \alpha = 2.00°)\)
\[
N_d = 30.11 \text{kN},
M_d = 184.50 \text{kNm},
V_d = 0.25 \text{kN}
\]

partial internal forces and moments according to the mirrored model

internal forces and moments in the periphery end-plate-beam:
\[
M_d = M_d + N_d \tan(\alpha) - V_d \tan(\alpha) = 184.52 \text{kNm}
\]
\[
N_{b,1,t} = (N_d \tan(\alpha) + M_d \sin(\alpha)) / \cos(\alpha) = 462.34 \text{kN},
Z_b = 386.7 \text{mm},
Z_{bu} = 193.4 \text{mm}
\]
\[
N_{c,c} = (N_{z} z_{c}/z_b + M'z_{c}/z_b) / \cos(\alpha_{c}) = 492.47 \text{ kN}, \quad z_b = 386.7 \text{ mm}, \quad z_{c} = 193.4 \text{ mm} \\
V_{b,w} = V_d + N_{c,c} \sin(\alpha_{c}) = 1.30 \text{ kN}
\]

### 2.2. Basic Components

**Beam splice w. end-plate:** selected basic component(s): 5

#### 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).
  - Distance centre-line of the bolt to beam flange m_1 = 33.0 mm

- **Effective Length of the T-Stub Flange (End-Plate)**
  - \(e_x = e - 30.0 \text{ mm}, \quad m_1 = 33.0 \text{ mm}, \quad w - b_0 = 2e = 90.0 \text{ mm} \) with \( b_0 = 180.0 \text{ mm}, \quad e = 45.0 \text{ mm} \)
  - End bolt-row outside tension flange of beam
    - \( \gamma_{n,c,sa} = \min(2 \pi x_m, \pi m_x + w, \pi m_x + e) = 193.6 \text{ mm} \)
    - \( \gamma_{n,c,sa} = \min(4m_x + 1.25 \sigma_x, \sigma + 2m_x + 0.625 \sigma_x, 0.5b_p, 0.5w + 2m_x + 0.625 \sigma_x) = 90.0 \text{ mm} \)
  - In mode 1: \( \gamma_{n,c,sa} = 90.0 \text{ mm} \)
  - In mode 2: \( \gamma_{n,c,sa} = 90.0 \text{ mm} \)

- **Tension Resistance of the T-Stub Flange**
  - \( n = \min(e_{min,1.25m} = 30.0 \text{ mm}, \quad e_{min} = 30.0 \text{ mm}, \quad m = 33.0 \text{ mm} \)
  - Resisting plastic moments:
    - In mode 1-2: \( M_{p,rd} = (0.25 \gamma_{n,c,sa} l^2 / l_f) / \gamma_{m0} = 2.11 \text{ kNm}, \quad l_f = 20.0 \text{ mm}, \quad l_f = 235.0 \text{ N/mm}^2, \quad \gamma_{m0} = 1.00 \)
  - Design value of tension resistance:
    - Tension resistance of one bolt: \( F_{t,Rd} = (k_2 f_{ub} A_s) / \gamma_{m2} = 176.40 \text{ kN}, \quad k_2 = 0.90 \)
  - In mode 3: \( F_{t,Rd} = 2/n_d F_{t,Rd} = 352.80 \text{ kN}, \quad n_d = 1 \)
  - Prying forces always appear at preloaded bolts!
  - Calculation with the alternative method:
    - Decisive diameter of the bolt \( d_w = d_p = 37.00 \text{ mm} \) \( \Rightarrow e_w = d_w/4 = 9.3 \text{ mm} \)
    - Mode 1: Complete yielding of the T-Stub Flange
      - \( F_{t,Rd} = (f_{ub} A_s) / (2 m_n w (m+n)) = 335.61 \text{ kN} \)
    - Mode 2: Bolt failure simultaneously with yielding of the T-Stub Flange
      - \( F_{t,Rd} = (2 f_{ub} d_p) / (2 m_n w (m+n)) = 235.34 \text{ kN} \)
    - Mode 3: Bolt failure
      - \( F_{t,Rd} = 2 f_{ub} d_p = 352.80 \text{ kN} \)
    - Tension resistance of the T-Stub Flange: \( F_{t,Rd} = \min(F_{t1,Rd}, F_{t2,Rd}, F_{t3,Rd}, F_{t4,Rd}) = 235.34 \text{ kN} \)
    - Resistance of a weld (req. 1): \( f_{w1} = f_u / (w \gamma_{m2}) = 360.0 \text{ N/mm}^2, \quad f_u = 360.0 \text{ N/mm}^2, \quad \gamma_{m2} = 0.80 \)
    - Tension resistance of welds: \( F_{t,Rd} = 21/2 f_{w1,d} \alpha_{eff} = 274.92 \text{ kN} (\geq 235.34 \text{ kN}, \text{ not decisive}) \)

- **Resistance and Effective Length of End-Plate in Bending (Projection)**
  - \( F_{t,sep,Rd,1} = 235.34 \text{ kN}, \quad \gamma_{n,c,sa} = 90.0 \text{ mm} \)

- **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**
  - Distance centre-line of the bolt to the stiffener \( m_2 = 29.9 \text{ mm} \)
  - Distance centre-line of the bolt to the edge of flange \( e = 45.0 \text{ mm} \)
  - Distance centre-line of the bolt to the stub web \( m = 37.3 \text{ mm} \)

- **Effective Length of the T-Stub Flange (End-Plate)**
  - Inner bolt-row outside tension flange of beam
    - Coefficient for stiffened column flanges and end-plates:
      - Input values \( \alpha = m_2 / (m+n) = 0.453, \quad \lambda = m_2 / (m+n) = 0.364 \Rightarrow \alpha = 6.36 \text{ (calculated)} \)
    - \( \gamma_{n,c,sa} = 2 \pi m = 234.4 \text{ mm} \)
    - \( \gamma_{n,c,sa} = \min(\left(\sum_{i=0}^{n} \left(F_{t,Rd,1} \times f_{w1,d} \times \alpha_{eff}ight)ight) = 274.92 \text{ kN} \leq 235.34 \text{ kN, not decisive}) \)

- **Tension Resistance of the T-Stub Flange**
  - \( n = \min(e_{min,1.25m} = 45.0 \text{ mm}, \quad e_{min} = 45.0 \text{ mm}, \quad m = 37.3 \text{ mm} \)
  - Resisting plastic moments:
    - In mode 1: \( M_{p,rd} = (0.25 \gamma_{n,c,sa} l^2 / l_f) / \gamma_{m0} = 5.51 \text{ kNm}, \quad l_f = 20.0 \text{ mm}, \quad l_f = 235.0 \text{ N/mm}^2, \quad \gamma_{m0} = 1.00 \)
    - In mode 2: \( M_{p,rd} = (0.25 \gamma_{n,c,sa} l^2 / l_f) / \gamma_{m0} = 5.58 \text{ kNm} \)
  - Design value of tension resistance:
tension resistance of one bolt: $F_{t,Rd} = (k_2 f_{ub} A_2) / \gamma_M = 176.40 \text{ kN}$, $k_2 = 0.90$
in mode 3: $\Sigma F_{t,Rd} = 2 \eta_b F_{t,Rd} = 352.80 \text{ kN}$, $\eta_b = 1$

prying forces always appear at preloaded bolts!
calculation with the alternative method
decisive diameter of the bolt $d_w = dp = 37.00 \text{ mm} \Rightarrow e_w = d_w/4 = 9.3 \text{ mm}$
mode 1: complete yielding of the T-stub flange
$F_{t,1,Rd} = ((8 \cdot n \cdot e_w)M_{pl,1,Rd}) / (2 \cdot m \cdot n \cdot e_w \cdot (m+n)) = 724.57 \text{ kN}$
mode 2: bolt failure simultaneously with yielding of the T-stub flange
$F_{t,2,Rd} = (2 M_{pl,2,Rd} + n \Sigma F_{t,Rd}) / (m+n) = 328.46 \text{ kN}$
mode 3: bolt failure
$F_{t,3,Rd} = \Sigma F_{t,Rd} = 352.80 \text{ kN}$
tension resistance of the T-stub flange: $F_{t,Rd} = \min(F_{t,1,Rd}, F_{t,2,Rd}, F_{t,3,Rd}) = 328.46 \text{ kN}$
resistance of a weld (req.1): $f_{w,1} = f_u \left(1 - \left(\frac{\beta_w \gamma_M}{2}ight)\right) = 360.0 \text{ N/mm}^2$, $f_u = 360.0 \text{ N/mm}^2$, $\beta_w = 0.80$
tension resistance of welds: $F_{t,w,Rd} = \frac{1}{2} f_{w,1}d_w a_{eff} = 198.60 \text{ kN}$ ($\geq 328.46 \text{ kN}$, not decisive)

resistances and effective lengths of end-plate in bending (per bolt-row):
$F_{ep,Rd,2} = 328.46 \text{ kN}$, $\ell_{eff,2} = 234.4 \text{ mm}$

2.3. connection capacity
2.3.1. moment resistance

distance of tension-bolt-rows from centre of compression: $h_1 = 433.2 \text{ mm}$, $h_2 = 343.2 \text{ mm}$
resistances acc. to EC 3-1-8, 6.2.7.2(6) for bolt-rows considered individually
row 1: $F_{t,Rd} = 235.3 \text{ kN}$
row 2: $F_{t,Rd} = 328.5 \text{ kN}$
resistance per bolt-row (tension)
row 1: $F_{t,Rd} = 235.3 \text{ kN}$
row 2: $F_{t,Rd} = 328.5 \text{ kN}$
$\Sigma F_{t,Rd} = 563.8 \text{ kN}$
resistance per bolt-row (bending)
row 1: $F_{t,Rd} = 235.3 \text{ kN}$
row 2: $F_{t,Rd} = 328.5 \text{ kN}$
$\Sigma F_{t,Rd} = 563.8 \text{ kN}$
potential failure by basic component 5
resistance of flanges (compression)
$\Sigma F_{c,Rd} = 0 \text{ kN}$

moment resistance regarding the centre of compression
$M_{b,Rd} = (F_{t,Rd} h_r) = 214.7 \text{ kN}\cdot\text{mm}$
tension resistance
$N_{b,Rd} = \Sigma F_{t,Rd} = 563.8 \text{ kN}$

2.4. verifications

internal lever arm for a bolted end-plate joint with projection and 2 tension-bolt-rows:
$z = h_b + h_{po} - 6e - 1b_{tu}/2 - p_t/2 = 388.2 \text{ mm}$

2.4.1. verification of the connection capacity by means of the connection method
axial force: $N_{b,Ed} = |N_{d} \cos(\alpha) + V_{d} \sin(\alpha)| = 30.10 \text{ kN} \leq 5\% N_{pl,Ed} = 99.30 \text{ kN} \Rightarrow$ moment resistance
regarding beam axis
with $N_{pl,Ed} = A_b f_{yd} / \gamma_M = 198.60 \text{ kN}$
internal moment: $M_{Ed} = M_a - N_d z_{bu} = 178.70 \text{ kN}\cdot\text{mm}$, $z_{bu} = 192.7 \text{ mm}$
bzgl. des centre of compressions
moment resistance
$M_{Ed} / M_{b,Rd} = 0.832 < 1 \text{ ok}$

2.4.2. verification of the connection capacity with partial internal forces and moments

tension force in the bolt-rows:
$N_{b,t} = (-N_d z_{bu} + M_a) / z = 460.27 \text{ kN}$, $z = z_{eq} = 388.2 \text{ mm}$, $z_{bu} = 192.7 \text{ mm}$
Gk 5: $F_{rd} = \Sigma F_{ep,Rd,1} = 553.0 \text{ kN}$, $F_{Ed} = N_{b,t} = 460.27 \text{ kN}$
$F_{Ed} = 460.3 \text{ kN} < F_{rd} = 553.0 \text{ kN} \Rightarrow U = 0.832 < 1 \text{ ok}$
utilization partial internal forces and moments $U_{gk} = 0.832 < 1 \text{ ok}$
2.4.3. verification result

maximum utilization: max U = 0.832 < 1 ok

3. final result

utilization of the connection

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<th>Lk</th>
<th>Uj</th>
<th>Gleichgewicht</th>
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<td>-</td>
<td>-</td>
<td>kN</td>
</tr>
<tr>
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<td>0.832*</td>
<td>30.11, 0.25, 184.50</td>
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*) maximum utilization

maximum utilization: max U = 0.832 < 1 ok

verification succeeded