Example: Portal frame - eaves moment connection

This example presents a method for calculating the moment resistance and the shear resistance of an eaves moment connection, as well as the design of welds. For the calculation of the moment resistance a simplified conservative method is used, which makes possible to avoid the calculation of bolt row groups. The connection is a Category A: Bearing type bolted connection using non-preloaded bolts.

Joint resistance of the eaves moment connection

<table>
<thead>
<tr>
<th>Resistance</th>
<th>Resistance of eaves moment connection</th>
</tr>
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<tbody>
<tr>
<td>Potential resistance of bolt rows in the tension zone</td>
<td>$F_{t,Rd}$</td>
</tr>
<tr>
<td>Compression resistance</td>
<td>$F_{c,Rd}$</td>
</tr>
<tr>
<td>Shear resistance of the column web panel</td>
<td>$V_{wp,Rd}$</td>
</tr>
<tr>
<td>Moment resistance</td>
<td>$M_{j,Rd}$</td>
</tr>
<tr>
<td>Shear resistance for vertical forces</td>
<td>$V_{Rd}$</td>
</tr>
</tbody>
</table>

1  Eaves Connection –Details and data
Main joint data

Configuration Rafter to column flange
Column IPE 500 S355
Beam IPE 450 S355
Type of connection End plate connection using non-preloaded bolts
End plate 990 × 200 × 20, S355
Bolts M24, grade 8.8

Column IPE 500, S355

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>$h_c = 500$ mm</td>
</tr>
<tr>
<td>Width</td>
<td>$b_c = 200$ mm</td>
</tr>
<tr>
<td>Thickness of the web</td>
<td>$t_{wc} = 10.2$ mm</td>
</tr>
<tr>
<td>Thickness of the flange</td>
<td>$t_{fc} = 16.0$ mm</td>
</tr>
<tr>
<td>Fillet radius</td>
<td>$r_c = 21$ mm</td>
</tr>
<tr>
<td>Area</td>
<td>$A_c = 116$ cm$^2$</td>
</tr>
<tr>
<td>Second moment of area</td>
<td>$I_{y,c} = 48200$ cm$^4$</td>
</tr>
<tr>
<td>Depth between fillets</td>
<td>$d_{c,c} = 426$ mm</td>
</tr>
<tr>
<td>Yield strength</td>
<td>$f_{y,c} = 355$ N/mm$^2$</td>
</tr>
<tr>
<td>Ultimate tensile strength</td>
<td>$f_{u,c} = 510$ N/mm$^2$</td>
</tr>
</tbody>
</table>
**Supported Beam IPE 450, S355**

- **Depth** \( h_b = 450 \text{ mm} \)
- **Width** \( b_b = 190 \text{ mm} \)
- **Thickness of the web** \( t_{wb} = 9.4 \text{ mm} \)
- **Thickness of the flange** \( t_{fb} = 14.6 \text{ mm} \)
- **Fillet radius** \( r_b = 21 \text{ mm} \)
- **Area** \( A_b = 98.8 \text{ cm}^2 \)
- **Second moment of area** \( I_{y,b} = 33740 \text{ cm}^4 \)
- **Depth between fillets** \( d_{c,b} = 378.8 \text{ mm} \)
- **Depth between flanges** \( h_{i,b} = 420.8 \text{ mm} \)
- **Yield strength** \( f_{y,b} = 355 \text{ N/mm}^2 \)
- **Ultimate tensile strength** \( f_{u,b} = 510 \text{ N/mm}^2 \)

**Haunch IPE 450, S355**

- **Depth** \( h_h = 450 \text{ mm} \)
- **Width** \( b_h = 190 \text{ mm} \)
- **Thickness of the web** \( t_{wh} = 9.4 \text{ mm} \)
- **Thickness of the flange** \( t_{fh} = 14.6 \text{ mm} \)
- **Fillet radius** \( r_h = 21 \text{ mm} \)
- **Yield strength** \( f_{y,h} = 355 \text{ N/mm}^2 \)
- **Ultimate tensile strength** \( f_{u,h} = 510 \text{ N/mm}^2 \)

**End plate 990 × 200 × 10, S355**

- **Depth** \( h_p = 990 \text{ mm} \)
- **Width** \( b_p = 200 \text{ mm} \)
- **Thickness** \( t_p = 20 \text{ mm} \)
- **Yield strength** \( f_{y,p} = 355 \text{ N/mm}^2 \)
- **Ultimate tensile strength** \( f_{u,p} = 510 \text{ N/mm}^2 \)
| Number of horizontal bolt rows in tension |  \( n_t = 5 \) |
| Number of bolt rows in shear |  \( n_s = 2 \) |
| Plate edge to first bolt row |  \( e_s = 50 \text{ mm} \) |
| Column flange edge to first bolt row |  \( e_1 = 50 \text{ mm} \) |
| Pitch between bolt rows in the tension zone |  \( p = 90 \text{ mm} \) |
| Pitch between last tension bolt and first shear bolt |  \( p_2 = 90 \text{ mm} \) |
| Pitch between bolt rows in the shear zone |  \( p_3 = 90 \text{ mm} \) |
| Tension flange of the rafter to end plate edge |  \( d_1 = 90 \text{ mm} \) |
| Pitch between bolt in the extended zone of the end plate and the first bolt row below the tension flange of the rafter |  \( d_2 = 100 \text{ mm} \) |
| Last shear bolt to bottom of compression flange of the haunch |  \( d_3 = 90 \text{ mm} \) |
| Distance between the bottom of the compression flange of the rafter and the edge of the end plate |  \( e_{pl} = 40 \text{ mm} \) |
| Plate edge to bolt line |  \( e_p = 50 \text{ mm} \) |
| Column edge to bolt line |  \( e_c = 50 \text{ mm} \) |
| Gauge (i.e. distance between cross centres) |  \( w = 100 \text{ mm} \) |

**Bolts M24, 8.8**

- Tensile stress area:  \( A_s = 353 \text{ mm}^2 \)
- Nominal bolt diameter:  \( d = 24 \text{ mm} \)
- Diameter of the holes:  \( d_0 = 26 \text{ mm} \)
- Yield strength:  \( f_{yb} = 640 \text{ N/mm}^2 \)
- Ultimate tensile strength:  \( f_{ub} = 800 \text{ N/mm}^2 \)

**Partial safety factors**

\( \gamma_{M0} = 1,0 \)
\( \gamma_{M,1} = 1,0 \)
\( \gamma_{M,2} = 1,25 \) (for shear resistance at ULS)

**Steel properties**

- Elastic modulus:  \( E = 210000 \text{ N/mm}^2 \)
### Design forces

\[ M_{Ed} = 880 \text{kNm} \]
\[ N_{Ed} = 175 \text{kN} \]
\[ V_{Ed} = 200 \text{kN} \]

### Additional geometric data

\[ m_{x,p} = (d_1 - e_x - 0.8\sqrt{2}a_{tf}) = (90 - 50 - 0.8\times\sqrt{2}\times8) \]
\[ m_{x,p} = 30.95 \text{mm} \]

\[ m_{p1} = \frac{(w - t_{wb} - 2 \times 0.8\sqrt{2}a_w)}{2} = \frac{(100 - 9.4 - 2 \times 0.8 \times \sqrt{2} \times 6)}{2} \]
\[ m_{p1} = 38.51 \text{mm} \]

\[ m_{p2} = d_2 - (d_1 - e_x) - \frac{t_{fb}}{\cos\left(\frac{\theta}{360}\right)} - 0.8\sqrt{2}a_{tf} \]
\[ m_{p2} = 100 - (90 - 50) - \frac{14.6}{\cos\left(\frac{5\times2\pi}{360}\right)} - 0.8\times\sqrt{2}\times8 \]
\[ m_{p2} = 36.29 \text{mm} \]

\[ m_{p3} = \frac{h_b}{\cos\left(\frac{\theta}{360}\right)} - 0.8\sqrt{2}a_w - [(e_x + d_2) - d_1] - 3p - \frac{t_{fb}}{\cos\left(\frac{\theta}{360}\right)} \]
\[ m_{p3} = \frac{450}{\cos\left(\frac{5\times2\pi}{360}\right)} - 0.8\times\sqrt{2}\times6 - [(50 + 100) - 90] - 3\times90 - \frac{14.6}{\cos\left(\frac{5\times2\pi}{360}\right)} \]
\[ m_{p3} = 100.27 \text{mm} \]

\[ m_{c1} = \frac{w - 0.8 \times 2r_c - t_{wc}}{2} = \frac{100 - 0.8 \times 2 \times 21 - 10.2}{2} \]
\[ m_{c1} = 28.1 \text{mm} \]
### End distances

\[ e_{\text{min}} = \min(e_{c1}, e_p) \]

\[ e_{\text{min}} = 50 \text{ mm} \]

\[ n_{p,c} = \min(e_{\text{min}}, 1,25m_{c1}) \]

\[ n_{p,c} = 35,13 \text{ mm} \]

\[ n_{p,\text{ep}} = \min(e_{\text{min}}, 1,25m_{p1}) \]

\[ n_{p,\text{ep}} = 48,14 \text{ mm} \]

### Area of the column

\[ \eta = 1,0 \]

\[ A_{v,c} = \max[A_c - 2b_c t_{fc} + t_{fc}(t_{wc} + 2r_c) - \eta h_{wc} t_{wc}] \]

\[ A_{v,c} = \max[11600 - 2 \times 200 \times 16 + 16 \times (10,2 + 2 \times 21) \times 1,0 \times 500 \times 10,2] \]

\[ A_{v,c} = 6035,2 \text{ mm}^2 \]

### Bolt resistance

\[ k_2 = 0,9 \]

\[ F_{t,Rd} = \frac{k_2 f_{\text{ub}} A_h}{\gamma_{M2}} = \frac{0,9 \times 800 \times 353}{1,25} = 203 \text{ kN (for one bolt)} \]

## 2 Welds

### 2.1 Tension flange to end-plate weld

According to the first option given in the NCCI on eaves moment connections, the following simple rule can be used to design a full strength weld:

\[ a_{\text{tf}} \geq 0,55 t_{\text{fb}} = 0,55 \times 14,6 = 8,03 \]

Therefore

\[ a_{\text{tf}} = 8 \text{ mm} \]
2.2 Web to end plate weld

Full strength weld can be designed according to the following expression:

\[ a_w \geq 0.55t_{wb} = 0.55 \cdot 9.4 = 5.17 \text{ mm} \]

Therefore,

\[ a_w = 6 \text{ mm} \]

2.3 Compression flange welds

Considering that a good contact can be provided, a nominal weld can be adopted. Haunch flange thickness is 14.6 mm, therefore adopt 6 mm throat thickness.

\[ a_{cf} = 6 \text{ mm} \]

3 Potential bolt row resistances in tension

3.1 Row 1

3.1.1 Column side

Effective length

The effective length of T-stub may be calculated from the minimum of the following expressions:

\[ 2\pi m_{c1} = 2\pi \times 28.1 = 176.56 \text{ mm} \]

\[ 4m_{c1} + 1.25e_x = 4 \times 28.1 + 1.25 \times 50 = 174.9 \text{ mm} \]

\[ \pi m_{c1} + 0.5p = \pi \times 28.1 + 0.5 \times 90 = 133.28 \text{ mm} \]

\[ 2m_{c1} + 0.625e_c + 0.5p = 2 \times 28.1 + 0.625 \times 50 + 0.5 \times 90 = 132.45 \text{ mm} \]

\[ e_x + \frac{d_2}{2} = 50 + \frac{100}{2} = 100 \text{ mm} \]

\[ l_{eff,1,c} = \min \left( \frac{2\pi m_{c1} ; 4m_{c1} + 1.25e_x ; \pi m_{c1} + 0.5p ; 2m_{c1} + 0.625e_c + 0.5p ; e_x + \frac{d_2}{2}}{176.56; 174.9; 133.28; 132.45; 100} \right) \]

\[ l_{eff,1,c} = 100 \text{ mm} \]
Column flange in bending

**Mode 1: Method 1**

\[
M_{pl,1,Rd,r1,c} = \frac{0,25 l_{eff,1,c} t_{fc}^2 f_{y,c}}{\gamma_{M0}} = \frac{0,25 \times 100 \times 16^2 \times 355}{1,0} = 2,272 \times 10^6 \text{ Nmm}
\]

\[
F_{T,1,Rd,fc} = \frac{4 M_{pl,1,Rd,r1,c}}{m_{c1}} = \frac{4 \times 2,272 \times 10^6}{28,1} = \frac{393,42 \text{ kN}}{2}
\]

\[
\therefore F_{T,1,Rd,fc} = 393,42 \text{ kN}
\]

**Mode 2**

\[
M_{pl,2,Rd,r1,c} = \frac{0,25 l_{eff,1,c} t_{fc}^2 f_{y,c}}{\gamma_{M0}} = \frac{0,25 \times 100 \times 16^2 \times 355}{1,0} = 2,272 \times 10^6 \text{ Nmm}
\]

\[
F_{T,2,Rd,fc} = \frac{2 M_{pl,2,Rd,r1,c} + n_{p,c} \sum F_{t,Rd}}{m_{c1} + n_{p,c}} = \frac{2 \times 2,272 \times 10^6 + 35,13 \times 406,66 \times 10^3}{28,1 + 35,13} = 297,8 \text{ kN}
\]

\[
\therefore F_{T,2,Rd,fc} = 297,8 \text{ kN}
\]

**Mode 3**

\[
F_{T,3,Rd,fc} = \sum F_{t,Rd}
\]

\[
F_{T,3,Rd,fc} = 2 \times 203 = 406 \text{ kN}
\]

Therefore the resistance of the column flange in bending is

\[
F_{T,Rd,fc} = \min \left( F_{T,1,Rd,fc}; F_{T,2,Rd,fc}; F_{T,3,Rd,fc} \right) = \min \left( 323; 298; 406 \right) = 298 \text{ kN}
\]
Column web in transverse tension

\[ F_{t,wc,Rd} = \frac{\omega_{r1,c} \cdot b_{eff,t,wc} \cdot f_y \cdot c_r}{\gamma_M} \]

According to the geometry of the connection

\[ \beta = 1 \]

And therefore,

\[ \omega_{r1,c} = \alpha_{h,1,c} \]

\[ b_{eff,t,wc} = l_{eff,1,c} \]

\[ \alpha_{h,1,c} = \frac{1}{\sqrt{1+1,3 \left( \frac{b_{eff,t,wc} \cdot f_y}{A_{vc}} \right)^2}} = \frac{1}{\sqrt{1+1,3 \left( \frac{100 \times 10,2}{6035,2} \right)^2}} \]

\[ \omega_{r1,c} = 0,98 \]

\[ \omega_{r1,c} = 0,98 \]

\[ F_{t,wc,Rd} = \frac{0,98 \times 100 \times 10,2 \times 355}{1,0} \]

\[ F_{t,wc,Rd} = 355 \text{ kN} \]

### 3.1.2 Beam side

**Effective length**

The effective length may be calculated from the minimum of the following expressions:
## CALCULATION SHEET

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<th>SX031a-EN-EU</th>
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<tr>
<td>Title</td>
<td>Example: Portal frame - eaves moment connection</td>
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<tr>
<td>Eurocode Ref.</td>
<td>EN 1993-1-8</td>
</tr>
<tr>
<td>Made by</td>
<td>Edurne Núñez</td>
</tr>
<tr>
<td>Date</td>
<td>Nov 2005</td>
</tr>
<tr>
<td>Checked by</td>
<td>Abdul Malik</td>
</tr>
<tr>
<td>Date</td>
<td>Feb 2006</td>
</tr>
</tbody>
</table>

The calculations are as follows:

\[
2\pi m_{x,p} = 2\pi \times 30,95 = 194,46 \text{ mm} \quad \text{SN041}
\]

\[
\pi m_{x,p} + w = \pi \times 30,95 + 100 = 197,23 \text{ mm} \quad \text{SN041}
\]

\[
\pi m_{x,p} + 2e_p = \pi \times 30,95 + 2 \times 50 = 197,23 \text{ mm} \quad \text{SN041}
\]

\[
4m_{x,p} + 1,25e_x = 4 \times 30,95 + 1,25 \times 50 = 186,3 \text{ mm} \quad \text{SN041}
\]

\[
e_p + 2m_{x,p} + 0,625e_x = 50 + 2 \times 30,95 + 0,625 \times 50 = 143,15 \text{ mm} \quad \text{SN041}
\]

\[
0,5b_p = 0,5 \times 200 = 100 \text{ mm} \quad \text{SN041}
\]

\[
0,5w + 2m_{x,p} + 0,625e_x = 0,5 \times 100 + 2 \times 30,95 + 0,625 \times 50 = 143,15 \text{ mm} \quad \text{SN041}
\]

\[
l_{\text{eff},1,b} = \min \left( \frac{2\pi m_{x,p}}{e_p + 2m_{x,p} + 0,625e_x} ; \frac{\pi m_{x,p} + w}{0,5b_p} ; \frac{\pi m_{x,p} + 2e_p}{0,5w + 2m_{x,p} + 0,625e_x} ; \frac{4m_{x,p} + 1,25e_x}{0,5b_p} \right) = \min(194,46; 197,23; 197,23; 186,3; 143,15; 100; 143,15) \quad \text{SN041}
\]

\[
l_{\text{eff},1,b} = 100 \text{ mm} \quad \text{SN041}
\]

### End plate in bending

**Mode 1: Method 1**

\[
M_{pl,1,Rd,r1,b_1} = 0,25l_{\text{eff},1,b}\frac{t_p^2 f_{y,p}}{\gamma_{M0}} = 0,25 \times 100 \times 20^2 \times 355 \quad \text{SN041}
\]

\[
M_{pl,1,Rd,r1,b_1} = 3,55 \times 10^6 \text{ Nmm} \quad \text{SN041}
\]

\[
F_{T,1,Rd,\text{ep}} = 4 \frac{4M_{pl,1,Rd,r1,b}}{m_{p1}} = 4 \times \frac{3,55 \times 10^6}{38,51} \quad \text{SN041}
\]

\[
F_{T,1,Rd,\text{ep}} = 368,7 \text{ kN} \quad \text{SN041}
\]

**Mode 2**

\[
M_{pl,2,Rd,r1,b} = 0,25l_{\text{eff},1,b}\frac{t_p^2 f_{y,p}}{\gamma_{M0}} = 0,25 \times 100 \times 20^2 \times 355 \quad \text{SN041}
\]

\[
M_{pl,2,Rd,r1,b} = 3,55 \times 10^6 \text{ Nmm} \quad \text{SN041}
\]
### Example: Portal frame - eaves moment connection

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\[
F_{T,2,Rd,\text{ep}} = \frac{2M_{p1,2,Rd,r1,b} + n_{p,\text{cp}}}{m_{p1} + n_{p,\text{cp}}} \sum F_{t,Rd}
\]

\[
= \frac{2 \times 3,55 \times 10^6 + 48,14 \times 406,66 \times 10^3}{38,51 + 48,14}
\]

\[
F_{T,2,Rd,\text{ep}} = 307,86 \text{ kN}
\]

**Mode 3**

\[
F_{T,3,Rd,\text{ep}} = \sum F_{t,Rd}
\]

\[
F_{T,3,Rd,\text{ep}} = 2 \times 203 = 406 \text{ kN}
\]

Therefore the resistance of the end plate in bending is:

\[
F_{T,1,Rd,\text{ep}} = \min\left(F_{T,1,Rd,\text{ep}}; F_{T,2,Rd,\text{ep}}; F_{T,3,Rd,\text{ep}}\right) = \min\left(369; 308; 406\right)
\]

\[
F_{T,1,Rd,\text{ep}} = 308 \text{ kN}
\]

\[
\therefore F_{t,Rd(\text{row1})} = \min(298; 355; 308) = 298 \text{ kN}
\]

### 3.2 Row 2

#### 3.2.1 Column side

**Effective length**

The effective length may be calculated from the minimum of the following expressions:
2\pi m_{c1} = 2\pi \times 28,1 = 176,56 \text{ mm}

4m_{c1} + 1,25e_c = 4 \times 28,1 + 1,25 \times 50 = 174,9 \text{ mm}

\pi m_{c1} + \frac{p}{2} = \pi \times 28,1 + \frac{90}{2} = 133,28 \text{ mm}

2m_{c1} + 0,625e_c + \frac{p}{2} = 2 \times 28,1 + 0,625 \times 50 + \frac{90}{2} = 132,45 \text{ mm}

\pi m_{c1} + \frac{d_2}{2} = \pi \times 28,1 + \frac{100}{2} = 138,28 \text{ mm}

2m_{c1} + 0,625e_c + \frac{d_2}{2} = 137,45 \text{ mm}

\frac{d_2}{2} + \frac{p}{2} = \frac{100}{2} + \frac{90}{2} = 95 \text{ mm}

l_{eff,2,c} = \min \left( \begin{array}{l} 2\pi m_{c1}; \ 4m_{c1} + 1,25e_c; \ \pi m_{c1} + \frac{p}{2}; \ 2m_{c1} + 0,625e_c + \frac{p}{2}; \\ \pi m_{c1} + \frac{d_2}{2}; \ 2m_{c1} + 0,625e_c + \frac{d_2}{2}; \ \frac{d_2}{2} + \frac{p}{2} \end{array} \right)

= \min (176,56; \ 174,9; \ 133,28; \ 132,45; \ 138,28; \ 137,45; \ 95)

l_{eff,2,c} = 95 \text{ mm}

**Column flange in bending**

**Mode 1; Method 1**

\[ M_{pl,1,Rd,r2,c} = \frac{0,25l_{eff,2,c}t_{fc}^2 f_{y,c}}{\gamma_{M0}} = \frac{0,25 \times 95 \times 16^2 \times 355}{1,0} \]

\[ M_{pl,1,Rd,r2,c} = 2,16 \times 10^6 \text{ Nmm} \]

\[ F_{T,1,Rd,fc} = \frac{4M_{pl,1,Rd,r2,c}}{m_{c1}} = \frac{4 \times 2,16 \times 10^6}{28,1} \]

\[ F_{T,1,Rd,fc} = 307,5 \text{ kN} \]
### Mode 2

\[
M_{pl,2,Rd,2,c} = 0,25 l_{eff,2,c} t_{c} f_{y,c}^2 \gamma_{M0} = \frac{0,25 \times 95 \times 16^2 \times 355}{1,0}
\]

\[
M_{pl,2,Rd,2,c} = 2,16 \times 10^6 \text{ Nmm}
\]

\[
F_{T,2,Rd,fc} = \frac{2 M_{pl,2,Rd,2,c} + n_{p,c} \sum F_{t,Rd}}{m_{c1} + n_{p,c}}
\]

\[
= \frac{2 \times 2,16 \times 10^6 + 35,13 \times 406,66 \times 10^3}{28,1 + 35,13}
\]

\[
F_{T,2,Rd,fc} = 294,3 \text{ kN}
\]

### Mode 3

\[
F_{T,3,Rd,fc} = \sum F_{t,Rd}
\]

\[
F_{T,3,Rd,fc} = 2 \times 203 = 406 \text{ kN}
\]

Therefore resistance of the column flange in bending is:

\[
F_{T,Rd,fc} = \min(F_{T,1,Rd,fc}; F_{T,2,Rd,fc}; F_{T,3,Rd,fc})
\]

\[
= \min(308; 294; 406)
\]

\[
F_{T,Rd,fc} = 294 \text{ kN}
\]

### Column web in transverse tension

\[
F_{t,wc,Rd} = \frac{\omega_{1r,2,c} b_{eff,t,wc} t_{wc} f_{y,c}}{\gamma_{M0}}
\]

\[
b_{eff,t,wc} = l_{eff,2,c}
\]

\[
\omega_{1r,2,c} = \omega_{1r,2,c} = \frac{1}{\sqrt{1 + 1,3 \left(\frac{b_{eff,t,wc} t_{wc}}{A_{vc}}\right)^2}} = \frac{1}{\sqrt{1 + 1,3 \left(\frac{95 \times 10,2}{6035,2}\right)^2}}
\]

\[
\omega_{1r,2,c} = 0,98
\]
3.2.2 Beam side

Effective length

The effective length may be calculated from the minimum of the following expressions:

\[ 2\pi m_{p1} = 2\pi \times 38.51 = 241.98 \text{ mm} \]

\[ \lambda_{r2,b} m_{p1} \]

\[ \alpha_{r2} \] depends on \( \lambda_{1,r2,b} \) and \( \lambda_{2,r2,b} \), defined as follows:

\[ \lambda_{1,r2,b} = \frac{m_{p1}}{m_{p1} + e_p} \]
\[ \lambda_{1,r2,b} = 0.44 \]

\[ \lambda_{2,r2,b} = \frac{m_{p2}}{m_{p1} + e_p} \]
\[ \lambda_{2,r2,b} = 0.41 \]

Therefore:

\[ \alpha_{r2,b} = 6.3 \]

\[ \alpha_{r2,b} m_{p1} = 6.3 \times 38.51 = 242.61 \text{ mm} \]

\[ l_{\text{eff},2,b} = \min(2\pi m_{p1}; \alpha_{r2,b} m_{p1}) = \min(241.98; 242.61) \]
\[ l_{\text{eff},2,b} = 241.98 \text{ mm} \]
End plate in bending

Mode 1: Method 1

\[ M_{pl,1,Rd,r2,b} = \frac{0.25 l^{0.5} t_{p} l_{y}^{2} f_{y,p}}{\gamma_{M0}} = \frac{0.25 \times 241.98 \times 20^2 \times 355}{1.0} \]
\[ M_{pl,1,Rd,r2,b} = 8.6 \times 10^6 \text{ Nmm} \]

\[ F_{T,1,Rd,ep} = \frac{4M_{pl,1,Rd,r2,b}}{m_{p1}} = \frac{4 \times 8.6 \times 10^6}{38.51} \]
\[ F_{T,1,Rd,ep} = 893.3 \text{ kN} \]

Mode 2

\[ M_{pl,2,Rd,r2,b} = \frac{0.25 l^{0.5} t_{p} l_{y}^{2} f_{y,p}}{\gamma_{M0}} = \frac{0.25 \times 241.98 \times 20^2 \times 355}{1.0} \]
\[ M_{pl,2,Rd,r2,b} = 8.6 \times 10^6 \text{ Nmm} \]

\[ F_{T,2,Rd,ep} = \frac{2M_{pl,2,Rd,r2,b} + n_{p, ep} \sum F_{t,Rd}}{m_{p1} + n_{p, ep}} = \frac{2 \times 8.6 \times 10^6 + 48.14 \times 406.66 \times 10^3}{38.51 + 48.14} \]
\[ F_{T,2,Rd,ep} = 424.4 \text{ kN} \]

Mode 3

\[ F_{T,3,Rd,ep} = \sum F_{t,Rd} \]
\[ F_{T,3,Rd,ep} = 2 \times 203 = 406 \text{ kN} \]

Therefore the resistance of the end plate in bending is:

\[ F_{T,Rd,ep} = \min(F_{T,1,Rd,ep}; F_{T,2,Rd,ep}; F_{T,3,Rd,ep}) = \min(893; 424; 406) \]
\[ F_{T,Rd,ep} = 406 \text{ kN} \]
Rafter web in tension

\[ F_{t,wb,Rd} = \frac{b_{\text{eff},t,wb} l_{wb} f_{y,beam}}{\gamma_{M0}} = \frac{241.98 \times 9.4 \times 355}{10} \]

\[ b_{\text{eff},t,wb} = l_{\text{eff},2,b} \]

\[ F_{t,wb,Rd} = 807 \text{ kN} \]

\[ : \quad F_{t,Rd(row2)} = \min(294; \ 337; \ 406; \ 807) = 294 \text{ kN} \]

### 3.3 Row 3
#### 3.3.1 Column side

**Effective length**

The effective length may be calculated from the minimum of the following expressions:

\[ 2\pi m_{c1} = 2\pi \times 28.1 = 176.56 \text{ mm} \]

\[ 4m_{c1} + 1.25e_c = 4 \times 28.1 + 1.25 \times 50 = 174.9 \text{ mm} \]

\[ \pi m_{c1} + \frac{p}{2} = \pi \times 28.1 + \frac{90}{2} = 133.28 \text{ mm} \]

\[ 2m_{c1} + 0.625e_c + \frac{p}{2} = 2 \times 28.1 + 0.625 \times 50 + \frac{90}{2} = 132.45 \text{ mm} \]

\[ p = 90 \text{ mm} \]

\[ l_{\text{eff},3,c} = \min \left( 2\pi m_{c1}; \ 4m_{c1} + 1.25e_c; \ \pi m_{c1} + \frac{p}{2}; \ 2m_{c1} + 0.625e_c + \frac{p}{2}; \ p \right) \]

\[ = \min(176.56; \ 174.9; \ 133.28; \ 132.45; \ 90) \]

\[ l_{\text{eff},3,c} = 90 \text{ mm} \]
Column flange in bending

**Mode 1: Method 1**

\[
M_{pl,1,Rd,r3,c} = \frac{0.25 l_{eff,3,c} t_{fc}^2 f_{y,c}}{\gamma_{M0}} = \frac{0.25 \times 90 \times 16^2 \times 355}{1.0} \]

\[M_{pl,1,Rd,r3,c} = 2.05 \times 10^6 \text{ Nmm}\]

\[
F_{T,1,Rd,fc} = \frac{4 \times M_{pl,1,Rd,r3,c}}{m_{c1}} = \frac{4 \times 2.05 \times 10^6}{28.1} \]

\[F_{T,1,Rd,fc} = 291.8 \text{ kN}\]

**Mode 2**

\[
M_{pl,2,Rd,r3,c} = \frac{0.25 l_{eff,3,c} t_{fc}^2 f_{y,c}}{\gamma_{M0}} = \frac{0.25 \times 90 \times 16^2 \times 355}{1.1} \]

\[M_{pl,2,Rd,r3,c} = 2.05 \times 10^6 \text{ Nmm}\]

\[
F_{T,2,Rd,fc} = \frac{2 M_{pl,2,Rd,r3,c} + n_{p,c} \sum F_{t,Rd}}{m_{c1} + n_{p,c}} = \frac{2 \times 2.05 \times 10^6 + 35.13 \times 406.66 \times 10^3}{28.1 + 35.13} \]

\[F_{T,2,Rd,fc} = 290.8 \text{ kN}\]

**Mode 3**

\[F_{T,3,Rd,fc} = \sum F_{t,Rd}\]

\[F_{T,3,Rd,fc} = 2 \times 203 = 406 \text{ kN}\]

Therefore the resistance of the column flange in bending is:

\[F_{T,Rd,fc} = \min(F_{T,1,Rd,fc}; F_{T,2,Rd,fc}; F_{T,3,Rd,fc}) = \min(292; 291; 406)\]

\[F_{T,Rd,fc} = 291 \text{ kN}\]
Column web in transverse tension

\[
F_{t,\text{wc},\text{Rd}} = \frac{\omega_{r3,c} b_{\text{eff},t,\text{wc}} t_{\text{wc}} f_{y,c}}{\gamma_{M0}}
\]

\[
b_{\text{eff},t,\text{wc}} = l_{\text{eff},3,c}
\]

\[
\omega_{r3,c} = \omega_{1,r3,c} = \frac{1}{\sqrt{1 + 1,3 \left( \frac{b_{\text{eff},t,\text{wc}} t_{\text{wc}}}{A_{\text{vc}}} \right)^2}} = \frac{1}{\sqrt{1 + 1,3 \left( \frac{90 \times 10,2}{6035,2} \right)^2}}
\]

\[
\omega_{r3,c} = 0,99
\]

\[
F_{t,\text{wc},\text{Rd}} = \frac{0,99 \times 90 \times 10,2 \times 355}{1,0}
\]

\[
F_{t,\text{wc},\text{Rd}} = 323 \text{ kN}
\]

### 3.3.2 Beam side

**Effective length**

The effective length may be calculated from the minimum of the following expressions:

\[
2\pi m_{p1} = 2\pi \times 38,51 = 241,98 \text{ kN}
\]

\[
4m_{p1} + 1,25e_{p} = 4 \times 38,51 + 1,25 \times 50 = 216,55 \text{ kN}
\]

\[
l_{\text{eff},3,b} = \min(2\pi m_{p1}; \ 4m_{p1} + 1,25e_{p}) = \min(241,98; \ 216,55)
\]

\[
l_{\text{eff},3,b} = 216,55 \text{ mm}
\]

**End plate in bending**

**Mode 1: Method 1**

\[
M_{p1,1,\text{Rd},r3,b} = \frac{0,25l_{\text{eff},3,b} t_{\text{p}}^2 f_{y,p}}{\gamma_{M0}} = \frac{0,25 \times 216,55 \times 20^2 \times 355}{1,0}
\]

\[
M_{p1,1,\text{Rd},r3,b} = 7,68 \times 10^6 \text{ Nmm}
\]
**CALCULATION SHEET**

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\[ F_{T,1,Rd,ep} = \frac{4M_{pl,1,Rd,r3,b}}{m_{p1}} = \frac{4 \times 7,68 \times 10^6}{38,51} \]

\[ F_{T,1,Rd,ep} = 797.7 \text{ kN} \]

**Mode 2**

\[ M_{pl,2,Rd,r3,b} = \frac{0,25l_{eff,3,b}t_{p}^2f_{y,p}}{\gamma_{M0}} = \frac{0,25 \times 216,55 \times 20^2 \times 355}{1,0} \]

\[ M_{pl,2,Rd,r3,b} = 7,68 \times 10^6 \text{ Nmm} \]

\[ F_{T,2,Rd,ep} = \frac{2M_{pl,2,Rd,r3,b} + n_{p,\text{ep}} \sum F_{t,Rd}}{m_{p1} + n_{p,\text{ep}}} = \frac{2 \times 7,68 \times 10^6 + 48,14 \times 406,66 \times 10^3}{38,51 + 48,14} \]

\[ F_{T,2,Rd,ep} = 403,2 \text{ kN} \]

**Mode 3**

\[ F_{T,3,Rd,ep} = \sum F_{t,Rd} \]

\[ F_{T,3,Rd,ep} = 2 \times 203 = 406 \text{ kN} \]

The resistance of the end plate in bending is:

\[ F_{T,Rd,ep} = \min(F_{T,1,Rd,ep}; F_{T,2,Rd,ep}; F_{T,3,Rd,ep}) \]

\[ F_{T,Rd,ep} = \min(798; 403; 406) \]

\[ F_{T,Rd,ep} = 403 \text{ kN} \]

**Rafter web in tension**

\[ F_{t,wb,Rd} = \frac{h_{eff,t,wb}l_{bw}f_{y,beam}}{\gamma_{M0}} = \frac{216,55 \times 9,4 \times 355}{1,0} \]

\[ h_{eff,t,wb} = l_{eff,3,b} \]

\[ F_{t,wb,Rd} = 723 \text{ kN} \]

\[ \therefore F_{t,Rd(row3)} = \min(291; 323; 403; 723) = 291 \text{ kN} \]
3.4 Row 4

3.4.1 Column side

**Effective length**

The effective length may be calculated from the minimum of the following expressions:

\[
2\pi m_{c1} = 2\pi \times 28,1 = 176,56 \text{ mm}
\]

\[
4m_{c1} + 1,25 e_c = 4 \times 28,1 + 1,25 \times 50 = 174,9 \text{ mm}
\]

\[
\pi m_{c1} + \frac{p}{2} = \pi \times 28,1 + \frac{90}{2} = 133,28 \text{ mm}
\]

\[
2m_{c1} + 0,625e_c + \frac{p}{2} = 2 \times 28,1 + 0,625 \times 50 + \frac{90}{2} = 132,45 \text{ mm}
\]

\[
p = 90 \text{ mm}
\]

\[
l_{\text{eff,4,c}} = \min \left(2\pi m_{c1}; 4m_{c1} + 1,25 e_c; \pi m_{c1} + \frac{p}{2}; 2m_{c1} + 0,625e_c + \frac{p}{2}; p\right)
\]

\[
l_{\text{eff,4,c}} = \min(176,56; 174,9; 133,28; 132,45; 90)
\]

\[
l_{\text{eff,4,c}} = 90 \text{ mm}
\]

**Column flange in bending**

**Mode 1; Method 1**

\[
M_{\text{pl,l,Rd,r4,c}} = \frac{0,25l_{\text{eff,4,c}} f_c^2 f_{y,c}}{\gamma_{M0}} = \frac{0,25 \times 90 \times 16^2 \times 355}{1,0}
\]

\[
M_{\text{pl,l,Rd,r4,c}} = 2,05 \times 10^6 \text{ Nmm}
\]

\[
F_{T,1,Rd,fc} = \frac{4 \cdot M_{\text{pl,l,Rd,r4,c}}}{m_{c1}} = \frac{4 \times 2,05 \times 10^6}{28,1}
\]

\[
F_{T,1,Rd,fc} = 291,8 \text{ kN}
\]
### Mode 2

\[ M_{pl,2,Rd,r4,c} = \frac{0.25f_{ec}^2}{\gamma_M 0} \times l_{eff,4,c} t_{fc} = 0.25 \times 90 \times 16^2 \times 355 \times 1.0 \]

\[ M_{pl,2,Rd,r4,c} = 2.05 \times 10^6 \text{ Nmm} \]

\[ F_{T,2,Rd,fc} = \frac{2M_{pl,2,Rd,r4,c} + n_{p,c} \sum F_{t,Rd}}{m_{c1} + n_{p,c}} = \frac{2 \times 2.05 \times 10^6 + 35.13 \times 406.66 \times 10^3}{28.1 + 35.13} \]

\[ F_{T,2,Rd,fc} = 290.8 \text{ kN} \]

### Mode 3

\[ F_{T,3,Rd,fc} = \sum F_{t,Rd} \]

\[ F_{T,3,Rd,fc} = 2 \times 203 = 406 \text{ kN} \]

Therefore the resistance of the column flange in bending is:

\[ F_{T,Rd,fc} = \min(F_{T,1,Rd,fc}; F_{T,2,Rd,fc}; F_{T,3,Rd,fc}) \]

\[ F_{T,Rd,fc} = \min(292; 291; 406) \]

\[ F_{T,Rd,fc} = 291 \text{ kN} \]

### Column web in transverse tension

\[ F_{t,wc,Rd} = \frac{\omega_{t,eff,wc} b_{t,eff,wc} t_{wc} f_{yc}}{\gamma_M 0} \]

\[ b_{eff,wc} = l_{eff,4,c} \]

\[ \omega_{t,eff,wc} = \frac{1}{\sqrt{1 + 1.3 \left( \frac{b_{eff,wc} t_{wc}}{A_{wc}} \right)^2}} = \frac{1}{\sqrt{1 + 1.3 \left( \frac{90 \times 10.2}{6035.2} \right)^2}} \]

\[ \omega_{t,eff,wc} = 0.99 \]

\[ F_{t,wc,Rd} = \frac{0.99 \times 90 \times 10.2 \times 355}{1.0} \]

\[ F_{t,wc,Rd} = 323 \text{ kN} \]
3.4.2 Beam side

**Effective length**

The effective length may be calculated from the minimum of the following expressions:

\[
\begin{align*}
2\pi m_1 &= 2\pi \times 38.51 = 241.98 \text{ kN} \\
4m_1 + 1,25e_p &= 4 \times 38.51 + 1,25 \times 50 = 216.55 \text{ kN} \\
I_{eff,4,b} &= \min(2\pi m_1; 4m_1 + 1,25e_p) = \min(241.98; 216.55) \\
\text{result: } I_{eff,4,b} &= 216.55 \text{ mm}
\end{align*}
\]

**End plate in bending**

**Mode 1; Method 1**

\[
\begin{align*}
M_{pl,1,Rd,r4,b} &= \frac{0.25l_{eff,4,b}t_p^2f_{y,p}}{\gamma_{M0}} = \frac{0.25 \times 216.55 \times 20^2 \times 355}{1,0} \\
M_{pl,1,Rd,r4,b} &= 7,68 \times 10^6 \text{ Nmm} \\
F_{T,1,Rd,\text{ep}} &= \frac{4M_{pl,1,Rd,r4,b}}{m_p} = \frac{4 \times 7,68 \times 10^6}{38,51} \\
F_{T,1,Rd,\text{ep}} &= 797.7 \text{ kN}
\end{align*}
\]

**Mode 2**

\[
\begin{align*}
M_{pl,2,Rd,r4,b} &= \frac{0.25l_{eff,4,b}t_p^2f_{y,p}}{\gamma_{M0}} = \frac{0.25 \times 216.55 \times 20^2 \times 355}{1,0} \\
M_{pl,2,Rd,r4,b} &= 14,48 \times 10^6 \text{ Nmm} \\
F_{T,2,Rd,\text{ep}} &= \frac{2M_{pl,2,Rd,r4,b} + n_{p,\text{ep}} \sum F_{t,Rd}}{m_p + n_{p,\text{ep}}} \\
&= \frac{2 \times 7,68 \times 10^6 + 48,14 \times 406,66 \times 10^3}{38,51 + 48,14} \\
F_{T,2,Rd,\text{ep}} &= 403.2 \text{ kN}
\end{align*}
\]
**Mode 3**

\[ F_{T,3,Rd,ep} = \sum F_{t,Rd} \]

\[ F_{T,3,Rd,ep} = 2 \times 203 = 406 \text{ kN} \]

The resistance of the end plate in bending is:

\[ F_{T,Rd,ep} = \min\left( F_{T,1,Rd,ep}; \ F_{T,2,Rd,ep}; \ F_{T,3,Rd,ep} \right) \]

\[ = \min\left( 798; \ 403; \ 406 \right) \]

\[ F_{T,Rd,ep} = 403 \text{ kN} \]

**Rafter web in tension**

\[ F_{t,wb,Rd} = \frac{b_{\text{eff,t,wb}} t_{\text{wb}} f_{y,\text{beam}}}{\gamma_{M0}} = \frac{216,55 \times 9,4 \times 355}{1,0} \]

\[ b_{\text{eff,t,wb}} = l_{\text{eff,4,b}} \]

\[ F_{t,wb,Rd} = 723 \text{ kN} \]

\[ \therefore F_{T,Rd(row4)} = \min\left( 291; \ 323; \ 403; \ 723 \right) = 291 \text{ kN} \]

### 3.5 Row 5

#### 3.5.1 Column side

\[ 2\pi m_{c1} = 2\pi \times 28,1 = 176,56 \text{ mm} \]

\[ 4m_{c1} + 1,25e_{c} = 4 \times 28,10 + 1,25 \times 50 = 174,9 \text{ mm} \]

\[ \pi m_{c1} + \frac{P}{2} = \pi \times 28,1 + \frac{90}{2} = 133,28 \text{ mm} \]

\[ 2m_{c1} + 0,625e_{c} + \frac{P}{2} = 2 \times 28,1 + 0,625 \times 50 + \frac{90}{2} = 132,45 \text{ mm} \]

\[ \frac{P_2}{2} + \frac{P}{2} = \frac{350}{2} + \frac{90}{2} = 220 \text{ mm} \]

\[ l_{\text{eff,5,c}} = \min\left( 2\pi m_{c1}; \ 4m_{c1} + 1,25e_{c}; \ \pi m_{c1} + \frac{P}{2}; \ 2m_{c1} + 0,625e_{c} + \frac{P}{2}; \ \frac{P_2}{2} + \frac{P}{2} \right) \]

\[ = \min\left( 176,56; \ 174,9; \ 133,28; \ 132,45; \ 220 \right) \]

\[ l_{\text{eff,5,c}} = 132,45 \text{ mm} \]
### Column flange in bending

**Mode 1: Method 1**

\[
M_{pl,1,Rd,r5,c} = \frac{0.25l_{eff,5,c} t_{c} f_{c}^2}{\gamma_{M0}} = \frac{0.25 \times 132.45 \times 16^2 \times 355}{1.0} \]

\[
M_{pl,1,Rd,r5,c} = 3 \times 10^6 \text{ kN} \]

\[
F_{T,1,Rd,fc} = \frac{4M_{pl,1,Rd,r5,c}}{m_{c1}} = \frac{4 \times 3 \times 10^6}{28.1} \]

\[
F_{T,1,Rd,fc} = 427 \text{ kN} \]

**Mode 2**

\[
M_{pl,2,Rd,r5,c} = \frac{0.25l_{eff,5,c} t_{c} f_{c}^2}{\gamma_{M0}} = \frac{0.25 \times 132.45 \times 16^2 \times 355}{1.0} \]

\[
M_{pl,2,Rd,r5,c} = 3 \times 10^6 \text{ Nmm} \]

\[
F_{T,2,Rd,fc} = \frac{2M_{pl,2,Rd,r5,b} + n_{p,c} \sum F_{t,Rd}}{m_{c1} + n_{p,c}} \]

\[
= \frac{2 \times 3 \times 10^6 + 35.13 \times 406.66 \times 10^3}{28.1 + 35.13} \]

\[
F_{T,2,Rd,fc} = 320.8 \text{ kN} \]

**Mode 3**

\[
F_{T,3,Rd,fc} = \sum F_{t,Rd} \]

\[
F_{T,3,Rd,fc} = 2 \times 203 = 406 \text{ kN} \]

Therefore the resistance of the column flange in bending is:

\[
F_{T,Rd,fc} = \min\left(F_{T,1,Rd,fc}; F_{T,2,Rd,fc}; F_{T,3,Rd,fc}\right) \]

\[
= \min(427; 321; 406) \]

\[
F_{T,Rd,fc} = 321 \text{ kN} \]
In the last bolt row a greater resistance than in any of the previous rows is not allowed, so $F_{t,Rd,fc}$ is limited to the resistance in bolt row 4. Therefore:

$$F_{t,Rd,fc} = 291 \text{kN}$$

**Column web in transverse tension**

$$F_{T,wc,Rd} = \frac{\omega_{5,c} \beta_{eff,t,wc} t_{wc} f_{y,c}}{\gamma_{M0}}$$

$$\beta_{eff,t,wc} = l_{eff,5,c}$$

According to the geometry of the connection

$$\beta = 1$$

And therefore,

$$\omega_{5,c} = \omega_{t,5,c} = \frac{1}{\sqrt{1 + 1,3 \left( \frac{\beta_{eff,t,wc} t_{wc}}{A_{vc}} \right)^2}}$$

$$= \frac{1}{\sqrt{1 + 1,3 \left( \frac{132,45 \times 10,2}{6035,2} \right)^2}}$$

$$\omega_{5,c} = 0,97$$

$$F_{T,wc,Rd} = \frac{0,97 \times 132,45 \times 10,2 \times 355}{1,0}$$

$$F_{T,wc,Rd} = 465 \text{kN}$$

**3.5.2 Beam side**

Effective length

The effective length may be calculated from the minimum of the following expressions:
### Calculation Sheet

**Title**: Example: Portal frame - eaves moment connection  
**Eurocode Ref**: EN 1993-1-8  
**Made by**: Edurne Núñez  
**Date**: Nov 2005  
**Checked by**: Abdul Malik  
**Date**: Feb 2006

\[
2\pi m_{p1} = 2\pi \times 38.51 = 241.98 \text{ mm}
\]

\[
4m_{p1} + 1.25e_p = 4 \times 38.51 + 1.25 \times 50 = 216.55 \text{ mm}
\]

\[
l_{\text{eff,5,b}} = \min (2\pi m_{p1}; \ 4m_{p1} + 1.25e_p) = \min (241.98; \ 216.55)
\]

\[
l_{\text{eff,5,b}} = 216.55 \text{ mm}
\]

#### Mode 1: Method 1

\[
M_{p1, Rd, r5, b} = \frac{0.25l_{\text{eff,5,b}}t_p^2 f_y, p}{\gamma_{M0}} = \frac{0.25 \times 216.55 \times 20^2 \times 355}{1,0}
\]

\[
M_{p1, Rd, r5, b} = 7,68 \times 10^6 \text{ Nmm}
\]

\[
F_{T,1, Rd, ep} = \frac{4M_{p1, Rd, r5, b}}{m_{p1}} = \frac{4 \times 7,68 \times 10^6}{38,51}
\]

\[
F_{T,1, Rd, ep} = 797.7 \text{ kN}
\]

#### Mode 2

\[
M_{p1,2, Rd, r5, b} = \frac{0.25l_{\text{eff,5,b}}t_p^2 f_y, p}{\gamma_{M0}} = \frac{0.25 \times 216.55 \times 20^2 \times 355}{1,0}
\]

\[
M_{p1,2, Rd, r5, b} = 7,68 \times 10^6 \text{ Nmm}
\]

\[
F_{T,2, Rd, ep} = \frac{2M_{p1,2, Rd, r5, b} + n_{p, ep} \sum F_{T, Rd}}{m_{p1} + n_{p, ep}}
\]

\[
F_{T,2, Rd, ep} = \frac{2 \times 7,68 \times 10^6 + 48,14 \times 406,66 \times 10^3}{38,51 + 48,14}
\]

\[
F_{T,2, Rd, ep} = 403.2 \text{ kN}
\]

#### Mode 3

\[
F_{T,3, Rd, ep} = \sum F_{T, Rd}
\]

\[
F_{T,3, Rd, ep} = 2 \times 203 = 406 \text{ kN}
\]
Therefore the resistance of the end plate in bending is:

\[ F_{t,Rd,cp} = \min(F_{t,1,Rd,cp} ; F_{t,2,Rd,cp} ; F_{t,3,Rd,cp}) = \min(798; 403; 406) \]

\[ F_{t,Rd,cp} = 403 \text{ kN} \]

**Rafter web in tension**

\[ F_{t,wb,Rd} = \frac{b_{eff,wb} f_{wb} f_{y,beam}}{\gamma_{M0}} \]

\[ b_{eff,wb} = l_{eff,5,b} \]

\[ F_{t,wb,Rd} = \frac{216.55 \times 9.4 \times 355}{10} = 723 \text{ kN} \]

In the last bolt row the potential tension resistance will be limited by the value of the previous row. Therefore:

\[ F_{t,wb,Rd} = 291 \text{ kN} \]

\[ \therefore \ F_{t,Rd(row5)} = \min(291; 465; 403; 723) = 291 \text{ kN} \]

**Summary:**

\[ F_{t,Rd(row1)} = 298 \text{ kN} \]

\[ F_{t,Rd(row2)} = 294 \text{ kN} \]

\[ F_{t,Rd(row3)} = 291 \text{ kN} \]

\[ F_{t,Rd(row4)} = 291 \text{ kN} \]

\[ F_{t,Rd(row5)} = 291 \text{ kN} \]

\[ \sum F_{t,Rd(row)} = 1465 \text{ kN} \]
4 Assessment of the Compression Zone

The following condition has to be satisfied:

\[ F_{c,Ed} \leq F_{c,Rd} \]

The acting force is the sum of the design tension resistances of the bolt rows:

\[ F_{c,Ed} = \sum F_{i,Rd(row)} = 1465 \text{kN} \]

The design compression resistance of the compression zone is the minimum of the design compression resistance of the column web and the design compression resistance of the haunch flange and web:

\[ F_{c,Rd} = \min(F_{c,wc,Rd}, F_{c,fg,Rd}) \]

4.1 Column web in transverse compression

\[ F_{c,wc,Rd} = \min \left( \frac{\omega_c k_{wc} b_{eff,c,wc} t_{wc} f_{y,wc}}{\gamma_{M0}}, \frac{\omega_c k_{wc} \rho_c b_{eff,c,wc} t_{wc} f_{y,wc}}{\gamma_{M1}} \right) \]

According to the geometry

\[ \beta = 1 \]

and therefore:

\[ \omega_c = \omega_{i,c} = \frac{1}{\sqrt{1+1.3 \left( \frac{b_{eff,c,wc} t_{wc}}{A_{vc}} \right)^2}} \]

Where:

\[ b_{eff,c,wc} = t_f + 2\sqrt{2} a_{cf} + 5(t_{fc} + r_c) + s_{p,c} \]

Where:

\[ s_{p,c} = \sqrt{2} t_p = \sqrt{2} \times 20 = 28.28 \text{mm} \]

\[ \therefore b_{eff,c,wc} = 14.6 + 2\sqrt{2} \times 6 + 5(16 + 21) + 28.28 = 244.85 \text{mm} \]

\[ \therefore \omega_c = \frac{1}{\sqrt{1+1.3 \left( \frac{244.85 \times 10}{6035.2} \right)^2}} = 0.9 \]
Conservatively:
\[ k_{wc} = 0,7 \]

\[ \omega_c k_{wc} b_{eff,c,wc} \ell_{wc} f_{y,wc} = \frac{0,9 \times 0,7 \times 244,85 \times 10,2 \times 355}{1,0} = 558,6 \text{ kN} \]

\[ \rho_c = \frac{\lambda_{p,c} - 0,2}{\lambda_{p,c}} \]

Where:
\[ \lambda_{p,c} = 0,932 \sqrt{\frac{b_{eff,c,wc} d_c f_{y,c}}{E t_{wc}^2}} = 0,932 \sqrt{\frac{244,85 \times 426 \times 355}{210000 \times 10,2^2}} \]

\[ \lambda_{p,c} = 1,21 \]

\[ \rho_c = \frac{(1,21 - 0,2)}{1,21^2} \]

\[ \rho_c = 0,69 \]

\[ \omega k_{wc} \rho_c b_{eff,c,wc} \ell_{wc} f_{y,wc} = \frac{0,9 \times 0,7 \times 0,69 \times 244,85 \times 10,2 \times 355}{1,0} = 385,4 \text{ kN} \]

\[ \therefore F_{c,wc,Rd} = \min(559; 385) = 385 \text{ kN} \]

\[ F_{c,wc,Rd} = 385 \text{ kN} \leq 1465 \text{ kN} = F_{c,Ed} \]

The resistance of the column web in compression is very small comparing to the acting force and therefore a stiffener is needed.

The design resistance of the compression stiffener is calculated in accordance with §9.1(3) of EN 1993-1-5.

\[ \therefore F_{c,wc,Rd} = 1966 \text{ kN} \geq 1465 \text{ kN} = F_{c,Ed} \]

Therefore with the stiffener, the compression check in the column web is ok.
4.2 Haunch flange and web in compression

\[ F_{c,\text{fh},\text{Rd}} = \frac{M_{c,\text{Rd}}}{(h - t_{\text{fh}})} \]

Where:

\[ M_{c,\text{Rd}} = W_{\text{el},y} \frac{f_{y,h}}{\gamma_{M0}} \]

The elastic modulus works out:

\[ W_{\text{el},y} = 3373,68 \text{ cm}^3 \]

\[ \therefore M_{c,\text{Rd}} = 3373,68 \times 10^3 \frac{355}{1,0} = 1198 \text{ kNm} \]

The lever arm \( h \) is:

\[ h = 845,4 \text{ mm} \]

\[ \therefore F_{c,\text{fh},\text{Rd}} = \frac{1198}{(845,4 - 14,6)} = 1442 \text{ kN} \]

The maximum resistance that can be allocated to the flange is:

\[ F_{c,\text{fh},\text{max}} \leq \frac{1}{0,8} b_{y}t_{\text{fh}} \frac{f_{y,h}}{\gamma_{M0}} = \frac{1}{0,8} 190 \times 14,6 \frac{355}{1,0} = 1230,9 \text{ kN} \]

Therefore the compression resistance of the haunch is the minimum of the above two:

\[ \therefore F_{c,\text{fh},\text{Rd}} = 1231 \text{ kN} \]

\[ \therefore F_{c,\text{Rd}} = \min(1966; \ 1231) = 1231 \text{ kN} < 1465 \text{ kN} = F_{c,\text{Ed}} \]

Since the requirement of \( F_{c,\text{Ed}} \leq F_{c,\text{Rd}} \) is not satisfied, a force redistribution is needed. See section 7 of this document for details on the redistribution.
5 Column web panel in shear

\[ \varepsilon_c = \sqrt{\frac{235}{f_{y,c}}} = \sqrt{\frac{235}{355}} = 0.81 \]

\[ \frac{d_c}{t_{wc}} = \frac{426}{102} = 41.76 \]

\[ 69\varepsilon_c = 69 \times 0.81 = 56.14 \]

\[ \frac{d_c}{t_{wc}} = 41.76 \leq 56.14 = 69\varepsilon_c \]

Therefore the column web panel resistance in shear is:

\[ V_{wp,Rd} = \frac{0.9 f_{y,wc} A_{vc}}{\sqrt{3 \gamma_{M0}}} = \frac{0.9 \times 355 \times 6035.2}{\sqrt{3 \times 1.0}} = 1113.3 \text{ kN} \]

To avoid the column web panel in shear being the critical check and limiting the tension resistance the bolts can develop, supplementary web plates are added in the column flange. The new resistance of the web panel in shear is:

\[ V_{wp,Rd,mod} = \frac{0.9 f_{y,wc} A_{vc,mod}}{\sqrt{3 \gamma_{M0}}} \]

The new shear area:

\[ A_{vc,mod} = A_{vc} + b_s t_{wc} \]

Where

\[ b_s = \min(40\varepsilon t_s; \ h_c - 2r_c - 2t_s - 2t_{fc}) \]

For a 10 mm thick web plate:

\[ 40\varepsilon t_s = 40 \times \sqrt{\frac{235}{355}} \times 10 = 325.45 \text{ mm} \]

\[ h_c - 2r_c - 2t_s - 2t_{fc} = 500 - 2 \times 21 - 2 \times 10 - 2 \times 16 = 406 \text{ mm} \]

\[ b_s = \min(325.45; \ 406) = 325.45 \text{ mm} \]
\[ A_{vc,mod} = 6035,2 + 325,45 \times 10,2 = 9354,75 \text{ mm}^2 \]

\[ V_{wp,Rd,mod} = \frac{0,9 \times f_{y,wc} A_{vc,mod}}{\sqrt{3} \gamma M_0} = \frac{0,9 \times 355 \times 9354,75}{\sqrt{3} \times 1,0} = 1726 \text{ kN} \]

### 6 Rafter web in compression

\[ F_{c,wb,Rd} = \min \left( \frac{\omega_b k_{w,b} b_{eff,cw,b} f_y,beam}{\gamma M_0} ; \frac{\omega_b P_c k_{w,b} b_{eff,cw,b} f_y,beam}{\gamma M_1} \right) \]

The procedure to calculate the compression resistance of the rafter web is the same as for the column web without a compression stiffener. Detail calculations are not shown here.

The acting force in the rafter web can be calculated according to the following acting forces triangle:

\[ F_{wb,Ed} = 283 \text{ kN} \]

\[ F_{c,wb,Rd} = 323 \text{ kN} > 283 \text{ kN} = F_{wb,Ed} \]

The resistance of the rafter web is greater than the acting force in the rafter web, therefore OK. If the compression resistance of the rafter web was not greater than the compression acting force, then a compression stiffener should be provided as for the column web.

### 7 Force distribution in bolt rows

The first condition the effective design tension resistance has to satisfy is:

\[ F_{c,Ed} \leq F_{c,Rd} \]
\[ F_{c,Ed} = \sum F_{1,Rd,\text{row}} = F_{1,Rd,1} + F_{1,Rd,2} + F_{1,Rd,3} + F_{1,Rd,4} + F_{1,Rd,5} = 298 + 294 + 291 + 291 + 291 = 1465 \text{ kN} \]

\[ F_{c,Rd} = \text{min}(F_{c,wc,Rd}; F_{c,fh,Rd}) = 1231 \text{ kN} \]

\[ \therefore \text{ Since } F_{c,Ed} > F_{c,Rd} \]

Therefore the following distribution will be adopted:

\[ F_{1,Rd} = 298 \text{ kN} \]
\[ F_{2,Rd} = 294 \text{ kN} \]
\[ F_{3,Rd} = 291 \text{ kN} \]
\[ F_{4,Rd} = 291 \text{ kN} \]
\[ F_{5,Rd} = 57 \text{ kN} \]
\[ \sum F_{\text{tr,Rd}} = 1231 \text{ kN} \]

The column web panel in shear check is as follows:

\[ \sum F_{1,Rd,\text{row}} \leq \frac{V_{wp,Rd,\text{mod}}}{\beta} \]

In this case \( \beta = 1 \)

\[ \sum F_{1,Rd,\text{row}} = 1231 < 1726 = \frac{V_{wp,Rd,\text{mod}}}{\beta} \]

Therefore this condition is satisfied and no more redistribution is needed.

The effective design tension resistance also has to satisfy the following:

\[ F_{tx,Rd} \leq 1.9 F_{1,Rd} \]

\[ 1.9 F_{1,Rd} = 1.9 \times 203 = 386 \text{ kN} \]

Considering the worst of the possible cases:

\[ F_{1,Rd} = 298 < 386 \text{ kN} \]

Therefore the condition is satisfied and the above mentioned resistances will be taken as the effective tension resistances of the bolt rows.
8 Moment resistance of the joint

\[ M_{j,Rd} = F_{t1,Rd}h_1 + F_{t2,Rd}h_2 + F_{t3,Rd}h_3 + F_{t4,Rd}h_4 + F_{t5,Rd}h_5 \]
\[ = 298 \times 892,7 + 294 \times 792,7 + 291 \times 702,7 + 291 \times 612,7 + 57 \times 522,7 \]
\[ = 912 \text{kNm} \]

\[ M_{j,Rd} = 912 \text{kNm} > 880 \text{kNm} = M_{Ed} \]

The resistance is greater than the acting moment, therefore OK.

9 Assessment of the shear resistance

9.1 Bolts in shear

The shear resistance of one bolt is:

\[ F_{v,Rd} = \frac{\alpha_v f_{ub} A_s}{\gamma_{M2}} \]

Where for 8.8 bolts:

\[ \alpha_v = 0,6 \]

\[ \therefore F_{v,Rd} = \frac{0,6 \times 800 \times 353}{1,25} = 136 \text{kN} \]

9.2 Bolts in bearing on column flange

The bearing resistance of one bolt on the column flange is:

\[ F_{b,i,Rd} = \frac{k_{1,c} \alpha_{b,c} f_{u,c} t_{fc}}{\gamma_{M2}} \]

Where:

\[ k_{1,c} = \min \left( 2,8 \frac{e_1}{d_0} - 1,7; \quad 1,4 \frac{w}{d_0} - 1,7; \quad 2,5 \right) \]

\[ 2,8 \frac{e_1}{d_0} - 1,7 = 2,8 \times \frac{50}{26} - 1,7 = 3,68 \]
\[ 1,4 \frac{w}{d_0} - 1,7 = 1,4 \times \frac{100}{26} - 1,7 = 3,68 \]
\[ \therefore k_1 = \min(3.68; 3.68; 2.5) = 2.5 \]

\[ \alpha_{b,c} = \min \left( \alpha_{d,c}, \frac{f_{ub}}{f_{u,c}}, 1.0 \right) \]

\[ \alpha_{d,c} = \min \left( \frac{e_{1,bc}}{3d_0}, \frac{p}{3d_0} \frac{1}{4} \right) \]

\[ \frac{e_{1,bc}}{3d_0} = \frac{130}{3 \times 26} = 1.66 \]

\[ \frac{p}{3d_0} \frac{1}{4} = \frac{90}{3 \times 26} \frac{1}{4} = 0.9 \]

\[ \alpha_{d,c} = \min(1.66; 0.9) = 0.9 \]

\[ \frac{f_{ub}}{f_{u,c}} = \frac{800}{510} = 1.57 \]

\[ \alpha_{b,c} = \min(0.9; 1.57; 1.0) = 0.9 \]

\[ F_{b,i,Rd} = \frac{2.5 \times 0.9 \times 510 \times 24 \times 16}{1.25} \]

\[ \therefore F_{b,i,Rd} = 353 \text{ kN} \]

### 9.3 Bolts in bearing on end plate

The bearing resistance of one bolt on the end plate:

\[ F_{b,i,p,Rd} = k_{1,p} \alpha_{b,c} f_{u,p} d t_p \gamma_{M2} \]

Where:

\[ k_{1,p} = \min \left( 2.8 \frac{e_1}{d_0} - 1.7; 1.4 \frac{w}{d_0} - 1.7; 2.5 \right) \]

\[ 2.8 \frac{e_1}{d_0} - 1.7 = 2.8 \times \frac{50}{26} - 1.7 = 3.68 \]
### Example: Portal frame - eaves moment connection

**Eurocode Ref:** EN 1993-1-8

**Made by:** Edurne Núñez  **Date:** Nov 2005

**Checked by:** Abdul Malik  **Date:** Feb 2006

<table>
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<tr>
<td>1.4 (\frac{w}{d_0}) - 1.7 = 1.4 (\frac{100}{26}) - 1.7 = 3.68</td>
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<td>(\therefore k_{1,p} = \min(3.68; 3.68; 2.5) = 2.5)</td>
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<td>(\alpha_{b,p} = \min\left(\alpha_{d,p}; \frac{f_{ub}}{f_{u,p}}; 1.0\right))</td>
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<td>(\alpha_{d,p} = \min\left(\frac{e_{1,bp}}{3d_0}; \frac{p}{3d_0} - \frac{1}{4}\right))</td>
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<tr>
<td>(e_{1,bp} = \frac{130}{3 \times 26} = 1.66)</td>
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<tr>
<td>(p = \frac{90}{3 \times 26} = \frac{1}{4} = 0.9)</td>
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<tr>
<td>(\alpha_{d,p} = \min(1.66; 0.9) = 0.9)</td>
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<tr>
<td>(\alpha_{b,p} = \min(0.9; 1.57; 1.0) = 0.9)</td>
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<tr>
<td>(F_{b,i,p,Rd} = \frac{2.5 \times 0.9 \times 510 \times 24 \times 20}{1,25})</td>
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<tr>
<td>(\therefore F_{b,i,p,Rd} = 441\text{kN})</td>
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The design shear resistance of one bolt is the minimum of the above three resistances, i.e. \(\min(136; 353; 441) = 136\text{kN}\).

Number of bolts required to resist the vertical shear is:

\[\frac{V_{Ed}}{136} = \frac{200}{136} = 1.47\text{, i.e. two bolts}\]

Therefore, number of bolt rows required for shear is one. Design shear resistance of the joint:

\(2 \times 136 = 272\text{kN}\)
# Quality Record

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