This NCCI provides information on the design method for a bolted apex moment connection. It includes several simplifications which are explained throughout the document, to obtain simpler but conservative calculations. This NCCI references repeatedly to SN041 to benefit from the common approach to design apex and eaves connections and therefore only presents those contents specific for apex.

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1. Design model

1.1 Stiffness

For apex connections apply the same procedure as for portal frame eaves connection. See SN041 §1.1

1.2 Strength

1.2.1 General model

The general model for the design of apex connections is basically the same as for eaves connections, see SN041 §1.2.1, but with the following considerations:

1. The moment resistance, $M_{j,Rd}$, and the shear resistance, $V_{j,Rd}$, of the joint depend on the connected members and the basic components of the joint that make a contribution to the joint resistance: bolts, end plate, haunch, rafter web and flanges and welds, see Figure 1.1.

![Diagram of Portal Frame Apex Connection](image)

**Figure 1.1** Portal frame apex connection with bolted extended end plate

2. The procedure to determine the joint resistance is presented in Table 1.1.
### Table 1.1  Procedure to determine $F_{tr,Rd}$ and the joint resistance

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Calculate potential tension resistance of each bolt row in the tension zone</td>
<td>$F_{t,Rd(row)}$</td>
</tr>
<tr>
<td>2.</td>
<td>Calculate the design compression resistance in the compression zone</td>
<td>$F_{c,Rd}$</td>
</tr>
<tr>
<td>3.</td>
<td>Calculate the effective design tension resistance of each bolt row</td>
<td>$F_{tr,Rd}$</td>
</tr>
<tr>
<td>4.</td>
<td>Calculate the moment resistance of the joint</td>
<td>$M_{j,Rd} = \sum h_r F_{tr,Rd}$</td>
</tr>
<tr>
<td>5.</td>
<td>Assessment for vertical shear forces</td>
<td>$V_{Ed} \leq V_{Rd}$</td>
</tr>
</tbody>
</table>

### 1.2.2  Simplifications

For apex connections, apply the same simplifications as for portal frame eaves connections. See SN041 §1.2.2.

### 2.  Parameters

![Portal frame apex: Parameter definition](image)

- $b_p$: width of the end plate
- $e_{pl}$: distance from the bottom of the tension flange of the haunch to the edge of the end plate
- $d_2$: pitch between the bolt row in the extended zone of the end plate and the first bolt row above the tension flange of the rafter
3. **Weld design**

For the relevant components of the apex connection, apply the same approach as presented in SN041§3 for eaves connection.

4. **Potential resistances of bolt rows in the tension zone**

*NOTE*: EN 1993-1-8 uses the symbol $F_{t,Rd}$ to refer to both the tension resistance of an individual bolt row and the tension resistance of one bolt. In this document $F_{t,Rd(rows)}$ has been used to refer to the tension resistance of the row.

For each bolt row, the potential design tension resistance is given in EN 1993-1-8 §6.2.7.2(6):

$$F_{t,Rd(rows)} = \min(F_{t,ep,Rd}, F_{t,wb,Rd})$$

**Table 4.1  Components of the joint to determine the potential design resistance of a bolt row**

<table>
<thead>
<tr>
<th>Component</th>
<th>Section number</th>
</tr>
</thead>
<tbody>
<tr>
<td>End plate in bending</td>
<td>$F_{t,ep,Rd}$</td>
</tr>
<tr>
<td>Rafter web in tension</td>
<td>$F_{t,wb,Rd}$</td>
</tr>
</tbody>
</table>

The potential design tension resistance $F_{t,Rd(rows)}$ for each bolt-row should be determined in sequence, starting from the furthest bolt row from the centre of compression (bolt row 1) and then progressing to the next one (bolt-row 2) until the last one, the closest one to the centre of compression, is calculated (see Figure 4.1). Assume the centre of compression is in line with the centre of the compression flange of the rafter.
For simplicity and ease of calculations, the potential design tension resistance of each bolt-row assumes that there is no overlap with other bolt-rows.

This simplified approach leads to conservative results assuming that T-stub effective length $\ell_{eff}$ is determined accordingly, see worked example SX031.

The effective design tension resistance $F_{tr,Rd}$ for each bolt row may be less than the potential design tension resistance $F_{tr,Rd}(row)$.

### 4.1 End plate in bending

The design resistance and failure mode of an end plate in transverse bending, together with the associated bolts in tension, should be taken as similar to those of an equivalent T-stub flange.

$$F_{ep,Rd} = \min(F_{T,1,Rd}, F_{T,2,Rd}, F_{T,3,Rd})$$

accounting for prying forces and the three failure modes (see SN041§4.3).

$\sum l_{eff}$ can be determined according to Figure 6.2, Figure 6.10 and Table 6.6 of EN 1993-1-8.

Alternatively a simple conservative approach as given below can be used.

For an individual bolt row the following simplification can be made:

$$\sum l_{eff,1} = \sum l_{eff,2} = L_{eff}$$

as shown in figure 4.2 below

$\sum l_{eff,1}$ is the value of $\sum l_{eff}$ for mode 1

$\sum l_{eff,2}$ is the value of $\sum l_{eff}$ for mode 2

This method is based on the assumption that the effective length is always limited to a maximum distance of the pitch between bolt centres. Figure 4.2 and table 4.3 of SN041 illustrate this approach.
4.2 Rafter web in tension

The resistance of the rafter web in tension can be calculated according to EN 1993-1-8 §6.2.6.8 as follows:

$$F_{t,wb,Rd} = \frac{b_{\text{eff},t,wb} f_{y,wb}}{\gamma_{M0}}$$

where:

$$b_{\text{eff},t,we} = l_{\text{eff}}$$, see section 4.1

5. Assessment of the compression zone

The resistance of the compression zone is the compression resistance of the rafter flange and web as given by the following expression in §6.2.6.7 of EN 1993-1-8.

$$F_{c,Rd} = F_{c,\text{tb},Rd} = \frac{M_{c,Rd}}{(h-t_{fb})}$$

where

$h$ is the depth of the beam including rafter and haunch
\( M_{c,Rd} \) is the design moment resistance of the beam (rafter + haunch) cross-section, reduced if necessary to allow for shear, see EN 1993-1-1§ 6.2.5. \( M_{c,Rd} \) may be calculated neglecting the intermediate flange.

\( t_{fb} \) is the flange thickness of the connected rafter.

If the height of the beam (rafter + haunch) exceeds 600 mm the contribution of the rafter web to the design compression resistance should be limited to 20%. This means that if the resistance of the flange is \( t_{fb} b_{fb} f_{y,fb} \) then:

\[
F_{c,fb,Rd} \leq \frac{t_{fb} b_{fb} f_{y,fb}}{0.8}
\]

Finally, \( F_{t,Rd} \) of bolt-row \( r \) should, if necessary, be reduced to ensure that, when account is taken of all bolt-rows up to and including bolt-row \( r \) the following condition is satisfied:

\[
\sum F_{t,Rd} \leq F_{c,fb,Rd}
\]

6. Force distribution in bolt rows

The force distribution in bolt rows in apex connections follows the same principles as for eaves connections, see SN041§8.

The Figure 8.1 of SN041 shows the procedure for an eaves end plate connection. That approach is similar for an apex extended end plate connection; it is important to take into account that the positions of the tension and compression zones are different for apex and eaves (see Figure 1.1).

7. Assessment of the shear resistance

The design shear resistance to vertical shear forces of the joint must be determined by accounting the contributions of the relevant basic components:

\[
V_{Rd} = n_s \cdot \min\left(F_{V,i,Rd}; F_{b,Ep,Rd}\right); \text{ see Table 7.1}
\]

where

\( n_s \) is the number of bolts that are required to resist shear, see EN 1993-1-8§6.2.2(2)

<table>
<thead>
<tr>
<th>Table 7.1</th>
<th>Components of the joint involved in the assessment of the shear resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>Section number</td>
</tr>
<tr>
<td>Bolts in shear</td>
<td>( F_{V,Rd} )</td>
</tr>
<tr>
<td>Bolts in bearing on end-plate</td>
<td>( F_{b,Ep,Rd} )</td>
</tr>
</tbody>
</table>
8. **Limits of application**

The application of this document must be in accordance with the rules and relevant limits of application set out in EN 1993-1-8. A summary of these is presented in SN041 §10.

9. **Background**

See SN041 §11.
## Quality Record

<table>
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<th>RESOURCE TITLE</th>
<th>NCCI: Design of portal frame apex connections</th>
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### Reference(s)

### ORIGINAL DOCUMENT

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