NCCI: Shear resistance of a simple end plate connection

This NCCI provides rules for the determination of shear resistance of a "Simple Joint" using an end plate connection for Beam/Column and Beam/Beam connections. This NCCI covers the rules for the end plate, the supported beam and the supporting column or beam. The rules may be used to evaluate the overall shear resistance of the connection, for all the possible modes of failure, based on the rules in EN 1993-1-8 for determining the resistances of individual components of the connection. The rules apply to a bolted connection using non-preloaded bolts (i.e. a Category A: Bearing type bolted connection). The rules given in this NCCI can be applied to both partial depth and full depth end plate connections.

Contents

1. Design model 2
2. Parameters 3
3. Bolts in shear 4
4. End plate in bearing 4
5. Supporting member in bearing 5
6. End plate in shear (gross section) 6
7. End plate in shear (net section) 6
8. End plate in shear (block shear) 6
9. End plate bending (in-plane) 7
10. Beam web in shear 7
11. Weld Design 8
12. Ductility requirements 9
13. Limits of application 9
14. Background 9
1. Design model

End plate connections may be considered as “simple joints” according to EN1993-1-1 §5.1.2 (1) and (2) and EN1993-1-8 §5.1.1 (1), (2) and (3). For further information about simple joints, see SN020. Thus the effects of joint behaviour need not be taken into account in the analysis of the frame.

![Assumed line of shear transfer](face of column)  
![Assumed line of shear transfer](face of web)  
![Assumed line of shear transfer](face of web)

Key:  
1. End plate  
2. Supported beam  
3. Column  
4. Supporting beam

*Figure 1.1  End plate connection subject to vertical shear force*

The shear resistance and mode of failure of the connection is the value and mode that has the lowest resistance of all the possible modes of failure. For rules for each of the modes of failure, refer to Table 1.1 given below.

*Table 1.1  Shear resistance of end plate connection*

<table>
<thead>
<tr>
<th>Mode of failure</th>
<th>Section number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolts in shear</td>
<td>$V_{Rd,1}$</td>
</tr>
<tr>
<td>End plate in bearing</td>
<td>$V_{Rd,2}$</td>
</tr>
<tr>
<td>Supporting member in bearing</td>
<td>$V_{Rd,3}$</td>
</tr>
<tr>
<td>End plate in shear (gross section)</td>
<td>$V_{Rd,4}$</td>
</tr>
<tr>
<td>End plate in shear (net section)</td>
<td>$V_{Rd,5}$</td>
</tr>
<tr>
<td>End plate in shear (block shear)</td>
<td>$V_{Rd,6}$</td>
</tr>
<tr>
<td>End plate in bending</td>
<td>$V_{Rd,7}$</td>
</tr>
<tr>
<td>Beam web in shear</td>
<td>$V_{Rd,8}$</td>
</tr>
</tbody>
</table>
2. Parameters

- $a$  Weld throat
- $A_{\text{v,net}}$  Net shear area of the end plate
- $d_o$  Diameter of hole
- $d_w$  Diameter of washer or width across points of bolt head or nut
- $e_1$  Longitudinal end distance (end plate)
- $e_2$  Transverse edge distance (end plate)
- $e_{2,c}$  Transverse edge distance (column flange)
- $f_{u,b}$  Ultimate tensile strength of the bolt
- $f_{u,b1}$  Ultimate tensile strength of supported beam
- $f_{u,b2}$  Ultimate tensile strength of supporting beam
- $f_{y,c}$  Yield strength of column
- $f_{u,c}$  Ultimate tensile strength of column
- $f_{u,p}$  Ultimate tensile strength of the end plate
- $f_{y,b1}$  Yield strength of supported beam
- $f_{y,b2}$  Yield strength of supporting beam
- $f_{y,p}$  Yield strength of the end plate
- $h_p$  Height of the end plate
- $m_p$  Distance between the bolt line and the toe of the weld connecting the end plate to the beam web (defined as $m$ in Figure 6.2 of EN1993-1-8)
- $n$  Total number of bolts (i.e. $n_1 \times n_2$)
- $n_1$  Number of horizontal rows of bolts
- $n_2$  Number of vertical lines of bolts. This NCCI is for $n_2=2$
- $p_1$  Longitudinal bolt pitch
- $p_3$  Gauge or distance between cross centres
- $t_{f,c}$  Thickness of column flange
- $t_p$  Thickness of the end plate
- $t_{w,b1}$  Thickness of supported beam web
- $t_{w,b2}$  Thickness of supporting beam web
3. **Bolts in shear**

\[ V_{Rd,1} = 0.8 \, n \, F_{v,Rd} \]

The shear resistance of a single bolt, \( F_{v,Rd} \) is given in Table 3.4 of EN1993-1-8 as:

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

Where \( A \) can be taken as the tensile stress area of the bolt \( A_s \).

Note: The reduction factor 0.8 allows for the presence of tension in the bolts. For further explanation (see Ref (1), sections 4.1.1.2 and 6.2.2).

4. **End plate in bearing**

Conservatively (From §3.7 (1) of EN1993-1-8)

\[ V_{Rd,2} = nF_{b,Rd} \]

But if \( F_{v,Rd} \geq F_{b,Rd} \) then:

\[ V_{Rd,2} = \sum F_{b,Rd} \]

The bearing resistance of a single bolt, \( F_{b,Rd} \) is given in Table 3.4 of EN1993-1-8 as:

\[ F_{b,Rd} = \frac{k_1 \alpha_b f_{u,p} d t_p}{\gamma_{M2}} \]

Where \( \alpha_b = \min \left( \frac{e_1}{3d_0}; \frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{u,p}}; 1,0 \right) \)

\[ k_1 = \min \left( 2,8 \frac{e_2}{d_0} - 1,7; 2,5 \right) \]
5. Supporting member in bearing

\[ V_{Rd,3} = nF_{b,Rd} \]

The bearing resistance of a single bolt, \( F_{b,Rd} \) is given in Table 3.4 of EN1993-1-8 as:

\[ F_{b,Rd} = k_1 \alpha_b f_u d t \]

When the supporting element is a column flange:

\[ t = t_{c,f} \]  
\[ f_u = f_{u,c} \]  
\[ \alpha_b = \min \left( \frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{u,c}}; 1,0 \right) \]  
\[ k_1 = \min \left( 2,8 \frac{d_0}{e_{2,c}} - 1,7; 2,5 \right) \]

When the supporting element is a column web:

\[ t = t_{w,c} \]  
\[ f_u = f_{u,c} \]  
\[ \alpha_b = \min \left( \frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{u,c}}; 1,0 \right) \]  
\[ k_1 = \min \left( 1,4 \frac{d_0}{p_3} - 1,7; 2,5 \right) \]

When the supporting elements is a beam web:

\[ t = t_{w,b2} \]  
\[ f_u = f_{u,b2} \]  
\[ \alpha_b = \min \left( \frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{u,b2}}; 1,0 \right) \]  
\[ k_1 = \min \left( 1,4 \frac{d_0}{p_3} - 1,7; 2,5 \right) \]
6. **End plate in shear (gross section)**

\[ V_{Rd,4} = \frac{2h pt_p}{1.27} \frac{f_{y,p}}{\sqrt[3]{\gamma_{M0}}} \]

Note: The coefficient 1.27 takes into account the reduction of the shear resistance, due to the presence of in-plane bending moment (see Ref (1), section 6.2.2). For further explanation, see Ref (3).

7. **End plate in shear (net section)**

\[ V_{Rd,5} = 2A_{v, net} \frac{f_{u,p}}{\sqrt[3]{\gamma_{M2}}} \]

where:

\[ A_{v, net} = t_p (h_p - n_1 d_0) \]

8. **End plate in shear (block shear)**

\[ V_{Rd,6} = 2V_{eff,Rd} \]

From §3.10.2 of EN1993-1-8:

Generally:

\[ V_{eff,Rd} = V_{eff,1,Rd} = \frac{f_{u,p} A_{nt}}{\gamma_{M2}} + \frac{f_{y,p} A_{nv}}{\sqrt[3]{\gamma_{M0}}} \]

But if \( h_p < 1.36 \rho_3 \) and \( n_1 > 1 \) then:

\[ V_{eff,Rd} = V_{eff,2,Rd} = \frac{0.5 f_{u,p} A_{nt}}{\gamma_{M2}} + \frac{f_{y,p} A_{nv}}{\sqrt[3]{\gamma_{M0}}} \]

where:

\[ A_{nt} \text{ is the net area subjected to tension, given by } A_{nt} = t_p \left(e_2 - \frac{d_0}{2}\right) \]

\[ A_{nv} \text{ is the net area subjected to shear, given by } A_{nv} = t_p \left(h_p - e_1 - (n_1 - 0.5)d_0\right) \]
9. End plate bending (in-plane)

Generally $h_p \geq 1.36 \, p_3$ (i.e. $p_3 \leq h_p/1.36$) hence:

$$V_{Rd,7} = \infty$$

However, when the gauge or distance between cross-centres is large i.e. $p_3 > h_p/1.36$ then the effects of in-plane bending moment in the central section of the end plate become predominant and reduce its shear resistance (i.e. $V_{Rd,7} < V_{Rd,4}$). Therefore the reduced shear resistance is:

$$V_{Rd,7} = \frac{2 \, W_{el}}{p_3 - t_{w,b1}} \frac{f_{y,p}}{\gamma_M}$$

Where:

$$W_{el} = \frac{t_p \, h_p^2}{6}$$

10. Beam web in shear

From §6.2.6 (2) of EN1993-1-1:

$$V_{Rd,8} = A_v \frac{f_{y,b1}}{\sqrt{3} \, \gamma_M}$$

For shear area $A_v$, §6.2.6 (3) does not specifically cover the case of a rectangular plate. However, from case (c) of §6.2.6(3), it would be reasonable to apply 0.9 factor to the area of the beam web connected to the end plate. Therefore:

$$A_v = 0.9 \, h_p \, t_{w,b1}$$

$$V_{Rd,8} = 0.9 \, h_p \, t_{w,b1} \, \frac{f_{y,b1}}{\sqrt{3} \, \gamma_M}$$
11. Weld Design

Provide full strength double fillet welds. The welds are considered as side fillet welds. The size of the weld throat “a” complies with the following requirement:

\[ a \geq 0.38 \times t_{w,b1} \] for S235 supported beam

\[ a \geq 0.39 \times t_{w,b1} \] for S275 supported beam

\[ a \geq 0.45 \times t_{w,b1} \] for S355 supported beam

*Figure 11.1 Fillet weld, throat and leg length.*
12. **Ductility requirements**

To ensure adequate ductility, the following requirement must be satisfied.

- If the supporting element is a beam or column web:
  \[ t_p \leq \frac{d}{2.8} \sqrt{\frac{f_{ub}}{f_{y,p}}} \]

- If the supporting element is a column flange:
  \[ t_p \leq \frac{d}{2.8} \sqrt{\frac{f_{ub}}{f_{y,p}}} \quad \text{or} \quad t_{f,c} \leq \frac{d}{2.8} \sqrt{\frac{f_{ub}}{f_{y,c}}} \]

Where \( d \) is the diameter of the bolt.

13. **Limits of application**

This NCCI applies to two vertical lines of bolts (i.e. \( n_2 = 2 \)) using non-preloaded bolts for Category A: Bearing type bolted connection in accordance with EN1993-1-8 §3.4.1.

14. **Background**

The rules in this NCCI are based on:


3. *Development of a European process for the design of simple structural joint in steel frames*” (in French), by RENKIN Sandra, Diploma work, University of Liege, June 2003
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<table>
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<th>RESOURCE TITLE</th>
<th>NCCI: Shear resistance of a simple end plate connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference(s)</td>
<td></td>
</tr>
</tbody>
</table>

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<table>
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<th>Date</th>
</tr>
</thead>
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