STEEL BUILDINGS IN EUROPE

Multi-Storey Steel Buildings
Part 5: Joint Design
Multi-Storey Steel Buildings
Part 5: Joint Design
FOREWORD

This publication is part five of a design guide, *Multi-Storey Steel Buildings*. The 10 parts in the *Multi-Storey Steel Buildings* guide are:

Part 1: Architect’s guide
Part 2: Concept design
Part 3: Actions
Part 4: Detailed design
Part 5: Joint design
Part 6: Fire Engineering
Part 7: Model construction specification
Part 8: Design software – section capacity
Part 9: Design software – simple connections
Part 10: Software specification for composite beams.

*Multi-Storey Steel Buildings* is one of two design guides. The second design guide is *Single Storey Steel Buildings*.

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SUMMARY

This design guide gives the design procedure for simple joints in multi-storey buildings according to the Eurocodes.

The guide covers different types of joints:

- Beam-to-beam and beam-to-column joints
  - Partial depth flexible end plate
  - Fin plate
  - Double angle web cleats
- Column splices
- Column bases

Each design procedure is illustrated by a worked example, using the recommended values given in the Eurocodes.
Part 5: Joint Design
1 INTRODUCTION

1.1 About this design guide

This technical guide is for designing simple joints (nominally pinned) for use in braced multi-storey buildings, designed according to the Eurocodes. Design procedures are provided for:

- Beam-to-beam and beam-to-column joints
  - Partial depth flexible end plates (also known as header plates)
  - Fin plates
  - Double angle web cleats
- Column splices
- Column bases

The design procedures start with recommended detailing rules (joint geometry) required to ensure ductile behaviour, followed by the checks for each stage of the load transition through the complete joint including welds, plates, bolts and the section webs or flanges as appropriate.

Whilst the Eurocodes establish a common framework for structural calculations across Europe, structural safety remains each country’s responsibility. For this reason there are some parameters, called National Determined Parameters (NDP), which each country can decide upon. These are given in the National Annex (NA) documents, which complement the core Eurocodes. However the Eurocode gives some recommendations as to what value each NDP should take. In designing the structure the NDP should be taken from the NA from the country where the structure is to be built.

In this publication the recommended values given in the Eurocode have been adopted in the worked examples.

This publication is complemented by a spreadsheet design tool which allows for NDP for a range of countries. The spreadsheet covers all the joint types included in this publication and can be used in various languages.

1.2 Joint behaviour

Normal practice in simple construction is for beams to be designed as simply supported and for columns to be designed for both the axial compression and, where appropriate, a nominal moment from the beam end connections. In order to ensure that the structure behaves appropriately it is necessary to provide ‘simple’ connections (‘nominally pinned’ joints) as defined in EN 1993-1-8, § 5.1.1[1], in which the joint may be assumed not to transfer bending moments. In other words, the joints possess sufficient rotation capacity and sufficient ductility.
Nominally pinned joints have the following characteristics:
1. they are assumed to transfer only the design shear reaction between members
2. they are capable of accepting the resulting rotation
3. they provide the directional restraint to members which has been assumed in the member design
4. they have sufficient robustness to satisfy the structural integrity requirements.


- Classification by stiffness: the initial rotational stiffness of the joint, calculated in accordance with Section 6.3.1 of EN 1993-1-8 is compared with the classification boundaries given in Section 5.2 of the same document.
- Classification by strength: the following two requirements must be satisfied in order to classify a joint as pinned:
  - the moment resistance of the joint does not exceed 25% of the moment resistance required for a full-strength joint
  - the joint is capable of accepting the rotation resulting from the design loads.

Alternatively, joints may also be classified based on experimental evidence, experience of previous satisfactory performance in similar cases or by calculations based on test evidence.

Generally, the requirements for nominally pinned behaviour are met by the use of relatively thin plates, combined with full strength welds. Experience and testing have demonstrated that the use of 8 mm or 10 mm end plates, fin plates and angles in S275, with M20 8.8 bolts leads to connections which behave as nominal pins. If details are chosen outside these recommended parameters, the connection should be classified in accordance with EN 1993-1-8.

1.3 Standardised joints

In a typical braced multi-storey frame, the joints may account for less than 5% of the frame weight, but 30% or more of the total cost. Efficient joints will therefore have the lowest detailing, fabrication and erection labour content – they will not necessarily be the lightest.

Use of standardised joints where the fittings, bolts, welds and geometry are fully defined offers the following benefits:

- Reduces buying, storage, and handling time
- Improves availability and leads to a reduction in material costs
- Saves fabrication time and leads to faster erection
- Leads to a better understanding of their performance by all sides of the industry
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- Leads to fewer errors.

To take advantage of these benefits, standardised joints are recommended in this publication. A summary of the typical components adopted in this guide is as follows:

- Material of grade S275 for components such as end plates and cleats
- M20 8.8 fully threaded bolts, 60 mm long
- 22 mm holes, punched or drilled
- Fillet welds of 6 mm or 8 mm leg length
- Distance from the top of the beam to the first bolt row of 90 mm
- Vertical bolt spacing (pitch) of 70 mm
- Horizontal bolt spacing (gauge) of 90 or 140 mm
- Top of partial depth end plate, cleat or fin plate is 50 mm below the top of the beam flange.

1.4 Tying resistance

The requirement for sufficient tying resistance is to safeguard the structure against disproportionate collapse. Guidance on the design tying force that a connection must carry is given in EN 1991-1-7 Annex A[2].

EN 1993-1-8 does not give any guidance on how to calculate the tying resistance of joints. Other authoritative sources[3] recommend that the ultimate tensile strength \(f_u\) should be used for calculating the tying resistance and the partial factor for tying \(\gamma_{Mu}\) should be taken as 1,10. This value applies to the design resistance of all components of the joint: welds, bolts, plate and beam.

1.5 Design guidance in this publication

In this publication, design checks are presented followed in each case by a numerical worked example. The guidance covers:

- partial depth flexible end plates
- fin plates
- double angle web cleats
- column splices
- column bases.

In all worked examples, the section headings correspond to the headings in the design procedure preceding each worked example.
1.6 Symbols

- $a$ is the throat of the fillet weld
- $b$ is the breadth of the supported beam
- $d$ is the diameter of the bolt
- $d_0$ is the diameter of the hole
- $f_{y,b}$ is the yield strength of the supported beam
- $f_{u,b}$ is the ultimate tensile strength of the supported beam
- $f_{y,p}$ is the yield strength of the plate (end plate, fin plate, flange cover plate, base plate)
- $f_{u,p}$ is the ultimate tensile strength of the plate (end plate, fin plate, flange cover plate, base plate)
- $f_{y,ac}$ is the yield strength of the angle cleats
- $f_{u,ac}$ is the ultimate tensile strength of the angle cleats
- $f_{ub}$ is the ultimate tensile strength of the bolt
- $h_b$ is the height of the supported beam
- $h_p$ is the height of the plate (end plate, fin plate, flange cover plate)
- $h_{ac}$ is the height of the angle cleats
- $n_b$ is the total number of bolts on supported beam side
- $n_s$ is the total number of bolts on supporting beam side
- $n_1$ is the number of horizontal bolt rows
- $n_2$ is the number of vertical bolt rows
- $t_f$ is the flange thickness of the supported beam
- $t_w$ is the thickness of the supported beam web
- $t_p$ is the thickness of the plate (End plate, Fin plate, Flange cover plate, Base plate)
- $t_{ac}$ is the thickness of the angle cleats
- $s$ is the leg length of the fillet weld
- $\gamma_{M0}$ is the partial factor for the resistance of cross section ($\gamma_{M0} = 1.0$ is recommended in EN 1993-1-1)
- $\gamma_{M1}$ is the partial factor for the resistance of members to instability assessed by member checks ($\gamma_{M1} = 1.0$ is recommended in EN 1993-1-1)
2 PARTIAL DEPTH END PLATE

2.1 Recommended details

1. Length of end plate \( h_p \geq 0.6h_b \) (see Note 1)
2. Face of beam or column
3. Plate thickness, \( t_p \)
   \( t_p = 10 \text{ mm or } 12 \text{ mm (see note 2)} \)
4. Bolt diameter, \( d \)
5. Hole diameter, \( d_0 \)
   \( d_0 = d + 2 \text{ mm for } d \leq 24 \text{ mm} \)
   \( d_0 = d + 3 \text{ mm for } d > 24 \text{ mm} \)
6. Gauge; \( p_3, 90 \text{ mm} \leq p_3 \leq 140 \text{ mm} \)
7. 10 mm clearance
8. 50 mm but \( \geq (t_{f,s} + r_s) \) and \( \geq (t + r) \)
9. Supported beam (single notched)
10. \( (h_{b,s} - 50 \text{ mm}) \) but \( \geq (h_b - t_f - r) \)
11. Supported beam (double notched)
12. Supporting beam

\( h_b \) is the height of the supported beam
\( h_{b,s} \) is the height of the supporting beam (if applicable)
\( t_f \) is the thickness of the flange of the supported beam
\( t_{f,s} \) is the thickness of the flange of the supporting beam (if applicable)
\( r \) is the root radius of the supported beam
\( r_s \) is the root radius of the supporting beam (if applicable)

Notes:
1. The end plate is generally positioned close to the top flange of the beam to provide adequate positional restraint. A plate length of at least 0.6\( h_b \) is usually adopted to give nominal torsional restraint.
2. Although it may be possible to satisfy the design requirements with \( t_p < 8 \text{ mm} \), it is not recommended in practice because of the likelihood of distortion during fabrication and damage during transportation.
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2.2 Checks for vertical shear

2.2.1 Shear resistance of the beam web

Shear resistance of the beam web at the end plate

Basic requirement: \( V_{Ed} \leq V_{c,Rd} \)

\( V_{c,Rd} \) is the design shear resistance of the supported beam connected to the end plate.

\[
V_{c,Rd} = V_{pl,Rd} = \frac{A_v f_y b}{\gamma_M 0}
\]

where:

\( A_v \) is the shear area, \( A_v = h_p t_w \) [Reference 8]

2.2.2 Bending resistance at the notch

\[
V_{Ed} \times (t_p + l_n) \leq M_{v,N,Rd} \text{ or } M_{v,DN,Rd}
\]

\( M_{v,N,Rd} \) is the moment resistance of a single notched supported beam at the notch in the presence of shear.

\( M_{v,DN,Rd} \) is the moment resistance of a double notched supported beam at the notch in the presence of shear.
2.2.2.1 For a single notched beam:
For low shear (i.e. $V_{Ed} \leq 0.5V_{pl,N,Rd}$)

$$M_{v,N,Rd} = \frac{f_{y,b} W_{el,N,y}}{\gamma_{M0}}$$

[Reference 4]

For high shear (i.e. $V_{Ed} > 0.5V_{pl,N,Rd}$)

$$M_{v,N,Rd} = \frac{f_{y,b} W_{el,N,y}}{\gamma_{M0}} \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,N,Rd}} - 1 \right)^{2} \right]$$

[Reference 4]

2.2.2.2 For double notched beam:
For low shear (i.e. $V_{Ed} \leq 0.5V_{pl,DN,Rd}$)

$$M_{v,DN,Rd} = \frac{f_{y,b} t_{w}}{6 \gamma_{M0}} \left( h_{b} - d_{nt} - d_{nb} \right)^{2}$$

[Reference 4]

For high shear (i.e. $V_{Ed} > 0.5V_{pl,DN,Rd}$)

$$M_{v,DN,Rd} = \frac{f_{y,b} t_{w}}{6 \gamma_{M0}} \left( h_{b} - d_{nt} - d_{nb} \right)^{2} \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,DN,Rd}} - 1 \right)^{2} \right]$$

[Reference 4]

$V_{pl,N,Rd}$ is the shear resistance at the notch for single notched beams

$V_{pl,N,Rd} = \frac{A_{v,N} f_{y,b}}{\sqrt{3} \gamma_{M0}}$

$A_{v,N} = A_{Tee} - b t_{f} + (t_{w} + 2r) t_{f} \frac{t_{f}}{2}$

$A_{Tee}$ is the area of the Tee section

$V_{pl,DN,Rd}$ is the shear resistance at the notch for double notched beams

$V_{pl,DN,Rd} = \frac{A_{v,DN} f_{y,b}}{\sqrt{3} \gamma_{M0}}$

$A_{v,DN} = t_{w} (h_{b} - d_{nt} - d_{nb})$

where:

$W_{el,N,y}$ is the elastic modulus of the section at the notch

d_{nt} is the depth of the top notch

d_{nb} is the depth of the bottom notch
2.2.3 Local stability of notched beam

When the beam is restrained against lateral torsional buckling, no account needs be taken of notch stability provided the following conditions are met:

**For one flange notched, basic requirement:**\(^{[5][6]}\)

\[
\begin{align*}
  d_{nt} &\leq \frac{h_b}{2} & \text{and:} \\
  l_n &\leq h_b & \text{for } h_b/t_w \leq 54.3 & \text{(S275 steel)} \\
  l_n &\leq \frac{160000 h_b}{(h_b/t_w)^3} & \text{for } h_b/t_w > 54.3 & \text{(S275 steel)} \\
  l_n &\leq h_b & \text{for } h_b/t_w \leq 48.0 & \text{(S355 steel)} \\
  l_n &\leq \frac{110000 h_b}{(h_b/t_w)^3} & \text{for } h_b/t_w > 48.0 & \text{(S355 steel)}
\end{align*}
\]

**For both flanges notched, basic requirement:**\(^{[7]}\)

\[
\begin{align*}
  \max (d_{ntb}, d_{nb}) &\leq \frac{h_b}{5} & \text{and:} \\
  l_n &\leq h_b & \text{for } h_b/t_w \leq 54.3 & \text{(S275 steel)} \\
  l_n &\leq \frac{160000 h_b}{(h_b/t_w)^3} & \text{for } h_b/t_w > 54.3 & \text{(S275 steel)} \\
  l_n &\leq h_b & \text{for } h_b/t_w \leq 48.0 & \text{(S355 steel)} \\
  l_n &\leq \frac{110000 h_b}{(h_b/t_w)^3} & \text{for } h_b/t_w > 48.0 & \text{(S355 steel)}
\end{align*}
\]

Where the notch length \(l_n\) exceeds these limits, either suitable stiffening should be provided or the notch should be checked to References 5, 6 and 7. For S235 and S460 members see References 5, 6 and 7.
2.2.4 Bolt group resistance

Basic requirement: \( V_{\text{Ed}} \leq F_{\text{Rd}} \)

\( F_{\text{Rd}} \) is the resistance of the bolt group \[\text{EN 1993-1-8, §3.7(1)}\]

If \( (F_{\text{b,Rd}})_{\text{max}} \leq F_{\text{v,Rd}} \) then \( F_{\text{Rd}} = \sum F_{\text{b,Rd}} \)

If \( (F_{\text{b,Rd}})_{\text{min}} \leq F_{\text{v,Rd}} \leq (F_{\text{b,Rd}})_{\text{max}} \) then \( F_{\text{Rd}} = n_s (F_{\text{b,Rd}})_{\text{min}} \)

If \( F_{\text{v,Rd}} < (F_{\text{b,Rd}})_{\text{min}} \) then \( F_{\text{Rd}} = 0,8 n_s F_{\text{v,Rd}} \)

2.2.4.1 Shear resistance of bolts

\( F_{\text{v,Rd}} \) is the shear resistance of one bolt

\[
F_{\text{v,Rd}} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}}
\] \[\text{EN 1993-1-8, Table 3.4}\]

where:

\( \alpha_v = 0,6 \) for 4.6 and 8.8 bolts

\( = 0,5 \) for 10.9 bolts

\( A \) is the tensile stress area of the bolt, \( A_s \)

\( \gamma_{M2} \) is the partial factor for resistance of bolts

2.2.4.2 Bearing resistance

\[
F_{\text{b,Rd}} = \frac{k_i \alpha_b f_{u,p} d t_{p}}{\gamma_{M2}}
\] \[\text{EN 1993-1-8 Table 3.4}\]

where:

\( \gamma_{M2} \) is the partial factor for plate in bearing

- For end bolts (parallel to the direction of load transfer)

\[
\alpha_b = \min \left( \frac{e_1}{3d_0}, \frac{f_{ub}}{f_{u,p}}, 1,0 \right)
\]
For inner bolts (parallel to the direction of load transfer)

\[ \alpha_b = \min \left( \frac{p_t}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{u,p}}; 1,0 \right) \]

For edge bolts (perpendicular to the direction of load transfer)

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

For inner bolts (perpendicular to the direction of load transfer)

\[ k_1 = \min \left( 1,4 \frac{d_2}{d_0} - 1,7; 2,5 \right) \]

### 2.2.5 Shear resistance of the end plate

![Diagram of shearing forces on end plate](image)

1. Critical section in shear and bearing
2. Block shear – check failure by tearing out of shaded portion

Basic requirement: \( V_{Ed} \leq V_{Rd,\min} \)

\[ V_{Rd,\min} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b}) \]

where:

- \( V_{Rd,g} \) is the shear resistance of the gross section
- \( V_{Rd,n} \) is the shear resistance of the net section
- \( V_{Rd,b} \) is the block tearing resistance

#### 2.2.5.1 Shear resistance of gross section

\[ V_{Rd,g} = 2 \times \frac{h_p f_p}{1,27 \sqrt{3\gamma_{M0}}} \frac{f_{y,p}}{T_p} \]

[Reference 8]

Note: The coefficient 1.27 takes into account the reduction in shear resistance due to the presence of the nominal in-plane bending which produces tension in the bolts\(^9\).
2.2.5.2 Shear resistance of net section

\[
V_{Rd,n} = 2 \times A_{v,\text{net}} \frac{f_{u,p}}{\sqrt{3} \gamma_{M2}} \tag{Reference 8}
\]

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

\(\gamma_{M2}\) is the partial factor for the resistance of net sections.

2.2.5.3 Block tearing resistance

\[
V_{Rd,b} = 2 \left( \frac{f_{u,p} A_{nt}}{\gamma_{M2}} + \frac{f_{y,p} A_{nv}}{\sqrt{3} \gamma_{M0}} \right) \tag{Reference 8}
\]

But if \(h_p < 1.36 p_3\) and \(n_1 > 1\) then:

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

\[
A_{nt} = t_p \left( e_2 - 0.5 d_0 \right)
\]

\[
A_{nv} = t_p \left( h_p - e_1 - (n_1 - 0.5) d_0 \right)
\]

where:

\(p_3\) is the gauge (cross centres)

2.2.6 Weld resistance

Full strength symmetrical fillet welds are recommended.

For a full strength weld, the size of each throat should comply with the following requirement\(^8\):

\(a \geq 0.46 t_w\) for S235 supported beam

\(a \geq 0.48 t_w\) for S275 supported beam

\(a \geq 0.55 t_w\) for S355 supported beam

\(a \geq 0.74 t_w\) for S460 supported beam

where:

\(a\) is the effective weld throat thickness

The leg length is defined as follows: \(s = a \sqrt{2}\)
2.3** Checks for tying**

EN 1993-1-8 does not have a partial factor for structural integrity checks. In this publication $\gamma_{Mu}$ has been used. A value of $\gamma_{Mu} = 1,1$ is recommended.

2.3.1** Resistance of the end plate in bending**

There are three modes of failure for end plates in bending:

Mode 1: complete yielding of the flange
Mode 2: bolt failure with yielding of the flange
Mode 3: bolt failure

Basic requirement: $F_{Ed} \leq \min(F_{Rd,u,1}; F_{Rd,u,2}; F_{Rd,u,3})$

Mode 1 (complete yielding of the end plate)

$$F_{Rd,u,1} = \left(8n - 2e_w\right)\frac{M_{pl,1,Rd,u}}{2mn - e_w (m + n)}$$  \[EN 1993-1-8, Table 6.2\]

Mode 2 (bolt failure with yielding of the flange)

$$F_{Rd,u,2} = \frac{2M_{pl,2,Rd,u} + n\Sigma F_{t,Rd,u}}{m + n}$$  \[EN 1993-1-8, Table 6.2\]

Mode 3 (bolt failure)

$$F_{Rd,u,3} = \Sigma F_{t,Rd,u}$$  \[EN 1993-1-8, Table 6.2\]

$$F_{t,Rd,u} = \frac{k_2 f_{ub} A}{\gamma_{Mu}}$$

where:

$$M_{pl,1,Rd,u} = \frac{0,25\Sigma l_{eff}^2 f_{u,p}}{\gamma_{Mu}}$$

$$M_{pl,2,Rd,u} = M_{pl,1,Rd,u}$$

$$m = \frac{p_3 - t_w - 2 \times 0,8 \times a \sqrt{2}}{2}$$

$$n = e_{min} \text{ but } n \leq 1,25m \text{ where } e_{min} = e_2$$
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\[ e_w = \frac{d_w}{4} \]

\( d_w \) is the diameter of the washer

\( k_2 = 0.63 \) for countersunk bolts
\( = 0.9 \) otherwise

\( A \) is the tensile stress area of the bolts, \( A_s \)

\( \Sigma l_{\text{eff}} \) is the effective length of one plastic hinge

\[ \Sigma l_{\text{eff}} = 2e_{1A} + (n_1 - 1)p_{1A} \]

\( e_{1A} = e_1 \) but \( \leq 0.5(p_3 - t_w - 2a\sqrt{2}) + \frac{d_o}{2} \)

\( p_{1A} = p_1 \) but \( \leq p_3 - t_w - 2a\sqrt{2} + d_o \)

The leg length is defined as follows: \( s = a\sqrt{2} \)

2.3.2 Beam web resistance

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = \frac{t_w h_p f_{u,b}}{\gamma_{Mu}} \quad \text{[Reference 8]} \]

2.3.3 Weld resistance

The weld size specified for shear will be adequate for tying resistance, as it is full strength.
2. Partial depth end plate

Details and data

Beam: IPE A 550  S275
Partial depth flexible end plate: 430 × 200 × 12, S275
Bolts: M20  8.8
Welds: 8 mm fillet (weld throat, \( a = 5.6 \) mm)
### Summary of full design checks

**Design forces**

\[ V_{Ed} = 550 \text{ kN} \]
\[ F_{Ed} = 275 \text{ kN} \quad \text{(Tie force)} \]

**Shear resistances**

- Shear resistance of the beam web: 614 kN
- Bending resistance at the notch: N/A
- Local stability of notched beam: N/A
- Bolt group resistance: 902 kN
- Resistance of the end plate: 1182 kN
- Weld resistance: OK

**Tying resistances**

- Resistance of the end plate in bending: 493 kN
- Tension resistance of the beam web: 1513 kN
- Weld resistance: OK

### 2.1. Recommended details

- End plate: 200×12 mm
- Height of plate: \( h_p = 430 \text{ mm} \quad > 0.6 h_b, \quad \text{OK} \)
- Bolts: M20, 8.8 at 140 mm gauge

### 2.2. Checks for vertical shear

#### 2.2.1. Shear resistance of the beam web

Basic requirement: \( V_{Ed} \leq V_{c,Rd} \)

The shear resistance of the beam web, \( V_{c,Rd} = \frac{A v f_{y,b} / \sqrt{3}}{\gamma_{M0}} \)

Unless noted otherwise, all references are to EN 1993-1-8

EN 1993-1-1 § 6.2.6(1)
Shear area of beam web,
\[ A_v = 430 \times 9 = 3870 \text{ mm}^2 \]
Shear resistance of beam web,
\[ V_{pl,Rd} = \frac{3870 \times 275 / \sqrt{3}}{10^{-3}} \times \frac{1}{0.3} = 614 \text{ kN} \]
\[ V_{Ed} = 550 \text{ kN} \leq 614 \text{ kN}, \text{ OK} \]

2.2.2. Bending resistance at the notch
Not applicable (No notch)

2.2.3. Local stability of notched beam
Not applicable (No notch)

2.2.4. Bolt group resistance

Basic requirement: \( V_{Ed} \leq F_{Rd} \)

The design resistance of the bolt group, \( F_{Rd} \):

\[
\text{if } (F_{b,Rd})_{\text{max}} \leq V_{v,Rd} \text{ then } F_{Rd} = \Sigma F_{b,Rd} \\
\text{if } (F_{b,Rd})_{\text{min}} \leq F_{v,Rd} < (F_{b,Rd})_{\text{max}} \text{ then } F_{Rd} = n_s (F_{b,Rd})_{\text{min}} \\
\text{if } F_{v,Rd} < (F_{b,Rd})_{\text{min}} \text{ then } F_{Rd} = 0.8 n_s F_{v,Rd}
\]

2.2.4.1. Shear resistance of bolts

The shear resistance of a single bolt, \( F_{v,Rd} = \frac{\alpha_y f_{ub} A}{\gamma M_2} \)

For M20 8.8 bolts, \( F_{v,Rd} = \frac{0.6 \times 800 \times 245}{1.25} \times 10^{-3} = 94 \text{ kN} \)
2.4 Worked Example – Partial depth end plate

2.2.4.2. Bearing resistance

Bearing resistance, \( F_{b,Rd} = \frac{k_1 \alpha_b f_{u,p} d_{p}}{\gamma M_2} \)

For edge bolts, \( k_1 = \min \left( \frac{2,8 \times e_2}{d_0} \right) \)

\( = \min \left( \frac{2,8 \times 30}{22} \right) = \min(2,12; 2,5) = 2,12 \)

For end bolts, \( \alpha_b = \min \left( \frac{e_1}{3d_0}; \frac{f_{sb}}{f_{u,p}}; 1,0 \right) = \min \left( \frac{40}{3 \times 22}; \frac{800}{430}; 1,0 \right) \)

\( = \min(0,61; 1,86; 1,0) = 0,61 \)

For inner bolts, \( \alpha_b = \min \left( \frac{p_1}{3d_0}; \frac{1}{4}; \frac{f_{sb}}{f_{u,p}}; 1,0 \right) = \min \left( \frac{70}{3 \times 22}; \frac{1}{4}; \frac{800}{430}; 1,0 \right) \)

\( = \min(0,81; 1,86; 1,0) = 0,81 \)

End bolts, \( F_{b,Rd,\text{end}} = \left( F_{b,Rd} \right)_\text{min} = \frac{2,12 \times 0,61 \times 430 \times 20 \times 12}{1,25} \times 10^{-3} = 107 \text{kN} \)

Inner bolts, \( F_{b,Rd,\text{inner}} = \left( F_{b,Rd} \right)_\text{max} = \frac{2,12 \times 0,81 \times 430 \times 20 \times 12}{1,25} \times 10^{-3} = 142 \text{kN} \)

94 kN < 107 kN thus \( F_{v,Rd} < (F_{b,Rd})_{\text{min}} \)

\( F_{Rd} = 0,8n_{p} (F_{v,Rd})_{\text{min}} = 0,8 \times 12 \times 94 = 902 \text{kN} \)

\( V_{Ed} = 550 \text{kN} \leq 902 \text{kN}, \text{ OK} \)

2.2.5. Shear resistance of the end plate

Basic requirement: \( V_{Ed} \leq V_{Rd,\text{min}} \)

\( V_{Rd,\text{min}} = (V_{Rd,\text{g}}; V_{Rd,n}; V_{Rd,b}) \)

\( \theta_2 = 30 \)

\( \theta_1 = 40 \)

\( h_p \)

\( (n_1 - 1) \rho_1 = 350 \)

\( \theta_1 = 40 \)

\( V_{Ed} = 550 \text{kN} \)
2.2.5.1. Shear resistance of gross section

\[ V_{Rd,g} = \frac{2h_pt_p f_{y,p}}{1,27 \sqrt{3} \gamma_{M0}} = \frac{2 \times 430 \times 12 \times 275}{1,27 \times \sqrt{3} \times 1,0} \times 10^{-3} = 1290 \text{ kN} \]

Ref (8)

2.2.5.2. Shear resistance of net section

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

Ref (8)

Net area, \( A_{v,net} = 12(430 - 6 \times 22) = 3576 \text{ mm}^2 \)

\[ V_{Rd,n} = 2 \times 3576 \times \frac{430}{\sqrt{3} \times 1,25} \times 10^{-3} = 1420 \text{ kN} \]

2.2.5.3. Block tearing resistance

\( h_p = 430 \) and \( 1,36p_3 = 1,36 \times 140 = 190 \text{ mm} \)

Since \( h_p > 1,36p_3 \) then

\[ V_{Rd,b} = 2 \times \left( \frac{f_{u,p} A_{at}}{\gamma_{M2}} + \frac{f_{y,p} A_{nv}}{\sqrt{3} \gamma_{M0}} \right) \]

Ref (8)

Net area subject to tension, \( A_{at} = t_p (e_2 - 0,5d_0) \)

\[ = 12(30 - 0,5 \times 22) = 228 \text{ mm}^2 \]

Net area subject to shear, \( A_{nv} = t_p (h_p - e_1 - (n_1 - 0,5)d_0) \)

\[ = 12(430 - 40 - (6 - 0,5)22) = 3228 \text{ mm}^2 \]

\[ V_{Rd,b} = 2 \times \left( \frac{430 \times 228}{1,25} + \frac{275 \times 3228}{\sqrt{3} \times 1,0} \right) \times 10^{-3} = 1182 \text{ kN} \]

\[ V_{Rd,min} = \min(1290; 1420; 1182) = 1182 \text{ kN} \]

\[ V_{Ed} = 550 \text{ kN} \leq 1182 \text{ kN}, \quad \text{OK} \]

2.2.6. Weld resistance

For a beam in S275 steel

Basic requirement: \( a \geq 0,48 t_w \)

\( 0,48t_p = 0,48 \times 9 = 4,32 \text{ mm} \)

\( a = 5,7 \text{ mm} \geq 0,48 t_w \quad \text{OK} \)
2.3. Checks for tying

2.3.1. Resistance of the end plate in bending

Basic requirement: \( F_{Ed} \leq \min( F_{Rd,u,1}, F_{Rd,u,2}, F_{Rd,u,3} ) \)

Mode 1:

\[
F_{Rd,u,1} = \left( 8n - 2e_w \right) \frac{M_{pl,1,Rd,u}}{2mn - e_w(m + n)}
\]

\[
\Sigma l_{eff} = 2e_{1A} + (n_1 - 1)p_{1A}
\]

\[
e_{1A} = e_1 \text{ but } \leq 0,5 \left( p_3 - t_w - 2a\sqrt{2} \right) + \frac{d_0}{2}
\]

\[
0,5(140 - 9 - 2 \times 5,6\sqrt{2}) + \frac{22}{2} = 69 \text{ mm}
\]

\[
\therefore e_{1A} = 40
\]

\[
p_{1A} = p_1 \text{ but } \leq p_3 - t_w - 2a\sqrt{2} + d_0
\]

\[
p_3 - t_w - 2a\sqrt{2} + d_0 = 140 - 9 - 2 \times 5,6\sqrt{2} + 22 = 137 \text{ mm}
\]

\[
\therefore p_{1A} = 70
\]

\[
\Sigma l_{eff} = 2e_{1A} + (n_1 - 1)p_{1A} = 2 \times 40 + (6 - 1) 70 = 430 \text{ mm}
\]

\[
M_{pl,1,Rd,u} = \frac{0,25 \Sigma l_{eff} f_u}{\gamma_{Mu}} = \frac{0,25 \times 430 \times 12^2 \times 430}{1,1} \times 10^{-6} = 6,05 \text{ kNm}
\]

\[
m = \frac{p_3 - t_w - 2 \times 0,8 \times a\sqrt{2}}{2} = \frac{140 - 9 - 2 \times 0,8 \times 5,6 \times \sqrt{2}}{2} = 59 \text{ mm}
\]

\[
e_w = \frac{d_w}{4} = \frac{37}{4} = 9,25 \text{ mm}
\]

\[
n = \min(e_2; 1,25m) = \min(30; 76) = 30 \text{ mm}
\]
Mode 2:

\[ F_{Rd,u,1} = \frac{2 \times 30 - 2 \times 9,25 \times 10^3}{2 \times 59 - 9,25 (59 + 30)} = 493 \text{kN} \]

\[ |F_{Rd,u,2}| = |n_1 \sum F_{t,Rd,u}| = 2M_{pl,2,Rd,u} + n \sum F_{t,Rd,u} \]

\[ M_{pl,2,Rd,u} = M_{pl,1,Rd,u} = 6,05 \text{kNm} \]

\[ F_{t,Rd,u} = k_2 f_{ub} A = 0,9 \times 800 \times 245 \times 10^{-3} = 160 \text{kN} \]

\[ F_{Rd,u,2} = \frac{2 \times 6,05 \times 10^3 + 30 \times 12 \times 160}{59 + 30} = 793 \text{kN} \]

Mode 3:

\[ F_{Rd,u,3} = \sum F_{t,Rd,u} = 12 \times 160 = 1920 \text{kN} \]

\[ \min(F_{Rd,u,1}, F_{Rd,u,2}, F_{Rd,u,3}) = \min(493; 793; 1920) = 493 \text{kN} \]

\[ F_{Ed} = 275 \text{kN} \leq 493 \text{kN}, \text{ OK} \]

### 2.3.2. Beam web resistance

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = \frac{f_{ub} A}{\gamma_{Mu}} = \frac{9 \times 430 \times 430}{1,1} \times 10^{-3} = 1513 \text{kN} \]

\[ F_{Ed} = 275 \text{kN} \leq 1513 \text{kN}, \text{ OK} \]

### 2.3.3. Weld resistance

The weld size specified for shear will be adequate for tying resistance, as it is full strength.
3 FIN PLATE

3.1 Recommended details

1. End projection $g_s$
2. All end and edge distances $\geq 2d$
3. Length of fin plate $h_p \geq 0.6 h_b$
4. Bolt diameter, $d$. Only 8.8 bolts to be used, untorqued in clearance holes
5. Hole diameter, $d_0$. $d_0 = d + 2$ mm for $d \leq 24$ mm; $d_0 = d + 3$ mm for $d > 24$ mm
6. Supporting column
7. Face of web
8. Long fin plate if $z \geq \frac{t_p}{0.15}$, $t_p =$ fin plate thickness
9. Fin plate thickness $t_p \leq 0.5d$
10. Double line of bolts
11. All end and edge distances $\geq 2d$
12. Supported beam (Single notched)
13. Supported beam (Double notched)
14. $50$ mm but $\geq (t_f + r)$ and $\geq (t_{f,s} + r_s)$
15. $(h_{b,s} - 50$ mm) but $\leq (h_s - t_{f,s} - r_s)$
16. $h_b$ is the height of the supported beam
17. $h_{b,s}$ is the height of the supporting beam (if applicable)
18. $t_f$ is the thickness of the flange of the supported beam
19. $t_{f,s}$ is the thickness of the flange of the supporting beam (if applicable)
20. $r$ is the root radius of the supported beam
21. $r_s$ is the root radius of the supporting beam (if applicable)
3.2 Checks for vertical shear

3.2.1 Bolt group resistance

3.2.1.1 Shear resistance of bolts

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = \frac{n_b F_{v,Rd}}{\sqrt{(1 + \alpha n_b)^2 + (\beta n_b)^2}}
\]  
[Reference 3]

\( F_{v,Rd} \) is the shear resistance of one bolt

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

where:

\( A \) is the tensile stress area of the bolt, \( A_s \)

\( \alpha \) = 0.6 for 4.6 and 8.8 bolts
\( = 0.5 \) for 10.9 bolts

\( \gamma_{M2} \) is the partial factor for resistance of bolts

For a single vertical line of bolts \((n_2 = 1)\)

\( \alpha = 0 \) and \( \beta = \frac{6z}{n_1 (n_1 + 1) p_1} \)

For a double vertical line of bolts \((n_2 = 2)\)

\( \alpha = \frac{z p_2}{2 I} \) and \( \beta = \frac{z p_1}{2 I} (n_1 - 1) \)

\( I = \frac{n_1}{2} p_2^2 + \frac{1}{6} n_1 (n_1^2 - 1) p_1^2 \)

\( z \) is the transverse distance from the face of the supporting element to the centre of the bolt group
3.2.1.2 Bearing resistance of bolts on the fin plate

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = \frac{n_b}{\left(1 + \alpha n_b\right)^2 + \left(\frac{\beta n_b}{F_{b,ver,Rd}}\right)^2}
\]

[Reference 3]

The bearing resistance of a single bolt is \( F_{b,Rd} = \frac{k_1 \alpha_b f_{u,p} d_t p}{\gamma_{M2}} \)

The vertical bearing resistance of a single bolt on the fin plate is as follows:

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

The horizontal bearing resistance of a single bolt on the fin plate is as follows:

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

\( \alpha \) and \( \beta \) are as defined previously

For \( F_{b,ver,Rd} \):

\[
k_1 = \min\left(2.8 \frac{e_2}{d_o} - 1.7; \ 1.4 \frac{p_2}{d_o} - 1.7; \ 2.5\right)
\]

\[
\alpha_b = \min\left(\frac{e_1}{3d_o}; \ \frac{p_1}{3d_o} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,p}}; 1.0\right)
\]

For \( F_{b,hor,Rd} \):

\[
k_1 = \min\left(2.8 \frac{e_1}{d_o} - 1.7; \ 1.4 \frac{p_1}{d_o} - 1.7; \ 2.5\right)
\]

\[
\alpha_b = \min\left(\frac{e_2}{3d_o}; \ \frac{p_2}{3d_o} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,p}}; 1.0\right)
\]

3.2.1.3 Bearing resistance of bolts on the beam web

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = \frac{n_b}{\left(1 + \alpha n_b\right)^2 + \left(\frac{\beta n_b}{F_{b,ver,Rd}}\right)^2}
\]

[Reference 3]

\[
F_{b,ver,Rd} = \frac{k_1 \alpha_b f_{u,b} d_t w}{\gamma_{M2}}
\]

\[
F_{b,hor,Rd} = \frac{k_1 \alpha_b f_{u,b} d_t w}{\gamma_{M2}}
\]
\( \alpha \) and \( \beta \) are as defined previously
\[
\gamma_{M_2} \quad \text{is the partial factor for beam web in bearing}
\]
For \( F_{b,\text{ver},Rd} \):
\[
k_1 = \min\left(2.8 \frac{e_{2,b}}{d_0} - 1.7; \ 1.4 \frac{P_2}{d_0} - 1.7; \ 2.5\right)
\]
\[
\alpha_b = \min\left(\frac{e_{1,b}}{3d_0}; \ \frac{p_1}{3d_0} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,b}}; \ 1.0\right)
\]
For \( F_{b,\text{hor},Rd} \):
\[
k_1 = \min\left(2.8 \frac{e_{1,b}}{d_0} - 1.7; \ 1.4 \frac{P_1}{d_0} - 1.7; \ 2.5\right)
\]
\[
\alpha_b = \min\left(\frac{e_{2,b}}{3d_0}; \ \frac{p_2}{3d_0} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,b}}; \ 1.0\right)
\]

### 3.2.2 Shear resistance of the fin plate

![Diagram of fin plate](image)

1. Critical section in shear and bending
2. Block shear – check failure by tearing out of shaded portion

Basic requirement: \( V_{Ed} \leq V_{Rd,min} \)

\[
V_{Rd,min} = \min(V_{Rd,g}; \ V_{Rd,n}; \ V_{Rd,b})
\]

#### 3.2.2.1 Shear resistance of gross section

\[
V_{Rd,g} = \frac{h_p f_{y,p}}{1,27 \sqrt{3} \gamma_{M0}} \quad \text{[Reference 8]}
\]

Note: The coefficient 1.27 takes into account the reduction in shear resistance due to the presence of the nominal in-plane bending which produces tension in the bolts.
3.2.2.2 Shear resistance of net section

\[ V_{Rd,n} = A_{v,net} \frac{f_{u,p}}{\sqrt{3} \gamma_{M2}} \]  
[Reference 8]

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

3.2.2.3 Block tearing resistance

\[ V_{Rd,b} = 0.5 f_{u,p} A_{nt} + \frac{f_{y,p} A_{nv}}{\gamma_{M2}} \]  
[Reference 8]

where:

For a single vertical line of bolts, \( A_{nt} = t_p \left( e_2 - 0.5 d_0 \right) \)

For a double vertical line of bolts, \( A_{nt} = t_p \left( e_2 + p_2 - \frac{3}{2} d_0 \right) \)

\[ A_{nv} = t_p \left( h_p - e_1 - (n_1 - 0.5) d_0 \right) \]

\( \gamma_{M2} \) is the partial factor for the resistance of net sections

3.2.3 Bending resistance of the fin plate

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

If \( h_p \geq 2.73 \times z \) then \( V_{Rd} = \infty \)  
[Reference 8]

Otherwise \( V_{Rd} = \frac{W_{cl,p} f_{y,p}}{z} \frac{1}{\gamma_{M0}} \)

where:

\[ W_{cl,p} = t_p h_p^2 \frac{2}{6} \]
3.2.4 Buckling resistance of the fin plate

Lateral-torsional buckling of the fin plate.

Basic requirement: $V_{Ed} \leq V_{Rd}$

If $z > \frac{t_p}{0.15}$ then $V_{Rd} = \min \left( \frac{W_{cl,p} f_{p,LT}}{z} \cdot \frac{W_{sl,p} f_{y,p}}{z} \cdot \gamma M_1 \cdot \gamma M_0 \right)$

Otherwise $V_{Rd} = \frac{W_{cl,p} f_{y,p}}{z} \cdot \gamma M_0$

where:

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

$f_{p,LT}$ is the lateral torsional buckling strength of the plate obtained from BS 5950-1 Table 17[10] (See Appendix A) and based on $\lambda_{LT}$ as follows:

$\lambda_{LT} = 2.8 \left( \frac{z_p h_p}{1.5 t_p^2} \right)^{1/2}$

$z$ is the lever arm

$z_p$ is the horizontal distance from the supporting web or flange to the first vertical bolt-row

3.2.5 Shear resistance of the beam web

3.2.5.1 Shear and block tearing resistance

Basic requirement: $V_{Ed} \leq V_{Rd,\text{min}}$

$V_{Rd,\text{min}} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b})$
Shear resistance of gross section

\[ V_{Rd,g} = A_{v,wb} \frac{f_{y,b}}{\sqrt{3} \gamma_{M0}} \]  \[ \text{[Reference 8]} \]

where:

\[ A_{v,wb} = A - 2bt_f + (t_w + 2r)t_f \quad \text{but} \quad \eta h_w t_w \quad \text{for un-notched beam} \]

\[ A_{v,wb} = A_{\text{Tee}} - bt_f + (t_w + 2r)t_f/2 \quad \text{for single notched beam} \]

\[ A_{v,wb} = t_w (e_{1,b} + (n_1 -1)p_1 + h_o) \quad \text{for double notched beam} \]

\[ \eta \quad \text{is a factor from EN 1993-1-5 (it may be conservatively taken as 1.0. National Annex may give an alternative value)} \]

\[ A_{\text{Tee}} \quad \text{is the area of the Tee section} \]

\[ d_{nt} \quad \text{is the depth of the top notch} \]

\[ d_{nb} \quad \text{is the depth of the bottom notch} \]

Shear resistance of net section

\[ V_{Rd,n} = A_{v,wb,\text{net}} \frac{f_{u,b}}{\sqrt{3} \gamma_{M2}} \]  \[ \text{[Reference 8]} \]

where:

\[ A_{v,wb,\text{net}} = A_{v,wb} - n_1d_0t_w \]

Block tearing resistance

\[ V_{Rd,b} = \frac{0.5f_{u,b}A_{nt}}{\gamma_{M2}} + \frac{f_{y,b}A_{nv}}{\sqrt{3} \gamma_{M0}} \]  \[ \text{[Reference 8]} \]

where:

For a single vertical line of bolts, \( A_{nt} = t_w (e_{2,b} - 0.5d_0) \)

For a double vertical line of bolts, \( A_{nt} = t_w \left( e_{2,b} + p_2 - \frac{3}{2}d_0 \right) \)

For a notched beam \( A_{nv} = t_w \left( e_{1,b} + (n_1 -1)p_1 - (n_1 -0.5)d_0 \right) \)

For an un-notched beam \( A_{nv} = t_w \left( e_{1,b} + (n_1 -1)p_1 - (n_1 -1)d_0 \right) \)

\[ \gamma_{M2} \quad \text{is the partial factor for the resistance of net sections.} \]
3.2.5.2 Shear and bending interaction at the 2nd line of bolts, if the notch length $l_n > (e_{2,b} + p_2)$

Basic requirement: $V_{Ed} (g_h + e_{2,b} + p_2) \leq M_{c,Rd}$

$M_{c,Rd}$ is the moment resistance of the notched beam at the connection in the presence of shear.

For single notched beam

For low shear (i.e. $V_{Ed} \leq 0.5 V_{pl,N,Rd}$)

$$M_{c,Rd} = \frac{f_{y,b} W_{el,N}}{\gamma_{M0}}$$

[Reference 4]

For high shear (i.e. $V_{Ed} > 0.5 V_{pl,N,Rd}$)

$$M_{c,Rd} = \frac{f_{y,b} W_{el,N}}{\gamma_{M0}} \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,N,Rd}} - 1 \right)^2 \right]$$

[Reference 4]

$V_{pl,N,Rd} = \min(V_{Rd,g}; V_{Rd,b})$

$W_{el,N}$ is the elastic section modulus of the gross Tee section at the notch

For double notched beam

For low shear (i.e. $V_{Ed} \leq 0.5 V_{pl,DN,Rd}$)

$$M_{c,Rd} = \frac{f_{y,b} t_w}{6\gamma_{M0}} (e_1 + (n_1 - 1)p_1 + h_e)^2$$

[Reference 4]

For high shear (i.e. $V_{Ed} > 0.5 V_{pl,DN,Rd}$)

$$M_{c,Rd} = \frac{f_{y,b} t_w}{6\gamma_{M0}} \left[ e_1 + (n_1 - 1)p_1 + h_e \right] \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,DN,Rd}} - 1 \right)^2 \right]$$

[Reference 4]

$V_{pl,DN,Rd} = \min(V_{Rd,g}; V_{Rd,b})$

$h_e$ is the distance between the bottom bolt row and the bottom of the section
3.2.5.3 Shear and bending interaction for un-notched beam

For short fin plates (i.e. \( z \leq t_p/0.15 \)) the resistance of the web does not need to be checked \([4]\).

For long fin plates (i.e. \( z > t_p/0.15 \)) it is necessary to ensure that the section labelled as ABCD in the figure can resist a moment \( V_{Ed}z_p \) for a single line of bolts or \( V_{Ed}(z_p+p_2) \) for a double line of bolts (AB and CD are in shear and BC is in bending).

Basic requirement:

**For a single vertical line of bolts (\( n_2 = 1 \))**

\[
V_{Ed} z_p \leq M_{c,BC,Rd} + F_{pl,AB,Rd} (n_1 - 1) p_1
\]

[Reference 4]

**For two vertical lines of bolts (\( n_2 = 2 \))**

\[
V_{Ed} (z_p + p_2/2) \leq M_{c,BC,Rd} + F_{pl,AB,Rd} (n_1 - 1)p_1
\]

\( M_{c,BC,Rd} \) is the moment resistance of the beam web BC

For low shear (i.e. \( V_{BC,Ed} \leq 0.5F_{pl,BC,Rd} \))

\[
M_{c,BC,Rd} = f_{yb} t_w \left[\left( n_1 - 1\right)p_1 \right]^2
\]

where:

For a single vertical line of bolts (\( n_2 = 1 \)):

\[
F_{pl,AB,Rd} = \min \left(\frac{e_{2,b} t_w f_{y,b}}{\sqrt{3} \gamma_{M0}}, \frac{\left(e_{2,b} - d_0/2\right) t_w f_{u,b}}{\sqrt{3} \gamma_{M2}}\right)
\]
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\[ F_{pl,BC,Rd} = \min \left( \frac{(n_1 - 1)p_1 f_{y,b}}{\sqrt{3} \gamma_{M0}}; \frac{[(n_1 - 1)p_1 - (n_1 - 1)d_0]f_{w,u,b}}{\sqrt{3} \gamma_{M2}} \right) \]

For two vertical lines of bolts \((n_2 = 2)\):

\[ F_{pl,AB,Rd} = \min \left( \frac{(e_{2,b} + p_2)f_{w,b}}{3 \gamma_{M0}}; \frac{(e_{2,b} + p_2 - 3d_0/2)f_{w,u,b}}{3 \gamma_{M2}} \right) \]

\[ F_{pl,BC,Rd} = \min \left( \frac{(n_1 - 1)p_1 f_{y,b}}{\sqrt{3} \gamma_{M0}}; \frac{[(n_1 - 1)p_1 - (n_1 - 1)d_0]f_{w,u,b}}{\sqrt{3} \gamma_{M2}} \right) \]

\( V_{BC,Ed} \) is the shear force on the beam web BC

\[ = V_{Ed} - (V_{Rd,min} - F_{pl,BC,Rd}) \text{ but } \geq 0 \]

\( V_{Rd,min} = \min(V_{Rd,g}; V_{Rd,n}) \)

\( z \) is the transverse distance from face of supporting element to the centre of bolt group.

\( \gamma_{M2} \) is the partial factor for the resistance of net sections.

### 3.2.6 Bending resistance at the notch

1 Critical sections
2 To notch or beam flange

#### 3.2.6.1 For single bolt line or for double bolt lines, if \( x_n \geq 2d \):

\[ V_{Ed} (g_h + l_n) \leq M_{v,N,Rd} \]

[Reference 4]

\( M_{v,N,Rd} \) is the moment resistance of the beam at the notch in the presence of shear

**For single notched beam:**

For low shear (i.e. \( V_{Ed} \leq 0.5 V_{pl,N,Rd} \))

\[ M_{v,N,Rd} = \frac{f_{y,b} W_{el,N}}{\gamma_{M0}} \]
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For high shear (i.e. $V_{Ed} > 0,5 V_{pl,N,Rd}$)

$$M_{v,N,Rd} = \frac{f_y b W_{el,N}}{\gamma_{M0}} \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,N,Rd}} - 1 \right)^2 \right]$$

For double notched beam:

For low shear (i.e. $V_{Ed} \leq 0,5 V_{pl,DN,Rd}$)

$$M_{v,DN,Rd} = \frac{f_y b t_w}{6 \gamma_{M0}} \left( e_{1,b} + (n_1 - 1)p_1 + h_e \right)^2$$

For high shear (i.e. $V_{Ed} > 0,5 V_{pl,DN,Rd}$)

$$M_{v,DN,Rd} = \frac{f_y b t_w}{4 \gamma_{M0}} \left( e_{1,b} + (n_1 - 1)p_1 + h_e \right)^2 \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,DN,Rd}} - 1 \right)^2 \right]$$

3.2.6.2 For double bolt lines, if $x_N < 2d$:

$$\max (V_{Ed} (g_h + l_n); V_{Ed} (g_h + e_{2,b} + p_2)) \leq M_{v,N,Rd}$$

$M_{v,N,Rd} = M_{c,Rd}$ from the previous check

where:

- $W_{el,N}$ is the elastic section modulus of the gross tee section at the notch
- $V_{pl,N,Rd}$ is the shear resistance at the notch for single notched beams
  $$= \frac{A_{v,N} f_y b}{\sqrt{3} \gamma_{M0}}$$
- $A_{v,N} = A_{Tee} - b f_t + (t_w + 2r) \frac{t_f}{2}$
- $V_{pl,DN,Rd}$ is the shear resistance at the notch for double notched beams
  $$= \frac{A_{v,DN} f_y b}{\sqrt{3} \gamma_{M0}}$$
- $A_{v,DN} = t_w (e_{1,b} + (n_1 - 1)p_1 + h_e)$
- $h_e$ is the distance between the bottom bolt row and the bottom of the section
- $A_{Tee}$ is the area of the Tee section
3.2.7 Local stability of the notched beam

When the beam is restrained against lateral torsional buckling, no account need be taken of notch stability provided the following conditions are met:

**For one flange notched, basic requirement:**\(^{[5],[6]}\)

\[
\begin{align*}
  d_{nt} &\leq \frac{h_b}{2} \quad \text{and:} \\
  l_n &\leq h_b & &\text{for } \frac{h_b}{t_w} \leq 54.3 \quad \text{(S275 steel)} \\
  l_n &\leq \frac{160000 h_b}{(h_b / t_w)^3} & &\text{for } \frac{h_b}{t_w} > 54.3 \quad \text{(S275 steel)} \\
  l_n &\leq h_b & &\text{for } \frac{h_b}{t_w} \leq 48.0 \quad \text{(S355 steel)} \\
  l_n &\leq \frac{110000 h_b}{(h_b / t_w)^3} & &\text{for } \frac{h_b}{t_w} > 48.0 \quad \text{(S355 steel)}
\end{align*}
\]

**For both flanges notched, basic requirement:**\(^{[7]}\)

\[
\begin{align*}
  \max (d_{nt}, d_{nb}) &\leq \frac{h_b}{5} \quad \text{and:} \\
  l_n &\leq h_b & &\text{for } \frac{h_b}{t_w} \leq 54.3 \quad \text{(S275 steel)} \\
  l_n &\leq \frac{160000 h_b}{(h_b / t_w)^3} & &\text{for } \frac{h_b}{t_w} > 54.3 \quad \text{(S275 steel)} \\
  l_n &\leq h_b & &\text{for } \frac{h_b}{t_w} \leq 48.0 \quad \text{(S355 steel)} \\
  l_n &\leq \frac{110000 h_b}{(h_b / t_w)^3} & &\text{for } \frac{h_b}{t_w} > 48.0 \quad \text{(S355 steel)}
\end{align*}
\]

Where the notch length \(l_n\) exceeds these limits, either suitable stiffening should be provided or the notch should be checked to References 5, 6 and 7. For S235 and S460 members see References 5, 6 and 7.
3.2.8 **Weld resistance**

Full strength symmetrical fillet welds are recommended.

For a full strength weld, the size of each throat should comply with the following requirement:

\[
a \geq \begin{cases} 
0.46t_p & \text{for S235 fin plate} \\
0.48t_p & \text{for S275 fin plate} \\
0.55t_p & \text{for S355 fin plate} \\
0.75t_p & \text{for S460 fin plate}
\end{cases}
\]

where:

- \( a \) is the weld throat thickness

The leg length is defined as follows: \( s = a \sqrt{2} \)

3.3 **Checks for tying**

EN 1993-1-8 does not have a partial factor for structural integrity checks. In this publication \( \gamma_{Mu} \) has been used. A value of \( \gamma_{Mu} = 1.1 \) is recommended.

3.3.1 **Fin plate and bolt group resistance**

3.3.1.1 **Shear resistance of bolts**

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[
F_{Rd} = n_b F_{v,u} \\
F_{v,u} = \alpha_v f_{ub} A / \gamma_{Mu}
\]

[Reference 8]
where:

\[ \alpha_v = 0.6 \text{ for 4.6 and 8.8 bolts} \]
\[ = 0.5 \text{ for 10.9 bolts} \]

\[ A \] is the tensile stress area of bolt, \( A_s \)

### 3.3.1.2 Bearing resistance of bolts on the fin plate

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = n_b F_{b,\text{hor,u,Rd}} \]

\[ F_{b,\text{hor,u,Rd}} = \frac{k_1 \alpha_b f_{u,p} d_t p}{\gamma_{Mu}} \]

[Reference 8]

where:

\[ k_1 = \min \left( 2.8 \frac{e_1}{d_0} - 1.7; \ 1.4 \frac{p_1}{d_0} - 1.7; \ 2.5 \right) \]

\[ \alpha_b = \min \left( \frac{e_2}{3d_0}; \ \frac{p_2}{3d_0} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,p}}; \ 1.0 \right) \]

### 3.3.1.3 Tension resistance of the fin plate

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = \min(F_{Rd,n}; F_{Rd,b}) \]

**Tension resistance of net section**

\[ F_{Rd,n} = 0.9 A_{\text{net}} \frac{f_{u,p}}{\gamma_{Mu}} \]

[Reference 8]

\[ A_{\text{net}} = t_p \left( h_p - d_0 n_1 \right) \]
**Block tearing resistance**

$$F_{Rd,b} = \frac{f_{u,p} A_{nt}}{\gamma_{Mu}} + \frac{f_{y,p} A_{nv}}{\sqrt{3} \gamma_{M0}}$$  [Reference 8]

Case 1:

$$A_{nt} = t_p \left( (n_1 - 1) p_1 - (n_1 - 1) d_0 \right)$$

For a single vertical line of bolts:  $$A_{nv} = 2 t_p \left( e_2 - 0.5 d_0 \right)$$

For a double vertical line of bolts:  $$A_{nv} = 2 t_p \left( e_2 + p_2 - \frac{3}{2} d_0 \right)$$

Case 2:

$$A_{nt} = t_p \left( e_1 + (n_1 - 1) p_1 - (n_1 - 0.5) d_0 \right)$$

For a single vertical line of bolts,  $$A_{nv} = t_p \left( e_2 - 0.5 d_0 \right)$$

For a double vertical line of bolts,  $$A_{nv} = t_p \left( e_2 + p_2 - \frac{3}{2} d_0 \right)$$

1. beam without notch
2. notched beam
3. fin plate
### 3.3.2 Beam web resistance

#### 3.3.2.1 Bearing resistance of bolts on the beam web

**Basic requirement:** $F_{Ed} \leq F_{Rd}$

$$F_{Rd} = n_b F_{b,\text{hor},u,Rd}$$

$$F_{b,\text{hor},u,Rd} = \frac{k_1 \alpha_b f_{u,b} d_w}{\gamma_{Mu}}$$

where:

$$k_1 = \begin{pmatrix} 2.8 \frac{e_{1,b}}{d_0} - 1.7; \frac{p_1}{d_0} - 1.7; 2.5 \end{pmatrix}$$

$$\alpha_b = \begin{pmatrix} 2 \frac{e_{2,b}}{3d_0}; \frac{p_2}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{u,b}}; 1.0 \end{pmatrix}$$

- $\alpha_v$ = 0.6 for 4.6 and 8.8 bolts
- = 0.5 for 10.9 bolts

#### 3.3.2.2 Tension resistance of the beam web

**Basic requirement:** $F_{Ed} \leq F_{Rd}$

$$F_{Rd} = \min(F_{Rd,n}; F_{Rd,b})$$
**Tension resistance of net section**

\[
F_{Rd,n} = 0.9 \frac{A_{net,wb} f_{u,b}}{\gamma_{Mu}}
\]

\[
A_{net} = t_w h_{wb} - d_0 n_1 t_w
\]

\(h_{wb}\) may be taken as the depth of the fin plate (it is conservative)

**Block tearing resistance**

\[
F_{Rd,b} = \frac{f_{u,b} A_{nt} + f_{y,b} A_{nv} / \sqrt{3}}{\gamma_{Mu} \gamma_{M0}}
\]

**Case 1:**

\[
A_{nt} = t_w \left((n_1 - 1)p_1 - (n_1 - 1)d_0\right)
\]

For a single vertical line of bolts, \(A_{nv} = 2t_w \left(e_{2,b} - 0.5d_0\right)\)

For a double vertical line of bolts, \(A_{nv} = 2t_w \left(e_{2,b} + p_2 - \frac{3}{2}d_0\right)\)

**Case 2** (for notched beam only):

\[
A_{nt} = t_w \left(e_{1,b} + (n_1 - 1)p_1 - (n_1 - 0.5)d_0\right)
\]

For a single vertical line of bolts, \(A_{nv} = t_w \left(e_{2,b} - 0.5d_0\right)\)

For a double vertical line of bolts, \(A_{nv} = t_w \left(e_{2,b} + p_2 - \frac{3}{2}d_0\right)\)

**3.3.3 Weld resistance**

The weld size specified for shear will be adequate for tying resistance, as it is full strength.
3. Fin plate

Details and data

Beam: IPE A 550  S275
Fin plate: 360 × 160 × 10 S275
Bolts: M20  8.8
Welds: 8 mm fillet (weld throat, a = 5.6 mm)
### Summary of full design checks

#### Design forces

- $V_{Ed} = 350\, \text{kN}$
- $F_{Ed} = 350\, \text{kN}$ (Tie force)

#### Shear resistances

- Bolt group resistance
  - Shear resistance of bolts: $584\, \text{kN}$
  - Bearing resistance of bolts on the fin plate: $605\, \text{kN}$
  - Bearing resistance of bolts on the beam web: $624\, \text{kN}$

- Shear resistance of the fin plate: $450\, \text{kN}$
- Bending resistance of the fin plate: $\infty$
- Buckling resistance of the fin plate: $743\, \text{kN}$

- Shear resistance of the beam web
  - Shear and block tearing resistance: $545\, \text{kN}$
  - Shear and bending interaction at the 2\textsuperscript{nd} line of bolts: N/A
  - Shear and bending interaction for un-notched beam: $66\, \text{kNm}$

- Bending resistance at the notch: N/A
- Local stability of the notched beam: N/A
- Weld resistance: OK

#### Tying resistances

- Fin plate and bolt group resistance
  - Shear resistance of bolts: $1070\, \text{kN}$
  - Bearing resistance of bolts on the fin plate: $1290\, \text{kN}$
  - Tension resistance of the fin plate: $880\, \text{kN}$

- Beam web resistance
  - Bearing resistance of bolts on the beam web: $1070\, \text{kN}$
  - Tension resistance of the beam web: $792\, \text{kN}$

- Weld resistance: OK
3.1. Recommended details

Fin plate thickness: \( t_p = 10\text{mm} \leq 0,5d \)
Height of fin plate: \( h_p = 360\text{mm} > 0,6h_b \)

Unless noted otherwise, all references are to EN 1993-1-8

3.2. Checks for vertical shear

3.2.1. Bolt group resistance

3.2.1.1. Shear resistance of bolts

Basic requirement: \( V_{\text{ed}} \leq V_{\text{Rd}} \)

\[
V_{\text{Rd}} = \frac{n_b F_{v,\text{Rd}}}{\sqrt{(1 + \alpha n_b)^2 + (\beta n_b)^2}}
\]

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

For M20 8.8 bolts, \( F_{v,\text{Rd}} = \frac{0.6 \times 800 \times 245}{125} \times 10^{-3} = 94\text{ kN} \)

For a double vertical line of bolts (i.e. \( n_2 = 2 \) and \( n_1 = 5 \)),

\[
\alpha = \frac{zp_2}{2I}
\]

\[
I = \frac{n_1}{2} p_2^2 + \frac{1}{6} n_1 (n_1^2 - 1) p_1^2 = \frac{5}{2} 60^2 + \frac{1}{6} 5(5^2 - 1)70^2 = 107000\text{ mm}^2
\]

\[
\alpha = \frac{80 \times 60}{2 \times 107000} = 0,022
\]

And \( \beta = \frac{zp_1}{2I} (n_1 - 1) = \frac{80 \times 70}{2 \times 107000} (5 - 1) = 0,105 \)

Thus \( V_{\text{Rd}} = \frac{10 \times 94}{\sqrt{(1 + 0,022 \times 10)^2 + (0,105 \times 10)^2}} = 584\text{ kN} \)
3.2.1.2. Bearing resistance of bolts on the fin plate

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = \frac{n_b}{\sqrt{\left( \frac{1 + a n_b}{F_{b,ver,Rd}} \right)^2 + \left( \frac{\beta n_b}{F_{b,hor,Rd}} \right)^2}}
\]

\( \alpha = 0,022 \) and \( \beta = 0,105 \), as above

The vertical bearing resistance of a single bolt, \( F_{b,ver,Rd} = \frac{k_1 \alpha_b f_{u,p} d_t p}{\gamma_{M2}} \)

\[
k_1 = \min \left( 2,8 \frac{e_1}{d_0} - 1,7; 1,4 \frac{p_1}{d_0} - 1,7; 2,5 \right)
\]

\[
= \min \left( 2,8 \frac{50}{22} - 1,7; 1,4 \frac{60}{22} - 1,7; 2,5 \right) = \min(4,67; 2,12; 2,5) = 2,12
\]

\[
\alpha_b = \min \left( \frac{e_1}{3d_0}; \frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{ab}}{f_{u,p}}; 1,0 \right) = \min \left( \frac{40}{3 \times 22}; \frac{70}{3 \times 22} - \frac{1}{4}; \frac{800}{430}; 1,0 \right)
\]

\[
= \min(0,61; 0,81; 1,86; 1,0) = 0,61
\]

\[
F_{b,ver,Rd} = \frac{2,12 \times 0,61 \times 430 \times 20 \times 10}{1,25} \times 10^{-3} = 89 \text{ kN}
\]

The horizontal bearing resistance of a single bolt, \( F_{b,hor,Rd} = \frac{k_1 \alpha_b f_{u,p} d_t p}{\gamma_{M2}} \)

\[
k_1 = \min \left( 2,8 \frac{e_1}{d_0} - 1,7; 1,4 \frac{p_1}{d_0} - 1,7; 2,5 \right)
\]

\[
= \min \left( 2,8 \frac{40}{22} - 1,7; 1,4 \frac{70}{22} - 1,7; 2,5 \right) = \min(3,39; 2,75; 2,5) = 2,5
\]

\[
\alpha_b = \min \left( \frac{e_2}{3d_0}; \frac{p_2}{3d_0} - 0,25; \frac{f_{ab}}{f_{u,p}}; 1,0 \right)
\]

\[
= \min \left( \frac{50}{3 \times 22}; \frac{60}{3 \times 22} - 0,25; \frac{800}{430}; 1,0 \right) = \min(0,75; 0,66; 1,0) = 0,66
\]

\[
F_{b,hor,Rd} = \frac{2,5 \times 0,66 \times 430 \times 20 \times 10}{1,25} \times 10^{-3} = 114 \text{ kN}
\]

\[
V_{Rd} = \frac{10}{\sqrt{\left( \frac{1 + 0,022 \times 10}{89} \right)^2 + \left( \frac{0,105 \times 10}{114} \right)^2}} = 605 \text{ kN}
\]
$V_{Ed} = 350 \text{kN} \leq 605 \text{kN}, \quad \text{OK}$

### 3.2.1.3. Bearing resistance of bolts on the beam web

Basic requirement: $V_{Ed} \leq V_{Rd}$

$$V_{Rd} = \frac{n_b}{\left( 1 + \alpha n_b \right)^2 + \left( \beta n_b \right)^2}$$

$\alpha = 0.022$ and $\beta = 0.105$, as above

The vertical bearing resistance for a single bolt, $F_{b,ver,Rd} = \frac{k_1 \alpha_b f_{u,b} dt_w}{\gamma M_2}$

- $k_1 = \min \left( 2.8 \frac{e_2}{d_0} - 1.7; 1.4 \frac{P_2}{d_0} - 1.7; 2.5 \right)$
  
  $$= \min \left( 2.8 \frac{40}{22} - 1.7; 1.4 \frac{60}{22} - 1.7; 2.5 \right) = \min(3.39; 2.12; 2.5) = 2.12$$

- $\alpha_b = \min \left( \frac{P_b}{3d_0} - \frac{1}{4} \frac{f_{ub}}{f_{u,b}}; 1.0 \right) = \min \left( \frac{70}{3 \times 22} - \frac{1}{4} \frac{800}{430}; 1.0 \right)$
  
  $$= \min(0.81; 1.86; 1.0) = 0.81$$

- $F_{b,ver,Rd} = \frac{2.12 \times 0.81 \times 430 \times 20 \times 9}{1.25} \times 10^{-3} = 106 \text{kN}$

The horizontal bearing resistance for a single bolt, $F_{b,hor,Rd} = \frac{k_1 \alpha_b f_{u,b} dt_w}{\gamma M_2}$

- $k_1 = \min \left( 1.4 \frac{P_b}{d_0} - 1.7; 2.5 \right) = \min \left( 1.4 \frac{70}{22} - 1.7; 2.5 \right)$
  
  $$= \min(2.75; 2.5) = 2.5$$

- $\alpha_b = \min \left( \frac{e_{2,b}}{3d_0} \frac{P_2}{3d_0} - \frac{1}{4} \frac{f_{ub}}{f_{u,b}}; 1.0 \right) = \min \left( \frac{40}{3 \times 22} - \frac{1}{4} \frac{60}{430}; 1.0 \right)$
  
  $$= \min(0.61; 0.81; 1.86; 1.0) = 0.61$$

- $F_{b,hor,Rd} = \frac{2.5 \times 0.61 \times 430 \times 20 \times 9}{1.25} \times 10^{-3} = 94 \text{kN}$

$$V_{Rd} = \sqrt{\frac{10}{\left( \frac{106}{106} \right)^2 + \left( \frac{0.105 \times 10}{94} \right)^2}} = 624 \text{kN}$$

$V_{Ed} = 350 \text{kN} \leq 624 \text{kN}, \quad \text{OK}$
### 3.2.2. Shear resistance of the fin plate

![Diagram of fin plate]

Basic requirement: $V_{Ed} \leq V_{Rd,min}$

$V_{Rd,min} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b})$

#### 3.2.2.1. Shear resistance of gross section

$$V_{Rd,g} = \frac{h_p t_p f_{y,p}}{1,27 \sqrt{3} \gamma_{M0}} = \frac{360 \times 10 \times 275}{1,27 \times 3 \times 1,0} = 450 \text{ kN}$$

Ref (8)

#### 3.2.2.2. Shear resistance of net section

$$V_{Rd,n} = A_{v,net} \frac{f_{u,p}}{\sqrt{3} \gamma_{M2}}$$

Net area, $A_{v,net} = t_p \left( h_p - n d_0 \right) = 10 \left( 360 - 5 \times 22 \right) = 2500 \text{ mm}^2$

$$V_{Rd} = 2500 \times \frac{430}{\sqrt{3} \times 1,25} \times 10^{-3} = 497 \text{ kN}$$

Ref [8]

#### 3.2.2.3. Block tearing resistance

$$V_{Rd,b} = \left( \frac{0,5 f_{u,p} A_{nt}}{\gamma_{M2}} + \frac{f_{y,p} A_{nv}}{\sqrt{3} \gamma_{M0}} \right) \times 10^{-3}$$

Net area subject to tension, $A_{nt} = t_p \left( p_2 + e_2 - 1,5 d_0 \right)$

$$= 10 \left( 60 + 50 - 1,5 \times 22 \right) = 770 \text{ mm}^2$$

Net area subject to shear, $A_{nt} = t_p \left( h_p - e_1 - (n_1 - 0,5) d_0 \right)$

$$= 10 \left( 360 - 40 - (5 - 0,5)22 \right) = 2210 \text{ mm}^2$$

$$V_{Rd,b} = \frac{0,5 \times 430 \times 770}{1,25} + \frac{275 \times 2210}{\sqrt{3} \times 1,0} = 483 \text{ kN}$$

$$V_{Rd,min} = \min(450; 497; 483) = 450 \text{ kN}$$

$V_{Ed} = 350 \text{ kN} \leq 450 \text{ kN}$, OK
3.2.3. Bending resistance of the fin plate

Basic requirement: $V_{Ed} \leq V_{Rd}$

$2,73 \times z = 2,73 \times 80 = 218$ mm

$h_p = 360$ mm $> 218$ mm

Then $V_{Rd} = \infty$

$V_{Ed} \leq V_{Rd}$, OK

3.2.4. Buckling resistance of the fin plate

Basic requirement: $V_{Ed} \leq V_{Rd}$

$t_p/0,15 = \frac{10}{0,15} = 67$ mm

$z = 80$ mm $> 67$ mm

$V_{Rd} = \min \left( \frac{W_{el,p}}{z}, \frac{f_{p,LT} W_{el,p}}{0,6 \gamma_{M1}}, \frac{W_{el,p} f_{y,p}}{z \gamma_{M0}} \right)$

$W_{el,p} = \frac{t_p h_p^2}{6} = \frac{10 \times 360^2}{6} = 216000$ mm$^3$

$z_p = 80$ mm

$\lambda_{LT} = 2,8 \left( \frac{z_p h_p}{1,5 t_p^2} \right)^{1/2} = 2,8 \left( \frac{50 \times 360}{1,5 \times 10^2} \right)^{1/2} = 31$

$f_{p,LT}$ is obtained by interpolation from Appendix A.

$f_{p,LT} = 274$ N/mm$^2$

$V_{Rd} = \min \left( \frac{216000}{80}, \frac{274}{0,6 \times 1,0} \times 10^{-3}; \frac{216000}{80} \times 275 \times 10^{-3} \right)$

$= \min (1233; 743) = 743$ kN

$V_{Ed} = 350$ kN $\leq 743$ kN, OK

3.2.5. Shear resistance of the beam web

3.2.5.1. Shear and block tearing resistance

Basic requirement: $V_{Ed} \leq V_{Rd,\text{min}}$

$V_{Rd,\text{min}} = \min (V_{Rd,g}; V_{Rd,n}; V_{Rd,b})$
Shear resistance of gross section

\[ V_{Rd,g} = A_{v,wb} \frac{f_{y,b}}{\sqrt{3} \gamma_{M0}} \]

Shear area of beam web,

\[ A_{v,wb} = A - 2ht_f + (t_w + 2r)t_f \]
\[ = 11700 - 2 \times 210 \times 15.7 + (9 + 2 \times 24)15.7 = 6001 \text{ mm}^2 \]

\[ \eta h_w t_w = 1.0 \times 515.6 \times 9 = 4640 \text{ mm}^2 \]

\[ V_{Rd,g} = \frac{6001 \times 275}{\sqrt{3} \times 1,0} \times 10^{-3} = 953 \text{ kN} \]

Shear resistance of net section

\[ V_{Rd,n} = A_{v,wb,net} \frac{f_{u,b}}{\sqrt{3} \gamma_{M2}} \]

Net area, \( A_{v,wb,net} = A - n_1 d_0 t_w = 6001 - 5 \times 22 \times 9 = 5011 \text{ mm}^2 \)

\[ V_{Rd,n} = 5011 \times \frac{430}{\sqrt{3} \times 1.25} \times 10^{-3} = 995 \text{ kN} \]

Block tearing resistance

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

Net area subject to tension, \( A_{nt} = t_b (p_2 + e_{2,b} - 1.5d_0) \)
\[ = 9(60 + 40 - 1.5 \times 22) = 603 \text{ mm}^2 \]

Net area subject to shear, \( A_{nv} = t_b (e_{1,b} + (n_1 - 1)p_1 - (n_1 - 0.5)d_0) \)
\[ = 9(90 + (5 - 1)70 - (5 - 1)22) = 2538 \text{ mm}^2 \]

\[ V_{Rd,b} = \left( \frac{0.5 \times 430 \times 603}{1.25} + \frac{275 \times 2538}{\sqrt{3} \times 1.0} \right) \times 10^{-3} = 507 \text{ kN} \]

\[ V_{Rd,min} = \min(953; 995; 507) = 507 \text{ kN} \]
\[ V_{Ed} = 350 \text{ kN} \leq 507 \text{ kN}, \quad \text{OK} \]
### 3.2.5.2. Shear and bending interaction at the 2\textsuperscript{nd} line of bolts

Not applicable

### 3.2.5.3. Shear and bending interaction of un-notched beam

Shear and bending interaction at the beam web

\[
\frac{t_p}{t_{0,15}} = \frac{10}{0,15} = 67 \text{ mm}
\]

\[z = 80 \text{ mm} > 67 \text{ mm}\]

Therefore this check is required.

**Basic requirement:**

\[V_{BC,Ed} (z + \frac{p_2}{2}) \leq M_{c,BC,Rd} + F_{pl,AB,Rd} (n_1 - 1) p_1\]

\[F_{pl,BC,Rd} = \min\left(\frac{(n_1 - 1)p_1 t_{w,y,b}}{\sqrt{3} \gamma_{M0}}, \frac{\left[(n_1 - 1)p_1 - (n_1 - 1)t_f, w_{u,b}\right]}{\sqrt{3} \gamma_{M2}}\right)\]

\[F_{pl,BC,Rd} = \min\left(\frac{(5 - 1)70 \times 9 \times 275}{\sqrt{3} \times 1,0} \times 10^{-3}, \frac{(5 - 1)70 - (5 - 1)22}{\sqrt{3} \times 1,25} \times 10^{-3}\right)\]

\[= \min(400; 343) = 343 \text{ kN}\]

\[V_{BC,Ed} \text{ is the shear force on the beam web BC}\]

\[V_{BC,Ed} = V_{Ed} - (V_{Rd,\min} - F_{pl,BC,Rd}) \text{ but } \geq 0\]

\[V_{BC,Ed} = 350 - (953 - 343) = -260 \text{ kN}\]

Therefore \(V_{BC,Ed} = 0 \text{ kN}\)

As \(V_{BC,Ed} \leq 0.5F_{pl,BC,Rd}\) then \(M_{c,BC,Rd} = \frac{f_{y,b} t_{w,y}}{6 \gamma_{M0}} \left[(n_1 - 1)p_1\right]^2\)

\[M_{c,BC,Rd} = \frac{275 \times 9}{6 \times 1,0} \left[(5 - 1)70\right]^2 \times 10^{-6} = 32 \text{ kNm}\]

\[F_{pl,AB,Rd} = \min\left(\frac{(e_{2,b} + p_2) t_{w,y,b}}{\sqrt{3} \gamma_{M0}}, \frac{(e_{2,b} + p_2 - 3d_0/2)t_{w,y,u,b}}{\sqrt{3} \gamma_{M2}}\right)\]

\[= \min\left(\frac{(40 + 60)9 \times 275}{\sqrt{3} \times 1,0} \times 10^{-3}, \frac{(40 + 60 - 3 \times 22/2)9 \times 430}{\sqrt{3} \times 1,25} \times 10^{-3}\right)\]

\[= \min(143; 120) = 120 \text{ kN}\]

\[M_{c,BC,Rd} + F_{pl,AB,Rd} (n_1 - 1) p_1 = 32 + 120(5 - 1)70 \times 10^{-3} = 66 \text{ kNm}\]

\[V_{Ed} (z + \frac{p_2}{2}) = 350(80 + 60/2) \times 10^{-3} = 38 \text{ kNm}\]

Therefore \(V_{Ed} (z + \frac{p_2}{2}) \leq M_{c,BC,Rd} + F_{pl,AB,Rd} (n_1 - 1) p_1 \quad \text{OK}\)
### 3.2.6. Bending resistance at the notch
Not applicable

### 3.2.7. Local stability of the notched beam
Not applicable

### 3.2.8. Weld resistance
For a fin plate in S275 steel

Basic requirement: \( a \geq 0.48t_p \)

\[
0.48t_p = 0.48 \times 10 = 4.8 \text{ mm}
\]

\[
a = 5.7 \text{ mm} \geq 0.48t_p \quad \text{OK}
\]

### 3.3. Checks for tying

#### 3.3.1. Fin plate and bolt group resistance

![Diagram of fin plate and bolts]

- \( e_1 = 40 \)
- \( \rho_1 = 70 \)
- \( \rho_2 = 70 \)
- \( \rho_3 = 70 \)
- \( \rho_4 = 70 \)
- \( e_2 = 50 \)
- \( p_2 = 60 \)
- \( h_b \)
- \( F_{Ed} = 350 \text{ kN} \)

#### 3.3.1.1. Shear resistance of bolts

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[
F_{Rd} = m_b F_{v,u}
\]

\[
F_{v,u} = \alpha_f \frac{f_{ub} A}{\gamma_{Mu}} = \frac{0.6 \times 800 \times 245}{1,1} \times 10^{-3} = 107 \text{ kN}
\]

\[
F_{Rd} = 10 \times 107 = 1070 \text{ kN}
\]

\[
F_{Ed} = 350 \text{ kN} \leq 1070 \text{ kN} \quad \text{OK}
\]

#### 3.3.1.2. Bearing resistance of bolts on the fin plate

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[
F_{Rd} = m_b F_{b,hor,u,Rd}
\]

\[
F_{b,hor,u,Rd} = \frac{k_1 \alpha_p f_{u,p} dt_p}{\gamma_{Mu}}
\]
\[ k_1 = \min \left( 2.8 \frac{e_1}{d_0} - 1.7; 1.4 \frac{P_1}{d_0} - 1.7; 2.5 \right) \]
\[ = \min \left( 2.8 \frac{40}{22} - 1.7; 1.4 \frac{70}{22} - 1.7; 2.5 \right) = \min (3.39; 2.75; 2.5) = 2.5 \]
\[ \alpha_b = \min \left( \frac{e_2}{3d_0}; \frac{p_2}{3d_0} - \frac{1}{4}; \frac{f_{ub}}{f_{up}}; 1.0 \right) = \min \left( \frac{50}{3 \times 22}; \frac{60}{3 \times 22} - \frac{1}{4}; \frac{800}{430}; 1.0 \right) = 0.66 \]
\[ F_{b,\text{hor},u,Rd} = 2.5 \times 0.66 \times 430 \times 20 \times 10 \times 10^{-3} = 129 \text{ kN} \]
\[ F_{\text{Rd}} = 10 \times 129 = 1290 \text{ kN} \]
\[ F_{\text{Ed}} = 350 \text{ kN} \leq 1290 \text{ kN}, \text{ OK} \]

### 3.3.1.3. Tension resistance of the fin plate

**Basic requirement:** \( F_{\text{Ed}} \leq F_{\text{Rd}} \)

\[ F_{\text{Rd}} = \min \left( F_{\text{Rd,b}} ; F_{\text{Rd,n}} \right) \]

#### Tension resistance of net section

\[ F_{\text{Rd,n}} = 0.9 A_{\text{net}} \frac{f_{up}}{\gamma_{Mu}} \]
\[ A_{\text{net}} = t_p (h_p - d_0 n_1) = 10 \left( 360 - 22 \times 5 \right) = 2500 \text{ mm}^2 \]
\[ F_{\text{Rd,n}} = 0.9 \times 2500 \times 430 \frac{1}{1,1} \times 10^{-3} = 880 \text{ kN} \]

#### Block tearing resistance

**Case 1**

\[ F_{\text{Rd,b}} = \frac{f_{up} A_{\text{nt}}}{\gamma_{Mu}} + \frac{f_{yp} A_{\text{nv}}}{\sqrt{3} \gamma_{M0}} \]
\[ A_{\text{nt}} = t_p \left[ (n_1 - 1) p_1 - (n_1 - 1) d_0 \right] = 10 [(5 - 1) \times 70 - (5 - 1) 22] = 1920 \text{ mm}^2 \]
\[ A_{\text{nv}} = 2 t_p \left( e_2 + p_2 - \frac{3}{2} d_0 \right) = 2 \times 10 \left( 50 + 60 - \frac{3}{2} \times 22 \right) = 1540 \text{ mm}^2 \]
\[ F_{\text{Rd,b}} = \left( \frac{430 \times 1920}{1,1} + \frac{275 \times 1540}{\sqrt{3} \times 1,0} \right) \times 10^{-3} = 995 \text{ kN} \]

**Case 2**

\[ A_{\text{nt}} = t_p (e_1 + (n_1 - 1) p_1 - (n_1 - 0.5) d_0) \]
\[ A_{\text{nt}} = 10 (40 + (5 - 1) \times 70 - (5 - 0.5) \times 22) = 2210 \text{ mm}^2 \]
\[ A_{av} = t_p \left( e_2 + p_2 - \frac{3}{2} d_0 \right) = 10 \left( 50 + 60 - \frac{3}{2} \times 22 \right) = 770 \text{ mm}^2 \]

\[ F_{Rd,b} = \left( \frac{430 \times 2210}{1.1} + \frac{275 \times 770}{\sqrt{3} \times 1.0} \right) \times 10^{-3} = 986 \text{ kN} \]

\[ F_{Rd} = \min(880; 995; 986) = 880 \text{ kN} \]

\[ F_{Ed} = 350 \text{ kN} \leq 880 \text{ kN}, \quad \text{OK} \]

### 3.3.2. Beam web resistance

#### 3.3.2.1. Bearing resistance of bolts on the beam web

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = m_b F_{b,hor,u,Rd} \]

\[ F_{b,hor,u,Rd} = \frac{k_1 \alpha_b f_{u,b} \delta_w}{\gamma_{Mu}} \]

\[ k_1 = \min \left( 2.8 \frac{e_{1,b}}{d_0}; 1.4 \frac{p_1}{d_0}; 1.7; 2.5 \right) \]

\[ = \min \left( 2.8 \frac{90}{22}; 1.4 \frac{70}{22}; 1.7; 2.5 \right) = \min(9.8; 2.75; 2.5) = 2.5 \]

\[ \alpha_b = \min \left( \frac{e_{2,b}}{3d_0}; \frac{p_2}{3d_0}; \frac{1}{f_{u,b}} \right) = \min \left( \frac{40}{3 \times 22}; \frac{60}{3 \times 22}; \frac{1}{4}; \frac{800}{430}; 1.0 \right) \]

\[ = \min(0.61; 0.66; 1.86; 1.0) = 0.61 \]

\[ F_{b,hor,u,Rd} = 2.5 \times 0.61 \times 430 \times 20 \times 9 \times 10^{-3} = 107 \text{ kN} \]

\[ F_{Rd} = 10 \times 107 = 1070 \text{ kN} \]

\[ F_{Ed} = 350 \text{ kN} \leq 1070 \text{ kN} \quad \text{OK} \]
### 3.3.2.2. Tension resistance of the beam web

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[
F_{Rd} = \min\left( F_{Rd,b} ; F_{Rd,n} \right)
\]

**Tension resistance of net section**

\[
F_{Rd,n} = 0.9 A_{\text{net,wb}} \frac{f_{u,b}}{\gamma_{Mu}}
\]

\[
A_{\text{net,wb}} = t_w h_{wb} - d_0 n_1 t_w = 9 \times 360 - 22 \times 5 \times 9 = 2250 \text{ mm}^2
\]

\[
F_{Rd,n} = 0.9 \times 2250 \times \frac{430}{1,1} \times 10^{-3} = 792 \text{ kN}
\]

**Block tearing resistance**

\[
F_{Rd,b} = \frac{f_{u,b} A_{nt}}{\gamma_{Mu}} + \frac{f_{y,b} A_{nv} / \sqrt{3}}{\gamma_{M0}}
\]

\[
A_{nt} = t_w \left[ (n_1 - 1) p_1 - (n_1 - 1) d_0 \right]
\]

\[
= 9 \left[ (5 - 1) \times 70 - (5 - 1) \times 22 \right] = 1728 \text{ mm}^2
\]

\[
A_{nv} = 2t_w \left( e_{2,b} + p_2 - \frac{3}{2} d_0 \right) = 2 \times 9 \left( 40 + 60 - \frac{3}{2} \times 22 \right) = 1206 \text{ mm}^2
\]

\[
F_{Rd,b} = \left( 430 \times 1728 + 275 \times 1206 \right) / \sqrt{3} \times 1,0 \times 10^{-3} = 867 \text{ kN}
\]

(Case 2 only applies to notched beams)

\[
F_{Rd} = \min(792; 867) = 792 \text{ kN}
\]

\[
F_{Ed} = 350 \text{ kN} \leq 792 \text{ kN}, \quad \text{OK}
\]

### 3.3.3. Weld resistance

The weld size specified for shear will be adequate for tying resistance, as it is full strength.
4 DOUBLE ANGLE WEB CLEATS

Unless noted otherwise, the design rules below have been developed from those established for partial depth end plates and fin plates from Reference 8.

4.1 Recommended details

1. Length of cleat $h_{ac} \geq 0.6h_b$
2. Face of beam or column
3. End projection, $g_e$, approximately 10 mm
4. Double line of bolts
5. Bolt diameter, $d$
6. Hold diameters, $d_0 = d + 2$ mm for $d \leq 24$ mm; $d_0 = d + 3$ mm for $d > 24$ mm
7. 10 mm clearance
8. Supported beam (single notched)
9. Supported beam (double notched)
10. Supporting beam
4.2 Checks for vertical shear

4.2.1 Bolt group resistance

4.2.1.1 Supported beam side

*Shear resistance of bolts*

![Diagram of bolt group resistance](image)

1 Assumed line of shear transfer

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = 2 \times \frac{n_b F_{v,Rd}}{\sqrt{(1 + m n_b)^2 + (\beta n_b)^2}}
\]

- \( F_{v,Rd} \) is the shear resistance of one bolt
- \( F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{M2}} \)

where:
- \( A \) is the tensile stress area of the bolt, \( A_s \)
- \( \alpha_v = 0.6 \) for 4.6 and 8.8 bolts
- \( = 0.5 \) for 10.9 bolts
- \( \gamma_{M2} \) is the partial factor for resistance of bolts

For a single vertical line of bolts \((n_2 = 1)\)

\[
\alpha = 0 \quad \text{and} \quad \beta = \frac{6z}{n_1 (n_1 + 1) p_1}
\]

For a double vertical line of bolts \((n_2 = 2)\)

\[
\alpha = \frac{z p_2^2}{2 I} \quad \text{and} \quad \beta = \frac{z p_1^2}{2 I} (n_1 - 1)
\]

\[
I = \frac{n_1}{2} p_2^2 + \frac{1}{6} n_1 \left(n_1^2 - 1\right) p_1^2
\]
$z$ is the transverse distance from the face of the supporting element to the centre of the bolt group

**Bearing resistance of bolts on the angle cleats**

*Single row*

*Double Row*

1 Check the bearing strength of cleat under eccentric load

Basic requirement: $V_{Ed} \leq V_{Rd}$

$$V_{Rd} = 2 \times \frac{n_b}{\left(\frac{1 + \alpha n_b}{F_{b,ver,Rd}}\right)^2 + \left(\frac{\beta n_b}{F_{b,hor,Rd}}\right)^2}$$

The bearing resistance of a single bolt is $F_{b,Rd} = \frac{k_1 \alpha_b f_u dt}{\gamma_{M2}}$

The vertical bearing resistance of a single bolt on the angle cleat is as follows:

$$F_{b,ver,Rd} = \frac{k_1 \alpha_b f_{u,ac} dt_{ac}}{\gamma_{M2}}$$

The horizontal bearing resistance of a single bolt on the angle cleat is as follows:

$$F_{b,hor,Rd} = \frac{k_1 \alpha_b f_{u,ac} dt_{ac}}{\gamma_{M2}}$$

$\alpha, \beta$ and $\gamma_{M2}$ are as defined previously.

For $F_{b,ver,Rd}$:

$$k_1 = \min\left(2,8 \frac{e_2}{d_0} - 1,7; \ 1,4 \frac{p_2}{d_0} - 1,7; \ 2,5\right)$$

$$\alpha_b = \min\left(\frac{e_1}{3d_0}; \ \frac{p_1}{3d_0} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,ac}}; \ 1,0\right)$$
Part 5: Joint Design

For $F_{b,\text{hor},\text{Rd}}$:

\[
\begin{align*}
 k_1 &= \min \left\{ 2,8 \frac{e_1}{d_0} - 1,7; 1,4 \frac{p_1}{d_0} - 1,7; 2,5 \right\} \\
 \alpha_b &= \min \left\{ \frac{e_2}{3d_0}; \frac{p_2}{3d_0} - 1,4; \frac{f_{ub}}{f_{un}}; 1,0 \right\}
\end{align*}
\]

**Bearing resistance of bolts on the beam web**

Basic requirement: $V_{Ed} \leq V_{Rd}$

\[
V_{Rd} = \frac{n_b}{\sqrt{\left( 1 + \alpha m_b \right)^2 + \left( \frac{\beta n_b}{F_{b,\text{ver},\text{Rd}}} \right)^2}}
\]

\[
F_{b,\text{ver},\text{Rd}} = \frac{k_1 \alpha_F f_{u,b} d_0 t_w}{\gamma M_2}
\]

\[
F_{b,\text{hor},\text{Rd}} = \frac{k_1 \alpha_F f_{u,b} d_0 t_w}{\gamma M_2}
\]

$\alpha$, $\beta$ and $\gamma M_2$ are as defined previously

For $F_{b,\text{ver},\text{Rd}}$,

\[
\begin{align*}
 k_1 &= \min \left\{ 2,8 \frac{e_{2,b}}{d_0} - 1,7; 1,4 \frac{p_2}{d_0} - 1,7; 2,5 \right\} \\
 \alpha_b &= \min \left\{ \frac{e_{1,b}}{3d_0}; \frac{p_1}{3d_0} - \frac{1}{4} \frac{f_{ub}}{f_{un}}; 1,0 \right\}
\end{align*}
\]
For $F_{b,\text{hor},\text{Rd}}$

$$k_1 = \min \left( 2,8 \frac{e_{1,b}}{d_0} - 1,7; \ 1,4 \frac{p_1}{d_0} - 1,7; \ 2,5 \right)$$

$$\alpha_b = \min \left( \frac{e_{2,b}}{3d_0}; \ \frac{p_2}{3d_0} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,b}}; \ 1,0 \right)$$

### 4.2.1.2 Supporting beam side

Basic requirement:

$$V_{Ed} \leq F_{Rd}$$

$F_{Rd}$ is the resistance of the bolt group \[\text{EN 1993-1-8, §3.7(1)}\]

If $(F_{b,Rd})_{\text{max}} \leq F_{v,Rd}$ then $F_{Rd} = \sum F_{b,Rd}$

If $(F_{b,Rd})_{\text{min}} \leq F_{v,Rd} \leq (F_{b,Rd})_{\text{max}}$ then $F_{Rd} = n_s(F_{b,Rd})_{\text{min}}$

If $F_{v,Rd} \leq (F_{b,Rd})_{\text{min}}$ then $F_{Rd} = 0,8n_sF_{v,Rd}$

### Shear resistance of bolts

$F_{v,Rd}$ is the shear resistance of one bolt

$$F_{v,Rd} = \alpha_v f_{ub} A \gamma_{M2}$$ \[\text{EN 1993-1-8, Table 3.4}\]

where:

- $\alpha_v = 0,6$ for 4.6 and 8.8 bolts
- $\alpha_v = 0,5$ for 10.9 bolts
- $A$ is the tensile stress area of the bolt, $A_s$

### Bearing resistance of bolts on the angle cleats

$F_{b,Rd}$ is the bearing resistance of a single bolt

$$F_{b,Rd} = \frac{k_1 \alpha_b f_{u,ac} dt_{ac}}{\gamma_{M2}}$$ \[\text{EN 1993-1-8, Table 3.4}\]

where:

- $\gamma_{M2}$ is the partial factor for plates in bearing
- For end bolts (parallel to the direction of load transfer)
  $$\alpha_b = \min \left( \frac{e_1}{3d_0}; \ \frac{f_{ub}}{f_{u,ac}}; \ 1,0 \right)$$
- For inner bolts (parallel to the direction of load transfer)
  $$\alpha_b = \min \left( \frac{p_1}{3d_0} - \frac{1}{4}; \ \frac{f_{ub}}{f_{u,ac}}; \ 1,0 \right)$$
Part 5: Joint Design

– For edge bolts (perpendicular to the direction of load transfer)

\[ k_1 = \min \left( 2.8 \frac{e_2}{d_0} - 1.7; \ 2.5 \right) \]

4.2.2 Shear resistance of the angle cleats

4.2.2.1 Supported beam side

Basic requirement: \( V_{Ed} \leq V_{Rd,min} \)

\[ V_{Rd,min} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b}) \]

Shear resistance of gross section

\[ V_{Rd,g} = 2 \times \frac{h_{ac} f_{ac}}{1.27} \frac{f_{y,ac}}{\sqrt{3} \gamma_{M0}} \]

Note: The coefficient 1.27 takes into account the reduction in shear resistance due to the presence of the nominal in-plane bending which produces tension in the bolts. \[9\]

Shear resistance of net section

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

\[ A_{v,net} = t_{ac} \left( h_{ac} - n_1 d_0 \right) \]

Block tearing resistance

\[ V_{Rd,b} = 2 \left( \frac{0.5 f_{u,ac} A_{nt}}{\gamma_{M2}} + \frac{f_{y,ac} A_{nv}}{\sqrt{3} \gamma_{M0}} \right) \]

\[ A_{nv} = t_{ac} \left( h_{ac} - e_1 - (n_1 - 0.5) d_0 \right) \]

For a single line of bolts:

\[ A_{nt} = t_{ac} \left( e_2 - 0.5 d_0 \right) \]
For a double line of bolts:

\[ A_{nt} = t_{ac} \left( e_2 + p_2 - 1.5 d_0 \right) \]

\[ \gamma_{M2} \] is the partial factor for the resistance of net sections.

### 4.2.2.2 Supporting beam side

**Critical section in shear and bearing**

1. Block shear – check failure by tearing out of shaded portion

**Basic requirement:**

\[ V_{Ed} \leq V_{Rd, min} \]

\[ V_{Rd, min} = \min(V_{Rd,g}; \ V_{Rd,n}; \ V_{Rd,b}) \]

**Shear resistance of gross section**

\[ V_{Rd,g} = 2 \times \frac{h_{ac} t_{ac}}{1.27} \frac{f_{y,ac}}{\sqrt{3} \gamma_{M0}} \]

Note: The coefficient 1.27 takes into account the reduction in shear resistance due to the presence of the nominal in-plane bending which produces tension in the bolts\[9\].

**Shear resistance of net section**

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

\[ A_{v,net} = t_{ac} \left( h_{ac} - n_1 d_0 \right) \]

**Block tearing resistance**

\[ V_{Rd,b} = 2 \left( \frac{0.5 f_{u,ac} A_{nt}}{\gamma_{M2}} + \frac{f_{y,ac} A_{nv}}{\sqrt{3} \gamma_{M0}} \right) \]

\[ A_{nt} = t_{ac} \left( e_2 - 0.5 d_0 \right) \]

\[ A_{nv} = t_{ac} \left( h_{ac} - e_1 - (n_1 - 0.5) d_0 \right) \]

\[ \gamma_{M2} \] is the partial factor for the resistance of net sections.
4.2.3 **Shear resistance of the beam web**

![Diagram of beam web with labeled sections](image)

1. Critical section in plain shear
2. Shear failure
3. Tension failure
4. Block shear failure tearing out of shaded portion

### 4.2.3.1 Shear and block tearing resistance

**Basic requirement:** $V_{Ed} \leq V_{Rd,min}$

$$V_{Rd,min} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b})$$

**Shear resistance of gross section**

$$V_{Rd,g} = A_{v,wb} \frac{f_{y,b}}{\sqrt{3} \gamma_{M0}}$$

$A_{v,wb} = A - 2bt_f + (t_w + 2r)t_f \text{ but } \geq \eta h_w t_w$ for un-notched beam

$A_{v,wb} = A_{Tee} - bt_f + (t_w + 2r)t_f/2$ for single notched beam
**Part 5: Joint Design**

\[ A_{v,wb} = t_w (e_{1,b} + (n_1 - 1)p_1 + h_e) \quad \text{for double notched beam} \]

\[ \eta \quad \text{is a factor from EN 1993-1-5 (it may be conservatively taken equal to 1.0)} \]

\[ A_{\text{Tee}} \quad \text{is the area of the Tee section} \]

**Shear resistance of net section**

\[ V_{Rd,n} = A_{v,wb,\text{net}} \frac{f_u}{3\gamma M_2} \]

\[ A_{v,wb,\text{net}} = A_{v,wb} - n_1 d_0 t_w \]

**Block tearing resistance**

\[ V_{Rd,b} = \frac{0.5 f_{u,b} A_{nt}}{\gamma M_2} + \frac{f_{y,b} A_{nv}}{\sqrt{3\gamma M_0}} \]

For a single vertical line of bolts, \[ A_{nt} = t_w \left( e_{2,b} - 0.5 d_0 \right) \]

For a double vertical line of bolts, \[ A_{nt} = t_w \left( e_{2,b} + p_2 - \frac{3}{2} d_0 \right) \]

\[ A_{nv} = t_w \left( e_{1,b} + (n_1 - 1)p_1 - (n_1 - 0.5)d_0 \right) \]

\[ \gamma M_2 \quad \text{is the partial factor for the resistance of net sections.} \]

**4.2.3.2 Shear and bending interaction at the 2nd line of bolts, if the notch length} l_n > (e_{2,b} + p_2) \]

Basic requirement: \[ V_{Ed} \left( g + e_{2,b} + p_2 \right) \leq M_{c,Rd} \quad \text{[Reference 4]} \]

\[ M_{c,Rd} \quad \text{is the moment resistance of the notched beam at the connection in the presence of shear.} \]
**For single notched beam:**

For low shear (i.e. \( V_{Ed} \leq 0.5 V_{pl,N,Rd} \))

\[
M_{c,Rd} = \frac{f_y b W_{el,N}}{\gamma_{M0}}
\]

For high shear (i.e. \( V_{Ed} > 0.5 V_{pl,N,Rd} \))

\[
M_{c,Rd} = \frac{f_y b W_{el,N}}{\gamma_{M0}} \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,N,Rd}} - 1 \right)^2 \right]
\]

\( V_{pl,N,Rd} = \min(V_{Rd,g}; V_{Rd,b}) \)

\( W_{el,N} \) is the elastic section modulus of the gross Tee section at the notch

**For double notched beam:**

For low shear (i.e. \( V_{Ed} \leq 0.5 V_{pl,DN,Rd} \))

\[
M_{c,Rd} = \frac{f_y b t_w}{6\gamma_{M0}} \left( e_1 + (n_1 - 1)p_1 + h_e \right)^2
\]

For high shear (i.e. \( V_{Ed} > 0.5 V_{pl,DN,Rd} \))

\[
M_{c,Rd} = \frac{f_y b t_w}{6\gamma_{M0}} \left( e_1 + (n_1 - 1)p_1 + h_e \right)^2 \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,DN,Rd}} - 1 \right)^2 \right]
\]

\( V_{pl,DN,Rd} = \min(V_{Rd,g}; V_{Rd,b}) \)

4.2.4 Bending resistance at the notch

Shear and bending interaction at the notch.

**4.2.4.1 For single bolt line or for double bolt lines, if \( x_n \geq 2d \):**

\[
V_{Ed} (g_n + l_n) \leq M_{c,N,Rd}
\]

[Reference 4]

\( M_{c,N,Rd} \) is the moment resistant of the beam at the notch in the presence of shear
For single notched beam

For low shear (i.e. \( V_{Ed} \leq 0,5 V_{pl,N,Rd} \))

\[
M_{v,N,Rd} = \frac{f_{y,b} W_{el,N}}{\gamma M0}
\]

For high shear (i.e. \( V_{Ed} > 0,5 V_{pl,N,Rd} \))

\[
M_{v,N,Rd} = \frac{f_{y,b} W_{el,N}}{\gamma M0} \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,N,Rd}} - 1 \right)^2 \right]
\]

For double notched beam:

For low shear (i.e. \( V_{Ed} \leq 0,5 V_{pl,DN,Rd} \))

\[
M_{v,DN,Rd} = \frac{f_{y,b} t_w}{6 \gamma M0} \left( e_{1,b} + (n_1 - 1)p_1 + h_e \right)^2
\]

For high shear (i.e. \( V_{Ed} > 0,5 V_{pl,DN,Rd} \))

\[
M_{v,DN,Rd} = \frac{f_{y,b} t_w}{4 \gamma M0} \left( e_{1,b} + (n_1 - 1)p_1 + h_e \right)^2 \left[ 1 - \left( \frac{2V_{Ed}}{V_{pl,DN,Rd}} - 1 \right)^2 \right]
\]

4.2.4.2 For double bolt lines, if \( x_N < 2d \):

\[
\max (V_{Ed} (gh + l_n); V_{Ed} (gh + e_{2,b} + p_2)) \leq M_{v,N,Rd}
\]

\[
M_{v,N,Rd} = M_{c,Rd} \quad \text{from the previous check}
\]

where:

\( W_{el,N} \) is the elastic section modulus of the gross Tee section at the notch

\( V_{pl,N,Rd} \) is the shear resistance at the notch for single notched beams

\[
= \frac{A_{v,N} f_{y,b}}{\sqrt{3} \gamma M0}
\]

\( A_{v,N} \) = \( A_{Tee} - bt_f + (t_w + 2r) \frac{t_f}{2} \)

\( V_{pl,DN,Rd} \) is the shear resistance at the notch for double notched beams

\[
= \frac{A_{v,DN} f_{y,b}}{\sqrt{3} \gamma M0}
\]

\( A_{v,DN} \) = \( t_w (e_{1,b} + (n_1 - 1)p_1 + h_e) \)

where:

\( A_{Tee} \) is the area of the Tee section
4.2.5 Local stability of the notched beam

When the beam is restrained against lateral torsional buckling, no account need be taken of notch stability provided the following conditions are met:

**For one flange notched, basic requirement:** \[5,6\]

\[
d_{nt} \leq \frac{h_b}{2} \quad \text{and:} \\
I_n \leq h_b \quad \text{for} \quad \frac{h_b}{t_w} \leq 54,3 \quad (\text{S275 steel}) \\
I_n \leq \frac{160000 h_b}{\left(\frac{h_b}{t_w}\right)^3} \quad \text{for} \quad \frac{h_b}{t_w} > 54,3 \quad (\text{S275 steel}) \\
I_n \leq h_b \quad \text{for} \quad \frac{h_b}{t_w} \leq 48,0 \quad (\text{S355 steel}) \\
I_n \leq \frac{110000 h_b}{\left(\frac{h_b}{t_w}\right)^3} \quad \text{for} \quad \frac{h_b}{t_w} > 48,0 \quad (\text{S355 steel})
\]

**For both flanges notched, basic requirement:** \[7\]

\[
\max (d_{nt}; d_{nb}) \leq \frac{h_b}{5} \quad \text{and:} \\
I_n \leq h_b \quad \text{for} \quad \frac{h_b}{t_w} \leq 54,3 \quad (\text{S275 steel}) \\
I_n \leq \frac{160000 h_b}{\left(\frac{h_b}{t_w}\right)^3} \quad \text{for} \quad \frac{h_b}{t_w} > 54,3 \quad (\text{S275 steel}) \\
I_n \leq h_b \quad \text{for} \quad \frac{h_b}{t_w} \leq 48,0 \quad (\text{S355 steel}) \\
I_n \leq \frac{110000 h_b}{\left(\frac{h_b}{t_w}\right)^3} \quad \text{for} \quad \frac{h_b}{t_w} > 48,0 \quad (\text{S355 steel})
\]

Where the notch length $l_n$ exceeds these limits, either suitable stiffening should be provided or the notch should be checked to References 5, 6 and 7. For S235 and S460 members see References 5, 6 and 7.
4.3 **Checks for tying**

EN 1993-1-8 does not have a partial factor for structural integrity checks. In this publication $\gamma_{Mu}$ has been used. A value of $\gamma_{Mu} = 1.1$ is recommended.

4.3.1 **Angle cleats and bolt group resistance**

4.3.1.1 **Resistance of the angle cleats in bending**

There are three modes of failure for angle cleats in bending:

Mode 1: complete yielding of the plate

Mode 2: bolt failure with yielding of the plate

Mode 3: bolt failure

Basic requirement: $F_{Ed} \leq F_{Rd}$

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

Mode 1 (the complete yielding of the angle cleats)

$$F_{Rd,u,1} = \frac{(8n - 2e_w)M_{pl,1,Rd,u}}{2mn - e_w(m + n)} \quad [\text{EN 1993-1-8 Table 6.2}]$$

Mode 2 (bolt failure with yielding of the angle cleats)

$$F_{Rd,u,2} = \frac{2M_{pl,2,Rd,u} + n\Sigma F_{t,Rd,u}}{m + n} \quad [\text{EN 1993-1-8 Table 6.2}]$$

Mode 3 (bolt failure)

$$F_{Rd,u,3} = \Sigma F_{t,Rd,u} \quad [\text{EN 1993-1-8 Table 6.2}]$$

$$F_{t,Rd,u} = \frac{k_2 f_{ub} A}{\gamma_{Mu}}$$
where:

\[ M_{pl,1,Rd,u} = \frac{0.25 \Sigma l_{eff} t^2_{ac} f_{u,ac}}{\gamma_{Mu}} \]

\[ M_{pl,2,Rd,u} = M_{pl,1,Rd,u} \]

\[ m = \frac{p_3 - t_w - 2t_{ac} - 2 \times 0.8 \times r}{2} \]

\[ n = e_{min} \text{ but } n \leq 1.25m \text{ where } e_{min} = e_2 \]

\[ e_w = \frac{d_w}{4} \]

\[ d_w \] is the diameter of the washer

\[ k_2 = 0.63 \text{ for countersunk bolts} \]

\[ = 0.9 \text{ otherwise} \]

\[ A \] is the tensile stress area of the bolt, \( A_s \)

\[ \Sigma l_{eff} \] is the effective length of a plastic hinge

\[ \Sigma l_{eff} = 2e_{1A} + (n_1 - 1) p_{1A} \]

\[ e_{1A} = e_1 \text{ but } e_1 \leq 0.5(p_3 - t_w - 2r) + \frac{d_0}{2} \]

\[ p_{1A} = p_1 \text{ but } p_1 \leq p_3 - t_w - 2r + d_0 \]

### 4.3.1.2 Shear resistance of bolts

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = 2n_b F_{v,u} \]

\[ F_{v,u} = \frac{\alpha_v f_{ub} A}{\gamma_{Mu}} \]

where:

\[ \alpha_v = 0.6 \text{ for 4.6 and 8.8 bolts} \]

\[ = 0.5 \text{ for 10.9 bolts} \]

\[ A \] is the tensile stress area of the bolt, \( A_s \)

### 4.3.1.3 Bearing resistance of bolts on the angle cleats

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = 2n_b F_{b,hor,u,Rd} \]

\[ F_{b,hor,u,Rd} = k_1 \alpha_b f_{u,ac} d_{t_{ac}} \]

\[ \frac{\gamma_{Mu}}{\gamma_{Mu}} \]
where:

\[ k_1 = \min \left(2,8 \frac{e_1}{d_0} - 1,7;1,4 \frac{p_1}{d_0} - 1,7;2,5 \right) \]

\[ \alpha_0 = \min \left(\frac{e_2}{3d_0} - \frac{p_2}{3d_0} - 1;4 \frac{f_{ub}}{f_{u,ac}};1,0 \right) \]

### 4.3.1.4 Block tearing resistance

**Case 1**

- Beam without notch
- Notched beam
- Double angle cleat

**Basic requirement**: \( F_{Ed} \leq F_{Rd,b} \)

\[ F_{Rd,b} = \frac{f_{u,ac} A_{nt}}{\gamma_{Mu}} + \frac{f_{v,ac} A_{nv}}{\sqrt{3} \gamma_{M0}} \]

**Case 1**:

\[ A_{nt} = 2t_{ac}[(n_1 - 1)p_1 - (n_1 - 1)d_0] \]

For a single vertical line of bolts: \( A_{nv} = 4t_{ac} \left( e_2 - 0,5d_0 \right) \)

For a double vertical line of bolts: \( A_{nv} = 4t_{ac} \left( e_2 + p_2 - \frac{3}{2} d_0 \right) \)

**Case 2**:

\[ A_{nt} = 2t_{ac}[e_1 + (n_1 - 1)p_1 - (n_1 - 0,5)d_0] \]

For a single vertical line of bolts: \( A_{nv} = 2t_{ac} (e_2 - 0,5d_0) \)

For a double vertical line of bolts: \( A_{nv} = 2t_{ac} \left( e_2 + p_2 - \frac{3}{2} d_0 \right) \)
4.3.2 Beam web resistance

4.3.2.1 Bearing resistance of bolts on the beam web

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[
F_{Rd} = n_b F_{b,\text{hor},u,Rd}
\]

\[
F_{b,\text{hor},u,Rd} = \frac{k_1 \alpha_b f_{u,b} d_{w,b}}{\gamma_{Mu}}
\]

where:

\[
k_1 = \left( 2,8 \frac{e_{1,b}}{d_0} - 1,7; \ 1,4 \frac{P_1}{d_0} - 1,7; \ 2,5 \right)
\]

\[
\alpha_b = \frac{e_{2,b}}{3d_0} \cdot \frac{P_2}{3d_0} - \frac{1}{4} \cdot \frac{f_{ub}}{f_{u,b}} + 1,0
\]

\[
\alpha_v = 0,6 \text{ for 4.6 and 8.8 bolts}
\]

\[
\alpha_v = 0,5 \text{ for 10.9 bolts}
\]

4.3.2.2 Tension resistance of the beam web

Basic requirement: \( F_{Ed} \leq F_{Rd,n} \)

\[
F_{Rd,n} = 0,9 A_{\text{net,wb}} \frac{f_{u,b}}{\gamma_{Mu}}
\]

where:

\[
A_{\text{net,wb}} = t_w h_{ac} - d_0 n_1 t_w
\]
4.3.2.3 Block tearing resistance

Basic requirement: $F_{Ed} \leq F_{Rd,b}$

$$F_{Rd,b} = \frac{f_{u,b} A_{nt}}{\gamma_{Mu}} + \frac{f_{y,b} A_{nv}}{\sqrt{3}\gamma_{M0}}$$

Case 1:

$$A_{nt} = t_w \left( (n_1 - 1)p_1 - (n_1 - 1)d_0 \right)$$

For a single vertical line of bolts, $A_{nv} = 2t_w \left( e_{2,b} - 0.5d_0 \right)$

For double vertical line of bolts, $A_{nv} = 2t_w \left( e_{2,b} + p_2 - \frac{3}{2}d_0 \right)$

Case 2 (for notched beams only):

$$A_{nt} = t_w \left( e_{1,b} + (n_1 - 1)p_1 - (n_1 - 0.5)d_0 \right)$$

For a single vertical line of bolts, $A_{nv} = t_w \left( e_{2,b} - 0.5d_0 \right)$

For double vertical line of bolts, $A_{nv} = t_w \left( e_{2,b} + p_2 - \frac{3}{2}d_0 \right)$
4. Angle Web Cleats

Details and data

Beam: IPE A 550  S275
Angle cleats: 2/90 × 90 × 10,  S275
Bolts: M20  8.8
<table>
<thead>
<tr>
<th><strong>Summary of full design checks</strong></th>
</tr>
</thead>
</table>

**Design forces**

\[ V_{Ed} = 450 \text{ kN} \]
\[ F_{Ed} = 370 \text{ kN} \quad \text{(Tie force)} \]

**Shear resistances**

Bolt group resistance

<table>
<thead>
<tr>
<th>Supported beam side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear resistance of bolts</td>
<td>962 \text{ kN}</td>
</tr>
<tr>
<td>Bearing resistance of bolts on the angle cleats</td>
<td>1075 \text{ kN}</td>
</tr>
<tr>
<td>Bearing resistance of bolts on the beam web</td>
<td>583 \text{ kN}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supporting beam side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td>902 \text{ kN}</td>
</tr>
</tbody>
</table>

Shear resistance of the angle cleats

<table>
<thead>
<tr>
<th>Supported beam side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear resistance</td>
<td>954 \text{ kN}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supporting beam side</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear resistance</td>
<td>954 \text{ kN}</td>
</tr>
</tbody>
</table>

Shear resistance of the beam web

<table>
<thead>
<tr>
<th>Shear and block tearing resistance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear resistance</td>
<td>501 \text{ kN}</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shear and bending interaction at the 2\textsuperscript{nd} line of bolts</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending resistance at the notch</td>
<td>N/A</td>
</tr>
<tr>
<td>Local stability of the notched beam</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Tying resistances**

Angle cleats and bolt group resistance

<table>
<thead>
<tr>
<th>Resistance of the angle cleats in bending</th>
<th>696 \text{ kN}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear resistance of bolts</td>
<td>1284 \text{ kN}</td>
</tr>
<tr>
<td>Bearing resistance of bolts on the angle cleats</td>
<td>1428 \text{ kN}</td>
</tr>
<tr>
<td>Block tearing resistance</td>
<td>2060 \text{ kN}</td>
</tr>
</tbody>
</table>

Beam web resistance

<table>
<thead>
<tr>
<th>Bearing resistance of bolts on the beam web</th>
<th>642 \text{ kN}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension resistance of the beam web</td>
<td>944 \text{ kN}</td>
</tr>
<tr>
<td>Block tearing resistance</td>
<td>927 \text{ kN}</td>
</tr>
</tbody>
</table>
4.1. Recommended details

Cleats 10 mm thick
Length, \( h_{ac} = 430 \text{mm} > 0.6h_b \), OK

4.2. Checks for vertical shear

4.2.1. Bolt group resistance

4.2.1.1. Supported beam side

Shear resistance of bolts

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = 2 \times \frac{n_b F_{v,Rd}}{\sqrt{(1 + \alpha n_b)^2 + (\beta n_b)^2}}
\]

\[
F_{v,Rd} = \frac{\alpha \gamma f_{ub} A}{\gamma M2}
\]

For M20 8.8 bolts, \( F_{v,Rd} = \frac{0.6 \times 800 \times 245}{1.25} \times 10^{-3} = 94 \text{kN} \)

For a single vertical line of bolts (i.e. \( n_2 = 1 \) and \( n_1 = 6 \)), \( \alpha = 0 \)

\[
\beta = \frac{6z}{n_1 (n_1 + 1) p_1} = \frac{6 \times 50}{6(6+1)70} = 0.102
\]

Thus \( V_{Rd} = 2 \times \sqrt{\frac{6 \times 94}{(1 + 0 \times 6)^2 + (0.102 \times 6)^2}} = 962 \text{kN} \)

\( V_{Ed} = 450 \text{kN} \leq 962 \text{kN} \), OK

Bearing resistance of bolts on the angle cleats

Basic requirement: \( V_{Ed} \leq V_{b,Rd} \)

\[
V_{b,Rd} = 2 \times \frac{n_b}{\sqrt{\left(1 + \alpha n_b \right)^2 + \left(\frac{\beta n_b}{F_{b,ver,Rd}}\right)^2}}
\]

\( \alpha = 0 \) and \( \beta = 0.102 \), as above

The vertical bearing resistance for a single bolt, \( F_{b,ver,Rd} = \frac{k_1 \alpha_b f_{u,ac} dt_{ac}}{\gamma M2} \)

\[
k_1 = \min \left( 2.8 \frac{c_1}{d_0}, 1.7; 2.5 \right) = \min \left( 2.8 \frac{40}{22}, 1.7; 2.5 \right) = \min \left( 3.39; 2.5 \right) = 2.5
\]
\[ \alpha_b = \min \left( \frac{e_1}{3d_0}; \frac{P_1}{3d_0}; \frac{1}{4}; \frac{f_{ub}}{f_{u,ac}}; 1,0 \right) \]
\[ = \min \left( \frac{40}{3 \times 22}; \frac{70}{3 \times 22}; -0,25; \frac{800}{430}; 1,0 \right) = \min(0,61; 0,81; 1,86; 1,0) \]
\[ \alpha_b = 0,61 \]
\[ F_{b,ver,Rd} = \frac{2,5 \times 0,61 \times 430 \times 20 \times 10}{1,25} \times 10^{-3} = 105 \text{ kN} \]

The horizontal bearing resistance for a single bolt, \( F_{b,hor,Rd} = \frac{k_1 \alpha_b f_{u,ac} d_{ac}}{\gamma_{M2}} \)

\[ k_1 = \min \left( 2,8 \frac{e_1}{d_0}; -1,7; 1,4 \frac{P_1}{d_0}; -1,7; 2,5 \right) \]
\[ = \min (2,8; \frac{40}{22}; -1,7; 1,4 \frac{70}{22}; -1,7; 2,5) = \min (3,39; 2,75; 2,5) = 2,5 \]
\[ \alpha_b = \min \left( \frac{e_2}{3d_0}; \frac{f_{ub}}{f_{u,ac}}; 1,0 \right) = \min \left( \frac{40}{3 \times 22}; \frac{800}{430}; 1,0 \right) \]
\[ = \min (0,61; 1,86; 1,0) = 0,61 \]
\[ F_{b,hor,Rd} = \frac{2,5 \times 0,61 \times 430 \times 20 \times 10}{1,25} \times 10^{-3} = 105 \text{ kN} \]

\[ V_{Rd} = 2 \times \frac{6}{\sqrt{\left(1 + 0 \times \frac{6}{105}\right)^2 + \left(0,102 \times \frac{6}{105}\right)^2}} = 1075 \text{ kN} \]
\[ V_{Ed} = 450 \text{ kN} \leq 1075 \text{ kN}, \quad \text{OK} \]
**Bearing resistance of bolts on the beam web**

Basic requirement: \( V_{Ed} \leq V_{Rd} \)

\[
V_{Rd} = \frac{n_b}{\sqrt{\left( \frac{1 + \alpha m_b}{F_{b,ver,Rd}} \right)^2 + \left( \frac{\beta n_b}{F_{b,hor,Rd}} \right)^2}}
\]

\( \alpha = 0 \) and \( \beta = 0,102 \), as above

The vertical bearing resistance of a single bolt, \( F_{b,ver,Rd} = \frac{k_1 \beta f_{u,b} d_t w}{\gamma M_2} \)

\[
k_1 = \min \left( 2,8 \frac{e_{1,b}}{d_0} - 1,7 ; 2,5 \right) = \min \left( 2,8 \frac{40}{22} - 1,7 ; 2,5 \right) = \min (3,4; 2,5)
\]

\( = 2,5 \)

\[
\alpha_b = \min \left( \frac{e_{1,b}}{3d_0}, \frac{p_1}{3d_0}, \frac{1}{4}, f_{s_b} \right) = \min \left( \frac{90}{3 \times 22}, \frac{70}{3 \times 22}, \frac{1}{4}, \frac{800}{430}, 1,0 \right)
\]

\( = \min (1,36; 0,81; 1,86; 1,0) = 0,81 \)

\[
F_{b,ver,Rd} = 2,5 \times 0,81 \times 430 \times 20 \times 9 \times 10^{-3} = 125 \text{ kN}
\]

The horizontal bearing resistance of a single bolt,

\[
F_{b,hor,Rd} = \frac{k_1 \beta f_{u,b} d_t w}{\gamma M_2}
\]

\[
k_1 = \min \left( 2,8 \frac{e_{1,b}}{d_0} - 1,7 ; 1,4 \frac{p_1}{d_0} - 1,7 ; 2,5 \right)
\]

\( = \min \left( 2,8 \frac{90}{22} - 1,7 ; 1,4 \frac{70}{22} - 1,7 ; 2,5 \right) = \min (9,75; 2,75; 2,5) = 2,5 \)
\[
\alpha_b = \min \left( \frac{e_{2,b}}{3d_0}, \frac{f_{ub}}{f_{u,b}}, 1,0 \right) = \min \left( \frac{40}{3 \times 22}, \frac{800}{430}, 1,0 \right) = \min(0,61; 1,86; 1,0) = 0,61
\]

\[
F_{b,hor,Rd} = 2,5 \times 0,61 \times 430 \times 20 \times 9 \times 10^{-3} = 94 \text{ kN}
\]

\[
V_{Rd} = \frac{6}{\sqrt{\left( \frac{1 + 0 \times 6}{125} \right)^2 + \left( \frac{0,102 \times 6}{94} \right)^2}} = 583 \text{ kN}
\]

\[V_{Ed} = 450 \text{ kN} \leq 583 \text{ kN}, \text{ OK}\]

### 4.2.1.2. Supporting beam side

\[\sigma_1 = 40°\]

\[\sigma_2 = 40°\]

\[(n_1-1)\rho_1 = 350\]

\[V_{Ed} = 450 \text{ kN}\]

Basic requirement: \(V_{Ed} \leq F_{Rd}\)

The design resistance of the bolt group, \(F_{Rd}\):

If \(F_{b,Rd})_{\text{max}} \leq F_{v,Rd}\)

then \(F_{Rd} = \Sigma F_{b,Rd}\)

If \((F_{b,Rd})_{\text{min}} \leq F_{v,Rd} < (F_{b,Rd})_{\text{max}}\)

then \(F_{Rd} = n_s (F_{b,Rd})_{\text{min}}\)

If \(F_{v,Rd} < (F_{b,Rd})_{\text{min}}\)

then \(F_{Rd} = 0,8 n_s F_{v,Rd}\)

**Shear resistance of bolts**

The shear resistance of a single bolt, \(F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma M2}\)

For M20 8.8 bolts, \(F_{v,Rd} = \frac{0,6 \times 800 \times 245}{1,25} \times 10^{-3} = 94 \text{ kN}\)
**Bearing resistance of bolts on the angle cleats**

\[ V_{b,Rd} = \frac{k_1 \alpha_b f_{u,ac} d_{t,ac}}{\gamma_{M2}} \]

For edge bolts, \( k_1 = \min(2,8 \frac{e_0}{d_0} - 1,7; 2,5) = \min(2,8 \times \frac{40}{22} - 1,7; 2,5) \)

\[ = \min(3,39; 2,5) = 2,5 \]

For end bolts, \( \alpha_b = \min\left(\frac{e_1}{3d_0}; \frac{f_{ab}}{f_{u,ac}}; 1,0\right) = \min\left(\frac{40}{3 \times 22}; \frac{800}{430}; 1,0\right) \)

\[ = \min(0,61; 1,86; 1,0) = 0,61 \]

For inner bolts, \( \alpha_b = \min\left(\frac{p_1}{3d_0} - \frac{1}{4}; \frac{f_{ab}}{f_{u,ac}}; 1,0\right) \)

\[ = \min\left(\frac{70}{3 \times 22} - \frac{1}{4}; \frac{800}{430}; 1,0\right) = \min(0,81; 1,86; 1,0) \]

\[ = 0,81 \]

End bolts, \( F_{b,Rd,end} = (F_{b,Rd})_{\text{min}} = \frac{2,5 \times 0,61 \times 430 \times 20 \times 10}{1,25} \times 10^{-3} \)

\[ = 105 \text{ kN} \]

Inner bolts, \( F_{b,Rd,inner} = (F_{b,Rd})_{\text{max}} = \frac{2,5 \times 0,81 \times 430 \times 20 \times 10}{1,25} \times 10^{-3} \)

\[ = 139 \text{ kN} \]

94 kN < 105 kN thus \( F_{v,Rd} < (F_{b,Rd})_{\text{min}} \)

\( F_{Rd} = 0,8 \eta_s F_{v,Rd} = 0,8 \times 12 \times 94 = 902 \text{ kN} \)

\( V_{Ed} = 550 \text{ kN} \leq 902 \text{ kN}, \text{ OK} \)

**4.2.2. Shear resistance of the angle cleats**

**4.2.2.1. Supported beam side**

Basic requirement: \( V_{Ed} \leq V_{Rd,\text{min}} \)

\( V_{Rd,\text{min}} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b}) \)

**Shear resistance of gross section**

\( V_{Rd,g} = 2 \times h_{ac} f_{y,ac} \)

\[ \frac{1,27}{\sqrt{3} \gamma_{M0}} = 2 \times \frac{430 \times 10 \times 275}{1,27 \times \sqrt{3} \times 1,0} \times 10^{-3} = 1076 \text{ kN} \]

**Shear resistance of net section**

\( V_{Rd,n} = 2 \times A_{v,net} \frac{f_{u,ac}}{\sqrt{3} \gamma_{M2}} \)
Net area, \( A_{v,\text{net}} = t_{ac} (h_{ac} - n_1 d_0) = 10(430 - 6 \times 22) = 2980 \text{ mm}^2 \)

\[ V_{Rd,n} = 2 \times 2980 \times \frac{430}{\sqrt{3} \times 1.25} \times 10^{-3} = 1184 \text{ kN} \]

**Block tearing resistance**

\[ V_{Rd,b} = 2 \left( 0.5 f_{u,ac} A_{nt} + f_{y,ac} A_{nv} \right) \]

\[ \gamma M_2 \]

Net area subject to tension, \( A_{nt} = t_{ac} \left( e_2 - 0.5d_0 \right) \)

\[ = 10(40 - 0.5 \times 22) = 290 \text{ mm}^2 \]

Net area subject to shear, \( A_{nv} = t_{ac} \left( h_{ac} - e_1 - (n_1 - 0.5)d_0 \right) \)

\[ = 10(430 - 40 - (6 - 0.5)22) = 2690 \text{ mm}^2 \]

\[ V_{Rd,b} = 2 \left( 0.5 \times 430 \times 290 \times 1.25 + \frac{275 \times 2690}{\sqrt{3} \times 1.0} \right) \times 10^{-3} = 954 \text{ kN} \]

\( V_{Rd,min} = 954 \text{ kN} \)

\( V_{Ed} = 450 \text{ kN} \leq 954 \text{ kN, OK} \)

### 4.2.2.2. Supporting beam side

Basic requirement: \( V_{Ed} \leq V_{Rd,min} \)

\( V_{Rd,min} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b}) \)

**Shear resistance of gross section**

\[ V_{Rd,g} = 2 \times \frac{h_{ac} t_{ac}}{1.27} \frac{f_{y,ac}}{\sqrt{3} \gamma_{M0}} = 2 \times \frac{430 \times 10 \times 275}{1.27 \times \sqrt{3} \times 1.0} \times 10^{-3} = 1076 \text{ kN} \]
Shear resistance of net section

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

Net area, \( A_{v,net} = t_{ac} \left( h_{ac} - n_1 d_0 \right) = 10(430 - 6 \times 22) = 2980 \text{ mm}^2 \)

\[ V_{Rd,n} = 2 \times 2980 \times \frac{430}{\sqrt{3} \times 1.25} \times 10^{-3} = 1184 \text{ kN} \]

Block tearing resistance

\[ V_{Rd,b} = 2 \left( \frac{0.5 f_{u,ac} A_{nt}}{\gamma_{M2}} + \frac{f_{y,ac} A_{nv}}{\sqrt{3} \gamma_{M0}} \right) \]

Net area subject to tension, \( A_{nt} = t_{ac} \left( e_2 - 0.5 d_0 \right) \)

\[ = 10(40 - 0.5 \times 22) = 290 \text{ mm}^2 \]

Net area subject to shear, \( A_{nv} = t_{ac} \left( h_{ac} - e_1 - (n_1 - 0.5) d_0 \right) \)

\[ = 10(430 - 40 - (6 - 0.5)22) = 2690 \text{ mm}^2 \]

\[ V_{Rd,b} = 2 \left( \frac{0.5 \times 430 \times 290}{1.25} + \frac{275 \times 2690}{\sqrt{3} \times 1.0} \right) \times 10^{-3} = 954 \text{ kN} \]

\[ V_{Rd,min} = 954 \text{ kN} \]

\[ V_{Ed} = 450 \text{ kN} \leq 954 \text{ kN}, \quad \text{OK} \]

4.2.3. Shear resistance of the beam web

4.2.3.1. Shear and block tearing resistance

![Diagram of beam web with shear forces and dimensions]

Basic requirement: \( V_{Ed} \leq V_{Rd,min} \)

\[ V_{Rd,min} = \min(V_{Rd,g}; V_{Rd,n}; V_{Rd,b}) \]
Shear resistance of gross section

\[ V_{Rd,g} = A_{v,wb} \frac{f_{y,b}}{\sqrt[3]{\gamma M_0}} \]

Shear area of beam web,

\[ A_{v,wb} = A - 2bt_t + (t_w + 2r)t_t = 11700 - 2 \times 210 \times 15,7 + (9 + 2 \times 24)15,7 \]
\[ A_{v,wb} = 6001 \text{ mm}^2 \]
\[ \eta h_w t_w = 1,0 \times 515,6 \times 9 = 4640 \text{ mm}^2 \]
\[ V_{Rd,g} = \frac{6001 \times 275}{\sqrt[3]{1},0} \times 10^{-3} = 953 \text{ kN} \]

Shear resistance of net section

\[ V_{Rd,n} = A_{v,wb,net} \frac{f_{u,b}}{\sqrt[3]{\gamma M_2}} \]

Net area, \( A_{v,wb,net} = A_{v,wb} - n_1 d_0 t_w = 6001 - 6 \times 22 \times 9 = 4813 \text{ mm}^2 \)
\[ V_{Rd,n} = 4813 \times \frac{430}{\sqrt[3]{1},25} \times 10^{-3} = 956 \text{ kN} \]

Block tearing resistance

\[ V_{Rd,b} = \left( 0,5 \frac{f_{u,b} A_{nt}}{\gamma M_2} + \frac{f_{y,b} A_{nv}}{\sqrt[3]{\gamma M_0}} \right) \]

Net area subject to tension, \( A_{nt} = t_w (e_{2,b} - 0,5d_0) \)
\[ = 9(40 - 0,5 \times 22) = 261 \text{ mm}^2 \]

Net area subject to shear, \( A_{nv} = t_w (e_{1,b} + (n_1 - 1)p_1 - (n_1 - 0,5)d_0) \)
\[ = 9(90 + (6 - 1)70 - (6 - 0,5)22) \]
\[ = 2871 \text{ mm}^2 \]
\[ V_{Rd,b} = \left( 0,5 \times 430 \times 261 + 275 \times 2871 \right) \times 10^{-3} = 501 \text{ kN} \]
\[ V_{Rd,min} = \min(953; 956; 501) = 501 \text{ kN} \]
\[ V_{Ed} = 450 \text{ kN} \leq 501 \text{ kN}, \quad \text{OK} \]

4.2.3.2. Shear and bending interaction at the 2nd line of bolts
Not applicable because it is un-notched

4.2.4. Bending resistance at the notch
Not applicable because it is un-notched
4.2.5. Local stability of the notched beam
Not applicable because it is un-notched

4.3. Checks for tying
4.3.1. Angle cleats and bolt group resistance
4.3.1.1. Resistance of the angle cleats in bending

Basic requirement: $F_{Ed} \leq F_{Rd}$

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

The tying resistance for Mode 1, $F_{Rd,u,1}$ is given by:

$$F_{Rd,u,1} = \frac{(8n - 2e_w) M_{pl,u,Rd,u}}{2mn} - e_u (m + n)$$

$$\Sigma_{eff} = 2e_A + (n_1 - 1) p_A$$

$$e_A = e_1 \text{ but } 0,5(p_3 - t_w - 2r) + \frac{d_0}{2}$$

$$0,5(109 - 9 - 2 \times 11) + \frac{22}{2} = 50 \text{ mm}$$

$$\therefore e_A = 40 \text{ mm}$$

$$p_A = p_1 \text{ but } p_3 - t_w - 2r + d_0$$

$$p_3 - t_w - 2r + d_0 = 109 - 9 - 2 \times 11 + 22 = 100 \text{ mm}$$

$$\therefore p_A = 70 \text{ mm}$$

$$\Sigma_{eff} = 2e_A + (n_1 - 1) p_A = 2 \times 40 + (6 - 1) 70 = 430 \text{ mm}$$

$$M_{pl,u,Rd,u} = \frac{0,25 \Sigma_{eff} t f_{u,ac}}{\gamma_{Mu}} = \frac{0,25 \times 430 \times 10^2 \times 430}{2} \times 10^{-6} = 4,2 \text{kNm}$$

$$m = p_3 - t_w - 2t_{ac} - 2 \times 0,8 \times r = \frac{109 - 9 - 2 \times 10 - 2 \times 0,8 \times 11}{2} = 31 \text{ mm}$$

$$e_w = \frac{d_w}{4} = \frac{37}{4} = 9,25 \text{ mm}$$

$$n = \min(e_2 ; 1,25m) = \min(40 ; 39) = 39 \text{ mm}$$
The tying resistance for mode 2, $F_{Rd,u,2}$ is given by:

$$F_{Rd,u,2} = \frac{2M_{pl,2,Rd,u} + n\Sigma F_{t,Rd,u}}{m + n}$$

$$M_{pl,2,Rd,u} = M_{pl,1,Rd,u} = 4,20 \text{kNm}$$

$$F_{t,Rd,u} = \frac{k_2 f_{ub} A}{\gamma_{Mu}} = \frac{0.9 \times 800 \times 245}{1,1} \times 10^{-3} = 160 \text{kN}$$

$$F_{Rd,u,2} = 2 \times 4,2 \times 10^3 + 39 \times 12 \times 160 \over 31 + 39 = 1190 \text{kN}$$

The tying resistance for mode 3, $F_{Rd,u,3}$ is given by

$$F_{Rd,u,3} = \Sigma F_{t,Rd,u} = 12 \times 160 = 1920 \text{kN}$$

$$F_Rd = \min(F_{Rd,u,1}, F_{Rd,u,2}, F_{Rd,u,3})$$

$$F_Rd = \min(696, 1190, 1920) = 696 \text{kN}$$

$$F_{Ed} = 370 \text{kN} \leq 696 \text{kN}, \text{ OK}$$

### 4.3.1.2. Shear resistance of bolts

Basic requirement: $F_{Ed} \leq F_{Rd}$

$$F_{Rd} = 2n_b F_{v,u}$$

$$F_{v,u} = \frac{\alpha_v f_{ub} A}{\gamma_{Mu}} = \frac{0.6 \times 800 \times 245}{1,1} \times 10^{-3} = 107 \text{kN}$$

$$F_{Rd} = 2 \times 6 \times 107 = 1284 \text{kN}$$

$$F_{Ed} = 370 \text{kN} \leq 1284 \text{kN}, \text{ OK}$$

### 4.3.1.3. Bearing resistance of bolts on the angle cleats

Basic requirement: $F_{Ed} \leq F_{Rd}$

$$F_{Rd} = 2n_b F_{b,hor,u,Rd}$$
4.4 Worked Example – Angle Web Cleats

\[ F_{b,\text{hor},u,Rd} = \frac{k_1 \alpha_b f_{u,ac} d_{ac}}{\gamma_{Mu}} \]

\[ k_1 = \min \left( 2,8 \frac{e_1}{d_0} - 1,7; \ 1,4 \frac{p_1}{d_0} - 1,7; \ 2,5 \right) \]
\[ = \min \left( 2,8 \frac{40}{22} - 1,7; \ 1,4 \frac{70}{22} - 1,7; \ 2,5 \right) = \min (3,39; \ 2,75; \ 2,5) = 2,5 \]

\[ \alpha_b = \min \left( \frac{e_2}{3d_0}; \ \frac{f_{ub}}{f_{u,ac}}; \ 1,0 \right) = \min \left( \frac{40}{3 \times 22}; \ \frac{800}{430}; \ 1,0 \right) \]
\[ = \min (0,61; \ 1,86; \ 1,0) = 0,61 \]

\[ F_{b,\text{hor},u,Rd} = \frac{2,5 \times 0,61 \times 430 \times 20 \times 10}{1,1} \times 10^{-3} = 119 \text{ kN} \]

\[ F_{Rd} = 2 \times 6 \times 119 = 1428 \text{ kN} \]

\[ F_{Ed} = 350 \text{ kN} \leq 1428 \text{ kN}, \quad \text{OK} \]

4.3.1.4. Block tearing resistance

\[ \theta_2 = 40 \]

Basic requirement: \( F_{Ed} \leq F_{Rd,b} \)

\[ F_{Rd,b} = \frac{f_{u,ac} A_{at}}{\gamma_{Mu}} + \frac{f_{y,ac} A_{rv}}{\sqrt{3} \gamma_{M0}} \]

Case 1

\[ A_{at} = 2t_{ac} [(n_1 - 1)p_1 - (n_1 - 1)d_0] = 2 \times 10 \times [(6 - 1) \times 70 - (6 - 1) \times 22] \]
\[ = 4800 \text{ mm}^2 \]

\[ A_{rv} = 4t_{ac} (e_2 - 0,5d_0) = 4 \times 10 (40 - 0,5 \times 22) = 1160 \text{ mm}^2 \]

\[ F_{Rd,b} = \left( \frac{430 \times 4800}{1,1} + \frac{275 \times 1160}{\sqrt{3} \times 1,0} \right) \times 10^{-3} = 2060 \text{ kN} \]
Case 2

\[ A_{nt} = 2t_{ac}\left[c_i + (n_i - 1)p_i - (n_i - 0.5)d_0\right] \]

\[ A_{nt} = 2 \times 10 \times \left[40 + (6 - 1) \times 70 - (6 - 0.5) \times 22\right] = 5380 \text{ mm}^2 \]

\[ A_{nv} = 2t_{ac}(e_2 - 0.5d_0) = 2 \times 10 \times (40 - 0.5 \times 22) = 580 \text{ mm}^2 \]

\[ F_{Rd,b} = \left(\frac{430 \times 5380}{1,1} + \frac{275 \times 580}{\sqrt{3 \times 1,0}}\right) \times 10^{-3} = 2195 \text{ kN} \]

\[ F_{Ed} = 370 \text{ kN} \leq 2060 \text{ and } 2195 \text{ kN}, \quad \text{OK} \]

4.3.2. Beam web resistance

4.3.2.1. Bearing resistance of bolts on the beam web

Basic requirement: \( F_{Ed} \leq F_{Rd} \)

\[ F_{Rd} = m_b F_{b_hor,u,Rd} \]

\[ F_{b_hor,u,Rd} = \frac{k_1 \alpha_b f_{u,b} d_w}{\gamma_{Mu}} \]

\[ k_1 = \min\left(1,4 \frac{p_i}{d_0} - 1,7; \ 2,5\right) = \min\left(1,4 \frac{70}{22} - 1,7; \ 2,5\right) = 2,5 \]

\[ \alpha_b = \min\left(\frac{e_{2,b}}{3d_0}; \ \frac{f_{ub}}{f_{u,b}}; \ 1,0\right) = \min\left(\frac{40}{3 \times 22}; \ \frac{800}{430}; \ 1,0\right) = 0,61 \]

\[ F_{b_hor,u,Rd} = \frac{2,5 \times 0,61 \times 430 \times 20 \times 9}{1,1} \times 10^{-3} = 107 \text{ kN} \]

\[ F_{Rd} = 6 \times 107 \times 642 \text{ kN} \]

\[ F_{Ed} = 370 \text{ kN} \leq 642 \text{ kN}, \quad \text{OK} \]

4.3.2.2. Tension resistance of the beam web

Basic requirement: \( F_{Ed} \leq F_{Rd,n} \)

\[ F_{Rd,n} = 0,9 A_{net,wb} \frac{f_{u,b}}{\gamma_{Mu}} \]

\[ A_{net,wb} = t_w h_{ac} - d_0 n_1 t_w = 9 \times 430 - 22 \times 6 \times 9 = 2682 \text{ mm}^2 \]
\[ F_{Rd,n} = 0.9 \times 2682 \times \frac{430}{1,1} \times 10^{-3} = 944 \text{ kN} \]

\[ F_{Ed} = 370 \text{ kN} \leq 944 \text{ kN}, \quad \text{OK} \]

### 4.3.2.3. Block tearing resistance

**Basic requirement:** \( F_{Ed} \leq F_{Rd,b} \)

\[ F_{Rd,b} = \frac{f_{u,b} A_{nt}}{\gamma_{Mu}} + \frac{f_{y,b} A_{nv}}{\sqrt{3} \gamma_{M0}} \]

**Case 1**

\[ A_{nt} = t_w [ (n_i - 1) p_i - (n_i - 1) d_o ] = 9[(6 - 1) \times 70 - (6 - 1)22] \]

\[ = 2160 \text{ mm}^2 \]

\[ A_{nv} = 2t_w (e_{2,b} - 0.5d_o) = 2 \times 9(40 - 0.5 \times 22) = 522 \text{ mm}^2 \]

\[ F_{Rd,b} = \left( \frac{430 \times 2160}{1,1} + \frac{275 \times 522}{\sqrt{3} \times 1,0} \right) \times 10^{-3} = 927 \text{ kN} \]

\[ F_{Ed} = 370 \leq 927 \text{ kN}, \quad \text{OK} \]

(Case 2 only applies to notched beams)
5 COLUMN SPLICES (BEARING TYPE)

Column splices are designed assuming they must resist both the axial compression and, where appropriate, a nominal moment from the connection to the beams.

In bearing type splices, the axial load is transferred directly between the ends of the column sections (with a division plate if necessary due to the change of serial size) and not via the splices plates. The plates provide the splice with adequate stiffness and tying resistance.

5.1 Recommended details

1  Web cover plate width ≥ 0,5\(h_{uc}\)
2  Multiple packs thickness \(t_{pa}\)
3  Web cover plate at least 4 no. M20, 8.8 bolts – See notes
   For double-sided web cover plates, thickness ≥ \(t_{wc,uc}/2\)
   For single-sided web cover plates, thickness ≥ \(t_{w,uc}\)
4  Flange cover plate. Height: \(h_p ≥ 2b_{uc}\) and 225 mm; Width: \(b_p ≥ b_{uc}\);
   Thickness: \(t_p ≥ t_{f,uc}/2\) and 10 mm
5  Bolts (normally untorqued in clearance holes) – See notes
6  Packs arranged as necessary
7  Wide bolt spacing for joint rigidity

Ends of column sections in direct bearing
Cleat length $> 0.5h_{uc}$

Web angle cleats at least 2 no. M20, 8.8 bolts each side

Multiple packs thickness $t_{pa}$

Flange cover plate as above

Division plate thickness should be at least, \[
\left(\frac{(h_{lc} - 2t_{lc}) - (h_{uc} - 2t_{uc})}{2}\right)/L_j
\]

Direct bearing onto a division plate

Web cover plate width $\geq 0.5h_{uc}$

Web cover plate at least 4 no. M20, 8.8 bolts

Flange cover plate. Height: $h_p \geq 2b_{uc}$ and 450 mm; Width: $b_p \geq (b_{uc} - 2t_{w,lc} - 2r_{lc})/2$; Thickness: $t_p \geq t_{w,uc}/2$ and 10 mm, ($r_{lc}$ = root radius)

Bolts (normally untorqued in clearance holes) – See notes

Packs arranged as necessary

Wide bolt spacing for joint rigidity

Internal flange cover plates
Notes:
1. Bolt spacing and edge distances should comply with the recommendations of EN 1993-1-8:2005
2. The thickness of the flange cover plate should be at least the minimum of 10, \( t_{	ext{fuc}}/2 \) and \( p_1/14 \).
3. The thickness mentioned in Note 2 is in most cases sufficient to transmit at least 25% of the maximum compressive force in the column, as required by EN 1993-1-8 [§6.2.7.1(14)].
4. The column splices should be located at approximately 600 mm above floor beam level. It is also recommended to use a minimum of four bolts. In a braced frame, columns containing such splices will behave satisfactorily even if the joint effectively behaves as a pin. In practice, typical bearing column splices as given in this guide will provide significant stiffness about both axes, although less than full stiffness.
5. In common practice the width of the flange cover plate would not be greater than the width of the lower column flange. However if the width of the flange cover plate is narrower than the upper column flange then edge and end distances should be checked against the Eurocode (EN 1993-1-8 Table 3.3).

If there is significant net tension then the following notes should be adhered to:

6. Bolt diameters must be at least 75% of packing thickness \( t_{	ext{pa}} \).
7. The number of plies in multiple packs should not exceed four.
8. There should not be more than one jump in serial size of column at the splice.
9. If external and internal flange covers are to be provided, the size should be similar to those shown in the figures and the combined thickness of the external and internal cover plates must be at least \( t_{	ext{fuc}} / 2 \). All cover plates should be at least 10 mm thick.
5.2 Checks for tension

5.2.1 Net tension

5.2.1.1 Net tension effects

The following checks the presence of net tension due to axial load and bending moment[4]:

If \( M_{Ed} \leq \frac{N_{Ed,G} \cdot h}{2} \), then net tension does not occur and so the splice need only be detailed to transmit axial compression by direct bearing.

If \( M_{Ed} > \frac{N_{Ed,G} \cdot h}{2} \), then net tension does occur and the flange cover plates and their fasteners should be checked for tensile force, \( F_{Ed} \).

\[
F_{Ed} = \frac{M_{Ed}}{h} - \frac{N_{Ed,G}}{2}
\]

\( M_{Ed} \) is the nominal moment due to factored permanent and variable loads (i.e. column design moment) at the floor level immediately below the splice.

\( N_{Ed,G} \) is the axial compressive force due to factored permanent loads only.

\( h \) is conservatively the overall depth of the smaller column (for external flange cover plates) or the centreline to centreline distance between the flange cover plates (for internal flange cover plates).

Preloaded bolts should be used when net tension induces stress in the upper column flange > 10% of the design strength of that column.
5.2.1.2 Tension resistance of the flange cover plate

Basic requirement: \( F_{Ed} \leq N_{t,Rd} \)

\( N_{t,Rd} = \min(N_{pl,Rd}; N_{u,Rd}; N_{bt,Rd}) \)

**Tension resistance of gross section**

\( N_{pl,Rd} \) is the tension plastic resistance of the gross section

\[
N_{pl,Rd} = \frac{A_{fp} f_{y,p}}{\gamma_M 0}
\]

[EN 1993-1-1 §6.2.3(2)]

where:

\( A_{fp} \) is the gross area of the flange cover plate(s) attached to one flange

**Tension resistance of net section**

\( N_{u,Rd} \) is the tension ultimate resistance of the net area

\[
N_{u,Rd} = \frac{0.9 A_{fp,net} f_{u,p}}{\gamma_M 2}
\]

[EN 1993-1-1 §6.2.3(2)]

where:

\( A_{fp,net} \) is the net area of the flange cover plate(s) attached to one flange

\( A_{fp,net} = A_{fp} - n_2 d_0 p \)
Part 5: Joint Design

**Block tearing resistance**

$N_{bt,Rd}$ is the block tearing resistance

For a concentrically loaded bolt group: $N_{bt,Rd} = V_{eff,1,Rd}$

$$V_{eff,1,Rd} = \frac{f_{u,p} A_{fp,nt} + \frac{f_{y,p} A_{fp,rv}}{\gamma_{M2}}}{\sqrt{3} \gamma_{M0}}$$  \[EN 1993-1-8 §3.10.2(2)]

For eccentrically loaded bolt group: $N_{bt,Rd} = V_{eff,2,Rd}$

$$V_{eff,2,Rd} = \frac{0.5 f_{u,p} A_{fp,nt} + \frac{f_{y,p} A_{fp,rv}}{\gamma_{M2}}}{\sqrt{3} \gamma_{M0}}$$  \[EN 1993-1-8 §3.10.2(3)]

where:

- $f_{y,uc}$ is the yield strength of the upper column
- $f_{u,uc}$ is the ultimate tensile strength of the upper column
- $A_{fp,rv}$ is the net area of the flange cover plate subjected to shear
  $$A_{fp,rv} = 2t_p \left( e_1 + (n_1 - 1)p_1 - (n_1 - 0.5)d_0 \right)$$
- $A_{fp,nt}$ is the net area of the flange cover plate subjected to tension
  If $p_2 \leq 2e_2$  
  $A_{fp,nt} = t_p(p_2 - d_0)$  \(\text{Figure A}\)
  If $p_2 > 2e_2$  
  $A_{fp,nt} = t_p(2e_2 - d_0)$  \(\text{Figure B}\)

$\gamma_{M2}$ is the partial factor for the resistance of net sections

**Check for significant net tension:**

If $\frac{F_{Ed}}{t_{f,uc} b_{f,uc} f_{y,uc}} > 0.1$ then preloaded bolts should be used\[4\].

where:

- $t_{f,uc}$ is the flange thickness of the upper column
$b_{fu,c}$ is the flange width of the upper column

### 5.2.1.3 Bolt group resistance

![Diagram of bolt group resistance]

**Basic requirement:** $F_{Ed} \leq F_{Rd}$

$F_{Rd,fp}$ is the design resistance of bolt group \[EN 1993-1-8, \S 3.7(1)\]

- $F_{Rd} = \sum F_{b,Rd}$ if $(F_{b,Rd})_{\text{max}} \leq F_{v,Rd}$
- $F_{Rd} = n_{fp}(F_{b,Rd})_{\text{min}}$ if $(F_{b,Rd})_{\text{min}} \leq F_{v,Rd} \leq (F_{b,Rd})_{\text{max}}$
- $F_{Rd} = n_{fp}F_{v,Rd}$ if $F_{v,Rd} \leq (F_{b,Rd})_{\text{min}}$

$n_{fp}$ is the number of bolts between one flange cover plate and upper column

**Shear resistance of bolts**

$F_{v,Rd}$ is the shear resistance of a single bolt

$$F_{v,Rd} = \beta_p \frac{\gamma_{M2}}{\alpha_v} \frac{F_{ub}}{A}$$ \[EN 1993-1-8, \text{Table 3.4}\]

where:

- $\alpha_v = 0.6$ for 4.6 and 8.8 bolts = 0.5 for 10.9 bolts
- $A$ is the tensile stress area of the bolt, $A_s$
- $\beta_p = 1.0$ if $t_{pa} \leq d/3$ \[EN 1993-1-8 \S 3.6.1(12)\]
- $\beta_p = \frac{9d}{8d + 3t_{pa}}$ if $t_{pa} > d/3$

$t_{pa}$ is the total thickness of the packing

$\gamma_{M2}$ is the partial factor for resistance of bolts
Check for long joint:  
$L_j$ is the joint length from EN1993-1-8[1], § 3.8  
If $L_j > 15d$ the design shear resistance $F_{v,Rd}$ should be reduced by multiplying it by a reduction factor $\beta_{L_f}$.

$$\beta_{L_f} = 1 - \frac{L_j - 15d}{200d}$$

**Bearing resistance**  
$F_{b,Rd}$ is the bearing resistance of a single bolt

$$F_{b,Rd} = \frac{k_1 \alpha_b \mu \tau_{ub}}{\gamma_{M2}}$$  
[EN 1993-1-8 Table 3.4]

Note: If the thickness of the column flange is less than the thickness of the flange cover plates, then the bearing resistance of the column flange should also be checked.

For end bolts:

$$\alpha_b = \min \left(\frac{e_1}{3d_0}; \frac{\mu \tau_{ub}}{f_{u,p}}; 1,0 \right)$$

For inner bolts:

$$\alpha_b = \min \left(\frac{p_1}{3d_0}; \frac{1}{4}; \frac{\mu \tau_{ub}}{f_{u,p}}; 1,0 \right)$$

For edge bolts:

$$k_1 = \min \left(2.8 \frac{e_2}{d_0} - 1.7; 2.5 \right)$$

For inner bolts:

$$k_1 = \min \left(1.4 \frac{p_2}{d_0} - 1.7; 2.5 \right)$$

$\gamma_{M2}$ is the partial factor for plate in bearing

**Resistance of preloaded bolts:**  
$F_{Ed} \leq F_{s,Rd}$  
For joints designed to be non-slip under factored loads.  
$F_{s,Rd}$ is the design slip resistance

$$F_{s,Rd} = \frac{k_s \mu}{\gamma_{M3}} F_{p,C}$$  
[EN 1993-1-8 §3.9.1(1)]
where:

- \( k_s = 1.0 \) for fasteners in standard clearance holes
  (Table 3.6 of EN1993-1-8\cite{1})
- \( n_{fs} \) is the number of friction surfaces
- \( \mu \) is the slip factor (Table 18 of EN1090-2 \cite{12})
- \( F_{p,C} = 0.7 f_{ub} A_s \) \[ EN 1993-1-8 §3.6.1(2) \]
- \( A_s \) is the tensile stress area of the bolt
- \( 
\gamma_{M3} \) is the partial factor for slip resistance at ultimate limit state

5.3 **Check for horizontal shear**

For a bearing type splice, any horizontal shear \( V_{Ed} \) is assumed to be resisted by friction across the splice interface\cite{4}.

Basic requirement: \( V_{Ed} \leq \) shear resistance of splice interface

The coefficient of friction \( \mu_f \) for a steel interface depends upon the surface condition of the steel and on any coatings provided.

Conservatively, for steel with no surface treatment, with mill scale, the coefficient of friction, \( \mu_f \) may be taken as 0.2.

Shear resistance of splice interface = Vertical load \( \times \) Coefficient of friction

5.4 **Checks for vertical tying**

If it is necessary to comply with structural integrity requirements, then checks 4.2.1.2 and 4.2.1.3 should be carried out\cite{4} with:

\[ F_{Ed} = \frac{F_{tie}}{2} \]
Part 5: Joint Design

The yield strength should be replaced with the ultimate strength.

The partial safety factors ($\gamma_{M0}, \gamma_{M2}$) should also be replaced with the partial factor for tying resistance. ($\gamma_{Mu} = 1,1$).

Note:
1. The structural integrity checks are based on the conservative assumption that the tie force is resisted by the two flange cover plates.
5. $F_{tie}$ is the tensile force from EN1991-1-7, § A.6.
5. Column Splice
Details and data

Flange cover plates: 2/260 × 12 × 525
Flange packs: 2/260 × 30 × 240
Cleats: 4/90 × 90 × 8 Angles × 150 long
Web Packs: 2/85 × 2 × 150
Division plate: 265 × 25 × 310
Bolts: M20 8.8
Fittings material: S275 steel
### Summary of full design checks

#### Design forces

<table>
<thead>
<tr>
<th>Force</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{Ed,G}$</td>
<td>760 kN</td>
</tr>
<tr>
<td>$N_{Ed,Q}$</td>
<td>870 kN</td>
</tr>
<tr>
<td>$M_{Ed}$</td>
<td>110 kNm (about yy axis of column)</td>
</tr>
<tr>
<td>$V_{Ed}$</td>
<td>60 kN</td>
</tr>
</tbody>
</table>

#### Tension resistances

- **Net tension**
  - Tensile resistance of the flange cover plate: 802 kN
  - Bolt group resistance: 272 kN

#### Horizontal shear resistance

- 161 kN

#### Tying resistances

- **Tensile resistance of the flange cover plate**: 912 kN
- **Bolt group resistance**: 308 kN

### 5.1. Recommended details

**External flange cover plates**

- Height, $h_p \geq 2h_{uc}$ and 450 mm
- Width, $b_p \geq b_{uc} = 260$ mm   Say 260 mm, OK

**Maximum vertical bolt spacing**, $p_1 = 14t_p$, i.e. minimum thickness is $p_1/14$

- **Thickness, $t_p$**
  - $\geq \frac{t_{f,uc}}{2}$ and 10 mm and $\frac{p_1}{14}$
  - $= \frac{17.5}{2}$ and 10 mm and $\frac{160}{14}$
  - $= 8.75$ mm and 10 mm and 11.4 mm

  Say 12 mm, OK

- **Packs, $t_{pa}$**
  - $= \frac{h_{lc} - h_{uc}}{2} = \frac{320 - 260}{2} = 30$ mm

  Say 30 mm, OK

**Division plate**

- **Thickness**
  - $\geq \frac{[h_{lc} - 2t_{f,lc} - (h_{uc} - 2t_{f,uc})]}{2}$
  - $= \frac{[320 - 2 \times 20.5 - (260 - 2 \times 17.5)]}{2} = 27$ mm

  Say 25 mm, OK
Web cleats
Use 90×90×8 angles to accommodate M20 bolts in opposite positions on adjoining legs.

Length \( \geq 0.5h_{uc} = 0.5 \times 260 = 130 \text{ mm} \) Say 150 mm, OK

Packs, \( t_{pa} = \frac{t_{w,le} - t_{w,uc}}{2} = \frac{11.5 - 10}{2} = 0.8 \text{ mm} \) Say 2 mm, OK

5.2. Checks for vertical shear

5.2.1. Net tension

5.2.1.1. Net tension effects

Basic requirement for no net tension: \( M_{Ed} \leq \frac{N_{Ed,G} \times h}{2} \)

\[
\frac{N_{Ed,G} \times h}{2} = \frac{760 \times 260}{2} \times 10^{-3} = 99 \text{ kNm}
\]

\( M_{Ed} = 110 \text{ kNm} > 99 \text{ kNm} \)

Net tension does occur and the flange cover plates and their fastenings must be checked for a tensile force \( F_{Ed} \).

\[
F_{Ed} = \frac{M_{Ed}}{h} - \frac{N_{Ed,G}}{2} = \frac{110}{260 \times 10^{-3}} - \frac{760}{2} = 43 \text{ kN}
\]

5.2.1.2. Tension resistance of the flange cover plate

Basic requirement: \( F_{Ed} \leq N_{t,Rd} \)

Where \( N_{t,Rd} = \min\left( N_{pl,Rd} ; N_{u,Rd} ; N_{bt,Rd} \right) \)

Tension resistance of gross section

\[
N_{pl,Rd} = \frac{A_{fp} f_{y,p}}{\gamma_{M0}}
\]

Gross area, \( A_{fp} = 260 \times 12 = 3120 \text{ mm}^2 \)

\[
N_{pl,Rd} = \frac{3120 \times 275}{1,0} \times 10^{-3} = 858 \text{ kN}
\]

Tension resistance of net section

\[
N_{u,Rd} = \frac{0.9 A_{fp,net} f_{u,p}}{\gamma_{M2}}
\]

Net area, \( A_{fp,net} = 260 \times 12 - 2 \times 22 \times 12 = 2592 \text{ mm}^2 \)

\[
N_{u,Rd} = \frac{0.9 \times 2592 \times 430}{1,25} \times 10^{-3} = 802 \text{ kN}
\]

Thus \( N_{u,Rd} = 802 \text{ kN} \)
5.4 Worked Example – Column Splice

**Block tearing resistance**

For concentrically loaded bolt group: $N_{bt,Rd} = V_{eff,1,Rd}$

$2e_2 = 2 \times 55 = 110 \text{ mm}$

$p_2 = 150 \leq 2e_2$

Hence

$A_{fp,nt} = t_p \left( 2e_2 - d_0 \right) = 12 \left( 2 \times 55 - 22 \right) = 1056 \text{ mm}^2$

$A_{fp,nv} = 2t_p \left( e_1 + (n_1 - 1)p_1 - (n_1 - 0,5)d_0 \right)$

$= 2 \times 12 \left( 40 + (2 - 1) \times 160 - (2 - 0,5) \times 22 \right) = 4008 \text{ mm}^2$

$V_{eff,1,Rd} = \left[ \frac{430 \times 1056}{1,25} + \frac{275 \times 4008}{\sqrt{3} \times 1,0} \right] \times 10^{-3} = 1000 \text{ kN}$

$N_{bt,Rd} = 1000 \text{ kN}$

$N_{t,Rd} = \min(858; 802; 1000) = 802 \text{ kN}$

$F_{Ed} = 43 \text{ kN} \leq 802 \text{ kN}, \text{ OK}$

**Check for the suitability of ordinary bolts.**

(It is sufficiently accurate to base this calculation on the gross area of the flange)

$\frac{F_{Ed}}{t_{f,ac} b_{f,ac} f_{y,uc}} = \frac{43 \times 10^3}{12,5 \times 260 \times 355} = 0,04 < 0,1$

There is no significant net tension in the column flange and the use of ordinary bolts in clearance holes is satisfactory.

**5.2.1.3. Bolt group resistance**

![Flange cover plate diagram](image)

Shear and bearing resistance of the flange cover plate

Basic requirement: $F_{Ed} \leq F_{Rd}$
The design resistance of the bolt group, \( F_{Rd,fp} \):  
\[
F_{Rd} = \sum F_{b,Rd} \quad \text{if } \left( F_{b,Rd} \right)_{\text{max}} \leq F_{v,Rd}
\]
\[
F_{Rd} = n_{fp}(F_{b,Rd})_{\text{min}} \quad \text{if } (F_{b,Rd})_{\text{min}} \leq F_{v,Rd} < (F_{b,Rd})_{\text{max}}
\]
\[
F_{Rd} = n_{fp}F_{v,Rd} \quad \text{if } F_{v,Rd} < (F_{b,Rd})_{\text{min}}
\]

**Shear resistance of bolts**

The shear resistance of a single bolt, \( F_{v,Rd} = \frac{\alpha_{v}f_{ub}A}{\gamma_{M2}} \) Table 3.4

A factor to account for the long joint effect must be introduced if \( L_j > 15d \)

\[
15d = 15 \times 20 = 300 \text{ mm}
\]

\[
L_j = 160 \text{ mm, } < 15d
\]

Therefore there is no long joint effect.

Total thickness of flange pack, \( t_{pa} = 30 \text{ mm} > \frac{d}{3} = 6,7 \text{ mm} \)

Therefore \( F_{v,Rd} \) must be multiplied by a reduction factor \( \beta_p \).

\[
\beta_p = \frac{9d}{8d + 3t_{pa}} = \frac{9 \times 20}{8 \times 20 + 3 \times 30} = 0,72
\]

For M20 8.8 bolts, \( F_{v,Rd} = 0,72 \times \frac{0,6 \times 800 \times 245}{1,25} \times 10^{-3} = 68 \text{ kN} \)

**Bearing resistance**

Bearing resistance, \( F_{b,Rd} = \frac{k_1 \alpha_{b}f_{u,p}dt_{p}}{\gamma_{M2}} \) Table 3.4

For edge bolts,  
\[
k_1 = \min \left( 2,8 \frac{e_2}{d_0}, 1,7; \ 2,5 \right) = \min \left( 2,8 \frac{55}{22}, 1,7; \ 2,5 \right)
\]

\[
= \min (5,3; \ 2,5) = 2,5
\]

For end bolts  
\[
\alpha_{b} = \min \left( \frac{e_1}{3d_0}; \ \frac{f_{ub}}{f_{u,p}}; \ 1,0 \right) = \min \left( \frac{40}{3 \times 22}; \ \frac{800}{430}; \ 1,0 \right)
\]

\[
= \min (0,61; \ 1,86; \ 1,0) = 0,61
\]

For inner bolts,  
\[
\alpha_{b} = \min \left( \frac{p_1}{3d_0} - 0,25; \ \frac{f_{ub}}{f_{u,p}}; \ 1,0 \right)
\]

\[
= \min \left( \frac{160}{3 \times 22} - 0,25; \ \frac{800}{430}; \ 1,0 \right)
\]

\[
= \min (2,17; \ 1,86; \ 1,0) = 1,0
\]
5.4 Worked Example – Column Splice

End bolts, \( F_{b,Rd,\text{end}} = (F_{b,Rd})_{\text{min}} = \frac{2.5 \times 0.61 \times 430 \times 20 \times 12}{1.25} \times 10^{-3} \)
\[= 126 \text{ kN} \]

Inner bolts, \( F_{b,Rd,\text{inner}} = (F_{b,Rd})_{\text{max}} = \frac{2.5 \times 1.0 \times 430 \times 20 \times 12}{1.25} \times 10^{-3} \)
\[= 206 \text{ kN} \]

Thus \( F_{v,Rd} < (F_{b,Rd})_{\text{min}} \)

\[F_{\text{Ed}} = \frac{n_{fp} \times F_{v,Rd}}{2} = 4 \times 68 = 272 \text{ kN} \]

\[F_{\text{Ed}} = 43 \text{ kN} \leq 272 \text{ kN}, \text{ OK} \]

5.2.2. Check for horizontal shear

For a bearing type splice, any horizontal shear \( V_{\text{Ed}} \) is assumed to be resisted by friction across the splice interface. Ref [4]

Basic requirement: \( V_{\text{Ed}} \leq \) shear resistance of splice interface

Vertical load with coexistent shear

\[M_{\text{Ed}} + \frac{N_{\text{Ed,G}}}{2} = \frac{110 \times 10^3}{260} + \frac{760}{2} = 803 \text{ kN} \]

Shear resistance of splice interface: \( 803 \times 0.2 = 161 \text{ kN} \)

\[V_{\text{Ed}} = 60 \text{ kN} \leq 161 \text{ kN}, \quad \text{OK} \]

5.3. Structural integrity

5.3.1. Tying force

Check 4.2.1.2 and 4.2.1.3 should be carried out with:

\[F_{\text{Ed}} = \frac{F_{\text{tie}}}{2} \]

\[F_{\text{tie}} = 2 \times F_{\text{Ed}} = 2 \times 43 = 86 \text{ kN} \]

5.3.2. Tensile resistance of the flange cover plate

Basic requirement: \( F_{\text{tie}} \leq N_{t,Rd} \)

Where \( N_{t,Rd} = \min\left( N_{p1,Rd} ; N_{u,Rd} ; N_{br,Rd} \right) \)

5.3.2.1. Tension resistance of the gross area

\[N_{p1,Rd} = \frac{A_{fp} f_{u,p}}{\gamma_{Mu}} \]

Gross area, \( A_{fp} = 260 \times 12 = 3120 \text{ mm}^2 \)

\[N_{p1,Rd} = \frac{3120 \times 430}{1.1} \times 10^{-3} = 1220 \text{ kN} \]
5.3.2.2. **Tension resistance of the net area**

\[ N_{u,Rd} = \frac{0.9 \, A_{fp,\text{net}} \, f_{u,p}}{\gamma_{Mu}} \]

Net area, \( A_{fp,\text{net}} = 260 \times 12 - 2 \times 22 \times 12 = 2592 \text{ mm}^2 \)

\[ N_{u,Rd} = \frac{0.9 \times 2592 \times 430}{1.1} \times 10^{-3} = 912 \text{ kN} \]

Thus \( N_{u,Rd} = 912 \text{ kN} \)

5.3.2.3. **Block tearing resistance**

For concentrically loaded bolt group: \( N_{bt,Rd} = V_{\text{eff},1,Rd} \)

\[ 2e_2 = 2 \times 55 = 110 \text{ mm} \]
\[ \rho_2 = 150 \leq 2e_2 \]

Hence

\[ A_{fp,nt} = t_p(2e_2 - d_0) = 12(2 \times 55 - 22) = 1056 \text{ mm}^2 \]
\[ A_{fp,nv} = 2t_p \left[ e_1 + (n_1 - 1)p_1 - (n_1 - 0.5)d_0 \right] \]
\[ = 2 \times 12 \left[ 40 + (2 - 1) \times 160 - (2 - 0.5) \times 22 \right] = 4008 \text{ mm}^2 \]

\[ V_{\text{eff},1,Rd} = \left( \frac{430 \times 1056}{1.1} + \frac{275 \times 4008}{\sqrt{3} \times 1.0} \right) \times 10^{-3} = 1049 \text{ kN} \]

\[ N_{bt,Rd} = 1049 \text{ kN} \]
\[ N_{t,Rd} = \min(1220; 912; 1049) = 802 \text{ kN} \]
\[ F_{\text{tie}} = 86 \text{ kN} \leq 912 \text{ kN}, \text{ OK} \]

5.3.2.4. **Bolt group resistance**

Shear and bearing resistance of the flange cover plate

Basic requirement: \( F_{\text{tie}} \leq F_{Rd} \)

The design resistance of the bolt group, \( F_{Rd,fp} \):  

\[ F_{Rd} = \sum F_{b,Rd} \quad \text{if} \quad \left( F_{b,Rd} \right)_{\text{max}} \leq F_{v,Rd} \]

\[ F_{Rd} = n_{fp} \left( F_{b,Rd} \right)_{\text{min}} \quad \text{if} \quad \left( F_{b,Rd} \right)_{\text{min}} \leq F_{v,Rd} < \left( F_{b,Rd} \right)_{\text{max}} \]

\[ F_{Rd} = n_{fp} F_{v,Rd} \quad \text{if} \quad F_{v,Rd} < \left( F_{b,Rd} \right)_{\text{min}} \]

**Shear resistance of bolts**

The shear resistance of a single bolt, \( F_{v,Rd} = \frac{\alpha_v f_{ub} A}{\gamma_{Mu}} \)

A factor to account for the long joint effect must be introduced if \( L_j > 15d \)

\[ 15d = 15 \times 20 = 300 \text{ mm} \]
\[ L_j = 160 \text{ mm}, < 15d \]
Therefore there is no long joint effect.

Total thickness of flange pack, \( t_{pa} = 30\text{mm} > \frac{d}{3} = 6,7 \text{ mm} \)

Therefore \( F_{v,Rd} \) must be multiplied by a reduction factor \( \beta_p \).

\[
\beta_p = \frac{9d}{8d + 3t_{pa}} = \frac{9 \times 20}{8 \times 20 + 3 \times 30} = 0,72
\]

For M20 8.8 bolts, \( F_{v,Rd} = 0,72 \times \frac{0,6 \times 800 \times 245}{1,1} \times 10^{-3} = 77 \text{ kN} \)

**Bearing resistance**

Bearing resistance, \( F_{b,Rd} = \frac{k_1 \alpha_b f_{u,p} d_t}{\gamma_{Mu}} \)

For edge bolts, \( k_1 = \min\left(2,8 \frac{e}{d_0} - 1,7; \ 2,5\right) = \min\left(2,8 \frac{55}{22} - 1,7; \ 2,5\right) \)

\( = \min(5,3; \ 2,5) = 2,5 \)

For end bolts \( \alpha_b = \min\left(\frac{e_1}{3d_0}; \frac{f_{ub}}{f_{u,p}}; \ 1,0\right) = \min\left(\frac{40}{3 \times 22}; \frac{800}{430}; \ 1,0\right) \)

\( = \min(0,61; \ 1,86; \ 1,0) = 0,61 \)

For inner bolts, \( \alpha_b = \min\left(\frac{p_1}{3d_0} - 0,25; \frac{f_{ub}}{f_{u,p}}; \ 1,0\right) \)

\( = \min\left(\frac{160}{3 \times 22} - 0,25; \frac{800}{430}; \ 1,0\right) \)

\( = \min(2,17; \ 1,86; \ 1,0) = 1,0 \)

End bolts, \( F_{b,Rd,\text{end}} = (F_{b,Rd})_{\min} = \frac{2,5 \times 0,61 \times 430 \times 20 \times 12}{1,1} \times 10^{-3} \)

\( = 143 \text{ kN} \)

Inner bolts, \( F_{b,Rd,\text{inner}} = (F_{b,Rd})_{\max} = \frac{2,5 \times 1,0 \times 430 \times 20 \times 12}{1,1} \times 10^{-3} \)

\( = 235 \text{ kN} \)

Thus \( F_{v,Rd} < (F_{b,Rd})_{\min} \)

\( F_{Rd} = n_{fp} \times F_{v,Rd} = 4 \times 77 = 308 \text{ kN} \)

\( F_{\text{tie}} = 86 \text{ kN} \leq 308 \text{ kN}, \quad \text{OK} \)
6 COLUMN BASES

This design method applied to fixed bases of I section columns transmitting an axial compressive force, and a shear force (i.e. a nominally pinned column base). The rectangular base plate is welded to the column section in a symmetrically position so that it has projections beyond the column flange outer edges on all sides.

6.1 Base plate size

Basic requirement: \( A_p \geq A_{req} \)  

\[
A_p =  \text{area of base plate} = h_p b_p \text{ for rectangular plates}  \\
A_{req} =  \text{required area of base plate} = \frac{F_{Ed}}{f_{jd}} \\
f_{jd} = \frac{2}{3} \alpha f_{cd} \\
\]

where:

\[
\alpha = \min \left[ \left( 1 + \frac{d_f}{\max(h_p, b_p)} \right), \left( 1 + 2 \frac{e_h}{h_p} \right), \left( 1 + 2 \frac{e_b}{b_p} \right), 3 \right]  \\
\]

If some dimensions are unknown, a value of \( \alpha = 1.5 \) is generally appropriate.

- \( h_p \) is the length of the base plate
- \( b_p \) is the width of the base plate
- \( d_f \) is the depth of the concrete foundation
- \( h_t \) is the length of the concrete foundation
Part 5: Joint Design

\[ b_f \] is the width of the concrete foundation
\[ t_f \] is the flange thickness of the column
\[ e_b \] is the additional width outside of the base plate
\[ e_h \] is the additional depth outside of the base plate
\[ f_{cd} = \alpha_{cc} \frac{f_{ck}}{\gamma_c} \] [EN 1992-1-1, §3.1.6(1)]
\[ \alpha_{cc} \] is a coefficient that takes into account long term effects on the compressive strength and of unfavorable effects resulting from the way the load is applied.\(^{[13]}\)
\[ \gamma_c \] is the material factor for concrete from EN 1992-1-1, §2.4.2.4\(^{[13]}\)

<table>
<thead>
<tr>
<th>Concrete class</th>
<th>C20/25</th>
<th>C25/30</th>
<th>C30/37</th>
<th>C35/45</th>
</tr>
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<tbody>
<tr>
<td>Cylinder strength, fck (N/mm²)</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Cube strength, fck,cube (N/mm²)</td>
<td>25</td>
<td>30</td>
<td>37</td>
<td>45</td>
</tr>
</tbody>
</table>

6.2 Calculation of \( c \)

Basic requirement: \( A_{req} = A_{eff} \)

- If \( 2c \leq h - 2t_f \), then there is no overlap.
Thus \( c \) may be calculated from the following equations for I and H sections:

\[ A_{eff} \approx 4c^2 + Per_{col}c + A_{col} \]

where:

\[ A_{col} \] is the cross sectional area of the column
\[ Per_{col} \] is the column perimeter

- If \( 2c > h - 2t_f \), then there is an overlap.
Thus \( c \) may be calculated from the following equations for I and H sections:

\[ A_{eff} \approx 4c^2 + 2(h + b)c + h \times b \]
To ensure that the effective area fits on the base plate:

\[ h + 2c < h_p \]
\[ b + 2c < b_p \]

### 6.3 Base plate thickness

![Base plate thickness diagram]

Basic requirement: \( t_p \geq t_{p,\text{min}} \)

\[
t_{p,\text{min}} = c \sqrt{\frac{3 f_{jd} y M_0}{f_{yp}}} \tag{Reference 3}
\]

where:

- \( f_{yp} \) is the yield strength of the base plate
- \( f_{jd} = \frac{2}{3} \alpha f_{cd} \)
- \( f_{cd} = \alpha c c f_{ck} \gamma_c \)

\( \alpha, \alpha_{cc}, \gamma_c, f_{ck}, \) and \( c \) are as defined previously.
6.4 Base plate welds

Basic requirement:
For shear: \( V_{Ed} \leq F_{w,Rd} \times \ell_{\text{weld,shear}} \)  \[\text{Reference 4}\]

For axial load:
This check is only necessary when the contact faces of the column and base plate are not in tight bearing. See Reference \[4\] for more details.

\( F_{Ed} \leq F_{w,Rd} \times \ell_{\text{weld,axial}} \)

where:

\( F_{w,Rd} \) is the resistance of the fillet weld per unit length = \( f_{vw,d} \times a \)

\[
f_{vw,d} = \frac{f_u}{\beta_w \gamma_{M2}} \quad \text{[EN 1993-1-8 §4.5.3.3(3)]}
\]

\( f_u \) is ultimate tensile strength of the weaker part joined
\( \beta_w \)
- = 0.8 for S235 steel
- = 0.85 for S275 steel
- = 0.9 for S355 steel
- = 1.0 for S460 steel

\( a \) is the weld throat
\( \ell_{\text{weld,shear}} \) is total effective length of the welds in the direction of shear
\[
\ell_{\text{weld,shear}} = 2(l - 2s) \quad \text{(for IPE, HE, HD sections)}
\]

\( l \) is the weld length in the direction of shear
\( \ell_{\text{weld,axial}} \) is the total effective length of the welds to the column flange for rolled sections
\( \gamma_{M2} \) is the partial factor for welds from EN 1993-1-8

The leg length is defined as follows: \( s = a \sqrt{2} \)
6. Column base
Details and data

1. $600 \times 600 \times 50$ Base plate S275
2. 8 mm fillet welds
3. M24 grade 4.6 holding down bolts
4. Contact faces of the column and the base plate are in direct bearing

Unless noted otherwise, all references are to EN 1993-1-8
6.1. Base plate size

Basic requirement: \( A_p \geq A_{req} \)

Area of base plate: \( A_p = h_p \times b_p = 600 \times 600 = 360000 \text{ mm}^2 \)

Design strength of the concrete: \( f_{cd} = \frac{f_{ck}}{\gamma_c} = \frac{1,0 \times 30}{1,5} = 20 \text{ N/mm}^2 \)

Area required: \( A_{req} = \frac{N_{Ed}}{f_{jd}} = \frac{4300 \times 10^3}{\frac{2}{3} \times 1,5 \times 20} = 215000 \text{ mm}^2 \)

\( A_p = 360000 \text{ mm}^2 > 215000 \text{ mm}^2 \) OK

6.2. Calculation of c

To calculate the effective area, assume first that there is no overlap.

\[ A_{eff} \approx 4c^2 + Per_{col}c + A_{col} \]

Column perimeter \( Per_{col} = 1771 \text{ mm} \)

Area of column \( A_{col} = 16130 \text{ mm}^2 \)

\[ A_{eff} \approx 4c^2 + 1771c + 16130 = 215000 = A_{req} \]

\( \therefore c = 93 \text{ mm} \)

To ensure that there is no overlap, \( c \) has to be less than half the depth between flanges:

\[ h - 2t_f = \frac{320 - 2 \times 20,5}{2} = 139,5 \text{ mm} > 93 \text{ mm} \]

Therefore the assumption that there is no overlap is correct.
To check that the effective area fits on the base plate:

\[ h + 2c = 320 + 2 \times 93 = 506 \text{ mm} < 600 \text{ mm} \]

\[ b + 2c = 300 + 2 \times 93 = 486 \text{ mm} < 600 \text{ mm} \]

Therefore the calculated value of \( c \) is valid (otherwise recalculate \( c \)).

### 6.3. Base plate thickness

\[ t_{p,\text{min}} = c \sqrt{\frac{3f_{jd}\gamma_{M0}}{f_{y,p}}} \]

\[ f_{jd} = \frac{2}{3} \alpha f_{cd} = \frac{2}{3} \times 1.5 \times 20 = 20 \text{ N/mm}^2 \]

Yield strength of the 50 mm plate, \( f_{y,p} = 255 \text{ N/mm}^2 \)

\[ t_{p,\text{min}} = 93 \sqrt{\frac{3 \times 20 \times 1.0}{255}} = 45 \text{ mm} \]

\[ t_p = 50 \text{ mm} > 45 \text{ mm} \quad \text{OK} \]

### 6.4. Base plate welds (Shear resistance of column-to-base weld)

Basic requirement: \( V_{Ed} \leq F_{W,Rd} \times \ell_{\text{eff,shear}} \)

Ultimate tensile strength of the 50 mm plate, \( f_{u,p} = 410 \text{ N/mm}^2 \)

\[ F_{W,Rd} = f_{vw,d} \times a = \frac{f_u}{\beta_{w,y} M_2} \times a = \frac{410/\sqrt{3}}{0.85 \times 1.25} \times 0.7 \times 8 = 1248 \text{ N/mm} \]

\[ \ell_{\text{eff,shear}} = 2 (l - 2s) = 2(100 - 2 \times 8) = 168 \text{ mm} \]

\[ F_{W,Rd} \times \ell_{\text{eff,shear}} = 1248 \times 168 \times 10^{-3} = 210 \text{ kN} \]

\[ V_{Ed} = 100 \text{ kN} \leq 210 \text{ kN} \quad \text{OK} \]
APPENDIX A  Lateral torsional buckling strength

Lateral torsional buckling strength taken from BS 5950-1 Table 17\(^{[10]}\)

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Flow charts

Flow charts for End plate, Fin plate and Column bases are available on the
Access Steel web site (http://www.access-steel.com)

The document references for these joint types are as follows:

Partial depth end plate   SF008a
Fin plate             SF009a
Column bases         SF010a