Steel Design to Eurocode 3

Restrained Beams

A beam is considered restrained if:

- The section is bent about its minor axis
- Full lateral restraint is provided
- Closely spaced bracing is provided making the slenderness of the weak axis low
- The compressive flange is restrained again
- The section has a high torsional and lateral bending stiffness

There are a number of factors to consider when designing a beam, and they all must be satisfied for the beam design to be adopted:

- Bending Moment Resistance
- Shear Resistance
- Combined Bending and Shear
- Serviceability

Bending Moment Resistance

In Eurocode 3:

- Clause 6.2 covers the cross-sectional resistance
  - Clause 6.2.5 deals with the cross-sectional resistance for bending.

EN 1993-1-1 Clause 6.2.4 Equation 6.12 states that the design moment ($M_{Ed}$) must be less than the design cross-sectional moment resistance ($M_{c,Rd}$)

$$\frac{M_{Ed}}{M_{c,Rd}} \leq 1.0 \quad (6.12)$$

The equation to calculate $M_{c,Rd}$ is dependent on the class of the section. A detailed assessment of cross-section classification can be found in the ‘Local Buckling and Cross-Section Classification’ handout.

For Class 1 and 2 cross-sections:

$$M_{c,Rd} = M_{pl,Rd} = W_{pl} f_y / \gamma$$ \quad (6.13)

For Class 3 cross-sections:

$$M_{c,Rd} = M_{el,Rd} = W_{el,min} f_y / \gamma$$ \quad (6.14)

For Class 4 cross sections:

$$M_{c,Rd} = W_{eff,min} f_y / \gamma$$ \quad (6.15)

$\gamma = 1.0$

Section Modulus, W

Subscripts are used to identify whether or not the section modulus is plastic or elastic and the axis about which it acts.

<table>
<thead>
<tr>
<th>BS 5950</th>
<th>EC3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elastic modulus about the major axis</td>
<td>$Z_{xx}$</td>
</tr>
<tr>
<td>Elastic modulus about the minor axis</td>
<td>$Z_{yy}$</td>
</tr>
<tr>
<td>Plastic modulus about the major axis</td>
<td>$S_{xx}$</td>
</tr>
<tr>
<td>Plastic modulus about the minor axis</td>
<td>$S_{yy}$</td>
</tr>
</tbody>
</table>

Table 1.0 Section modulus terminology comparison between BS 5950 and EC3

Cross-section Classification Summary

1. Get $f_y$ from Table 3.1
2. Get $\varepsilon$ from Table 5.2
3. Substitute the value of $\varepsilon$ into the class limits in Table 5.2 to work out the class of the flange and web
4. Take the least favourable class from the flange outstand, web in bending and web in compression results to get the overall section class

Bending Moment Resistance Summary

1. Determine the design moment, $M_{Ed}$
2. Choose a section and determine the section classification
3. Determine $M_{c,Rd}$, using equation 6.13 for Class 1 and 2 cross-sections, equation 6.14 for Class 3 cross-sections, and equation 6.15 for Class 4 sections. Ensure that the correct value of $W$, the section modulus is used.
4. Carry out the cross-sectional moment resistance check by ensuring equation 6.12 is satisfied.

Shear Resistance

In Eurocode 3:

- Clause 6.2 covers the cross-sectional resistance
  - Clause 6.2.6 deals with the cross-sectional resistance for shear.

EN 1993-1-1 Clause 6.2.6 Equation 6.17 states that the design shear force ($V_{Ed}$) must be less than the design plastic shear resistance of the cross-section ($V_{pl,Rd}$)

$$\frac{V_{Ed}}{V_{pl,Rd}} \leq 1.0 \quad (6.17)$$
γ_{M0} = 1.0

Shear Resistance Summary

1. Calculate the shear area, $A_v$
2. Substitute the value of $A_v$ into equation 6.18 to get the design plastic shear resistance
3. Carry out the cross-sectional plastic shear resistance check by ensuring equation 6.17 is satisfied.

Serviceability

Deflection checks should be made against unfactored permanent actions and unfactored variable actions.

<table>
<thead>
<tr>
<th>Loading</th>
<th>Maximum deflection</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>$WL^1_{48EI}$</td>
</tr>
<tr>
<td>$udf = W$</td>
<td>$WL^1_{384EI}$</td>
</tr>
<tr>
<td>$WL^1_{192EI}$</td>
<td>$WL^1_{3EI}$</td>
</tr>
<tr>
<td>$WL^1_{8EI}$</td>
<td>$WL^1_{8EI}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design Situation</th>
<th>Deflection limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cantilever</td>
<td>Length/180</td>
</tr>
<tr>
<td>Beams carrying plaster of other  brittle finish</td>
<td>Span/360</td>
</tr>
<tr>
<td>Other beams (except purlins and sheeting rails)</td>
<td>Span/200</td>
</tr>
<tr>
<td>Purlins and sheeting rails</td>
<td>To suit the characteristics of particular cladding</td>
</tr>
</tbody>
</table>

Table 3.0: Vertical Deflection Limits from NA 2.23 Clause 7.2.1(1) B

Shear Area, $A_v$

EC3 should provide a slightly larger shear area compared to BS 5950 meaning that the overall resistance will be larger as shown in Figure 1.

Shear Area Calculations

<table>
<thead>
<tr>
<th>Type of member</th>
<th>Shear Area, $A_v$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled I and H sections (load parallel to web)</td>
<td>$A_v = A - 2bt_f + (t_w + 2r)t_f$ but $\geq \eta h_w t_w$</td>
</tr>
<tr>
<td>Rolled Channel sections (load parallel to web)</td>
<td>$A_v = A - 2bt_f + (t_w + r)t_f$</td>
</tr>
<tr>
<td>Rolled PHS of uniform thickness (load parallel to depth)</td>
<td>$A_v = Ah/(b+h)$</td>
</tr>
<tr>
<td>CHS and tubes of uniform thickness</td>
<td>$A_v = 2A/\pi$</td>
</tr>
<tr>
<td>Plates and solid bars</td>
<td>$A_v = A$</td>
</tr>
</tbody>
</table>

Table 2.0: Shear area formulas

Table 3.0: Shear area parameter descriptions

Figure 1: Differences in shear area calculated using BS 5950 and EC3

Figure 2: Standard case deflections and corresponding maximum deflection equations

The maximum deflection calculated must not exceed the deflection limit. The deflection limits are not given directly in Eurocode 3, instead, reference must be made to the National Annex.

Figure 1: Visual definition of the parameters used in the shear area calculation. (Source: Blue Book)