*The development of the new Blue Book on member resistances highlighted some new methods. Edurne Nunez Moreno of the SCI explains the background to two of the issues.*

# 1. Web Bearing and Buckling to BS EN 1993-1

Web Bearing and Buckling are modes of failure that arise from concentrated forces being transversely applied onto the flanges of beams or columns.

Web bearing failure means that the web yields at its most vulnerable location, close to the root radius adjacent to the flange where the force is applied, as illustrated in Figure 1.a.

Buckling of the web happens when the web is too slender to carry the transverse force being transferred from the flange. In this mode the web has to work as a strut in compression and it buckles as shown in Figure 1.b. It is assumed that the flange is adequately restrained in the lateral direction and therefore it can neither rotate nor move laterally.

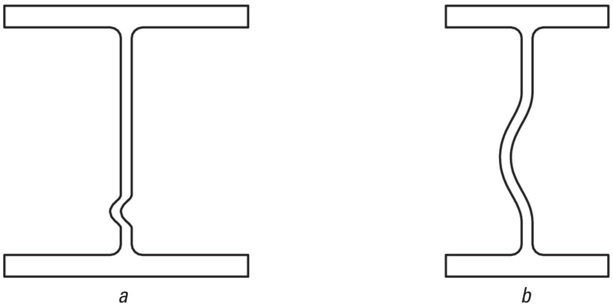

*Figure 1: Web bearing (a) and buckling (b) failure modes*

BS5950-1 requires that two independent checks are carried out for web bearing and buckling. The Eurocode presents a single check to deal with these two failure modes. This single check accounts for the bearing and buckling of the web when the member is subject to a transverse force.

Web bearing and buckling is not in fact covered in BS EN 1993-1-1 but the designer is referred to section 6 of BS EN 1993-1-5: *Resistance to transverse forces*. The design resistance to transverse forces $F_{w,Rd}$ is calculated as given in equation 6.1:

$$F_{w,Rd} = \frac{f_{yw} L_{eff} t_w}{\gamma_{M1}} \qquad (6.1)$$

In this expression $f_{yw}$ is the yield strength of the web; $t_w$ is the thickness of the web; $\gamma_{M1}$ is the partial factor for resistance of members, given in the National Annex to BS EN 1993-1-5 (in the UK National Annex $\gamma_{M1}$ is given as 1.0) and $L_{eff}$ represents the effective length for resistance to transverse forces, calculated as $\chi_F \ell_y$, where:

$$\chi_F = \frac{0.5}{\overline{\lambda}_F} \leq 1.0 \qquad (6.3)$$

$$\overline{\lambda}_F = \sqrt{\frac{\ell_y t_w f_y}{F_{cr}}} \qquad (6.4)$$

$\ell_y$ is the effective loaded length, taken as the minimum of the following three values:

$$\ell_{y1} = s_s + 2t_f \left(1 + \sqrt{m_1 + m_2}\right) \qquad (6.10)$$

$$\ell_{y2} = \ell_e + t_f \sqrt{\frac{m_1}{2} + \left(\frac{\ell_e}{t_f}\right)^2 + m_2} \qquad (6.11)$$

$$\ell_{y3} = \ell_e + t_f \sqrt{m_1 + m_2} \qquad (6.12)$$

$F_{cr}$, $m_1$, $s_s$ and $\ell_e$ are all simple to calculate and fully defined in BS EN 1993-1-5.

Note that, at the time of printing this article, the published document BS EN 1993-1-5 refers to equations 6.11, 6.12 and 6.13 instead of 6.10, 6.11 and 6.12. This is due to be amended by CEN in the forthcoming corrigendum of the standard.

The calculation of $m_2$ and $\overline{\lambda}_F$ is not straightforward, as they are interdependent. $\overline{\lambda}_F$ depends on $\ell_y$, which in turn is affected by $m_2$. However, $m_2$ can take two values, depending on the value of $\overline{\lambda}_F$ :

$$m_2 = 0.02\left(\frac{h_w}{t_f}\right)^2 \qquad \text{if } \overline{\lambda}_F > 0.5$$

$$m_2 = 0 \qquad \text{if } \overline{\lambda}_F \leq 0.5$$

This means that two alternatives must be checked, considering both possibilities for the value of $m_2$, as shown in the following example.

**Example**

The following example shows how to calculate the resistance to transverse forces according to BS EN 1993-1-5

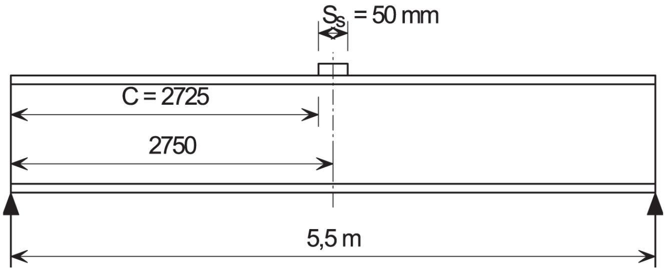

*Figure 2: Beam size: UB 406 x 140 x 39*

Assume firstly that $\overline{\lambda}_F < 0.5$. Then:

$$m_1 = \frac{f_{yf} b_f}{f_{yw} t_w} = \frac{355 \times 141.8}{355 \times 6.4} = 22.2$$

$$m_2 = 0$$

$$\ell_e = \frac{k_F E t_w^2}{2 f_{yw} h_w} = 190.9\text{mm}$$

where $k_F = 6$ from Figure 6.1 in BS EN 1993-1-5.

Using the expressions for $\ell_y$ given above the following values are obtained:

From equation 6.10: $\ell_{y1} = 148$ mm
From equation 6.11: $\ell_{y2} = 384$ mm
From equation 6.12: $\ell_{y3} = 231$ mm

The lowest of these three values is used to calculate the value of $\overline{\lambda}_F$, to check the validity of the original assumption.

From the equations in BS EN 1993-1-5 the critical force is calculated as $F_{cr} = 780649$ N

$$\ell_y = 148 \text{ mm, therefore } \overline{\lambda}_F = \sqrt{\frac{\ell_y t_w f_y}{F_{cr}}} = 0.66 > 0.5 .$$

This shows that the slenderness is not in the range assumed for the calculation of $m_2$ and therefore the alternative range for $\overline{\lambda}_F$ has to be analysed.

Try with $\overline{\lambda}_F > 0.5$. Then:

$m_1 = 22.2$, as per the first calculation

$$m_2 = 0.02\left(\frac{h_w}{t_f}\right)^2 = 0.02\left(\frac{380.8}{8.6}\right)^2 = 39.2$$

$$\ell_e = \frac{k_F E t_w{}^2}{2 f_{yw} h_w} = 190.9\text{mm}$$

where $k_F = 6$ from Figure 6.1 in BS EN 1993-1-5.

Using the expressions for $l_y$ given above:

From equation 6.10: $l_{y1} = 202$ mm

From equation 6.11: $l_{y2} = 389$ mm

From equation 6.12: $l_{y3} = 258$ mm

The lowest of these three values is used to calculate the value of $\overline{\lambda}_F$ .

As in the previous case the critical force is calculated as $F_{cr} = 780649$ N from the equations in BS EN 1993-1-5.

$l_y = 202$ mm, therefore $\overline{\lambda}_F = \sqrt{\dfrac{\ell_y t_w f_y}{F_{cr}}} = 0.77 > 0.5$. This shows that the slenderness is in the range assumed for the calculation of $m_2$ and therefore the calculation can be finalised using this value:

$$\chi_F = \frac{0.5}{\overline{\lambda}_F} = \frac{0.5}{0.77} = 0.65 < 1.0$$

$$L_{eff} = \chi_F \ell_y = 0.65 \times 202 = 131\text{mm}$$

$$\therefore F_{w,Rd} = \frac{f_{yw} L_{eff} t_w}{\gamma_{M1}} = \frac{355 \times 131 \times 64}{1.0} \times 10^{-3} = 298\text{kN}$$

This value compares with 327 kN for web bearing and 202 kN for web buckling calculated in accordance to BS5950-1.

# 2. Buckling modes of angles and channels in compression

Torsional buckling modes affect sections like angles, channels and cruciform sections in compression and can be critical in I sections when the flanges are not equally restrained. Clause 6.3.1.4 of BS EN 1993-1-1: 2005 requires torsional modes to be checked.

For angles in compression the following buckling modes should be considered:

- Flexural buckling about the y-y, z-z, v-v and u-u axis
- Torsional-flexural buckling
- Torsional buckling.

Clauses 6.3.1.3 and 6.3.1.4 of BS EN 1993-1-1 provide guidance to calculate slenderness for the buckling resistance for all of these modes.

- Slenderness for flexural buckling:

$$\overline{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1}, \quad \text{for class 3 angles} \qquad (6.50)$$

$$\overline{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1} \quad \text{for class 4 angles} \qquad (6.51)$$

where $\lambda_1 = 93.9\sqrt{\dfrac{235}{f_y}}$

These expressions are straightforward. $N_{cr}$ is more commonly known as the Euler buckling load, or alternatively the slenderness can be calculated as the BS 5950 slenderness divided by a constant. Note that $\dfrac{L_{cr}}{i} = \dfrac{L_e}{r_{yy}}$ and $\lambda_1$ is a constant, which depends on the yield strength.

- Slenderness for torsional-flexural buckling and torsional buckling (one single check):

$$\overline{\lambda}_T = \sqrt{\frac{A f_y}{N_{cr}}} \quad \text{for class 3 angles} \qquad (6.52)$$

$$\overline{\lambda}_T = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} \quad \text{for class 4 angles} \qquad (6.53)$$

where $N_{cr} = \min(N_{cr,TF}; N_{cr,T})$

To avoid the complex iterative procedure to calculate $N_{cr,TF}$ , Annex BB of BS EN 1993-1-1 allows an alternative approach which accounts for the practical types of end connections, which increase the member resistance. Annex BB gives the following modified expressions for the effective flexural slenderness:

$\overline{\lambda}_{eff,v} = 0.35 + 0.7\lambda_v$ for buckling about the v-v axis

$\overline{\lambda}_{eff,y} = 0.50 + 0.7\lambda_y$ for buckling about the y-y axis

$\overline{\lambda}_{eff,z} = 0.50 + 0.7\lambda_z$ for buckling about the z-z axis

In these expressions $\overline{\lambda}_v$, $\overline{\lambda}_y$ and $\overline{\lambda}_z$ are the values obtained from equations 6.50 or 6.51 as appropriate. These effective values of the flexural slenderness account for both flexural and torsional-flexural buckling in a much simpler way than by calculating $N_{cr,TF}$. These expressions are applicable provided the angles are appropriately restrained at the ends (at least two bolts if bolted, or welded).

The code does not include an expression for the effective slenderness for buckling about the u-u axis. One could think that in some situations, when the angle is restrained about the v-v axis buckling about the u-u axis could be critical. However practical restraints against v-v buckling will also increase the torsional flexural resistance in the u-u axis.

The torsional buckling resistance is not covered by the effective slenderness approach and must be calculated using $N_{cr,T}$. Torsional buckling resistances are given in the new Blue Book.

Channels in compression are also affected by all these buckling modes. Although the calculation of $N_{cr,TF}$ and $N_{cr,T}$ for channels is quite involved, it does not require iteration and therefore the torsional and the torsional-flexural buckling resistance can be calculated by using the minimum of $N_{cr,TF}$ and $N_{cr,T}$ in equation 6.52 or 6.53.

The flexural buckling resistance of channels is calculated using equation 6.50 or 6.51 for concentrically loaded channels and for channels connected only through its web when considering buckling about the major (y-y) axis. For channels connected only through its web when considering buckling about the minor (z-z) axis the following expression from Annex BB is used for the effective slenderness:

$$\overline{\lambda}_{eff,z} = 0.50 + 0.7\overline{\lambda}_z$$

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# Codes & Standards

## New and Revised Codes & Standards

(from BSI Updates April 2008)

### BRITISH STANDARDS UNDER REVIEW

**BS EN 10056:- -**
Specification for structural steel equal and unequal angles

**BS EN 10056-1:1999**
Dimensions

**BS EN 10058:2003**
Hot rolled flat steel bars for general purposes. Dimensions and tolerances on shape and dimensions

**BS EN 10059:2003**
Hot rolled square steel bars for general purposes. Dimensions and tolerances on shape and dimensions

**BS EN 10060:2003**
Hot rolled round steel bars for general purposes. Dimensions and tolerances on shape and dimensions

**BS EN 10061:2003**
Hot rolled hexagon steel bars for general purposes. Dimensions and tolerances on shape and dimensions

### DRAFT BRITISH STANDARDS FOR PUBLIC COMMENT

**08/30128144 DC**
***BS EN 1993-1-11*** UK National Annex to Eurocode 3. Design of steel structures.
Part 1-11. Design of structures with tension components

### ISO PUBLICATIONS

**ISO 13918:2008**
(Edition 2)
Welding. Studs and ceramic ferrules for arc stud welding
*Will be implemented as an identical British Standard.*

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# Technical

## Buckling modes of angles and channels in compression

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In this expression $\overline{\lambda}_z$ is calculated as given in 6.50 or 6.51. This expression is applicable provided the channel is appropriately restrained at the ends (at least two bolts if bolted, or welded). In any other case provision for the eccentricity must be made by following the rules for combined bending and axial force, given in clause 6.2.9 of BS EN 1993-1-1.

The new Blue Book to the Eurocodes follows this approach when calculating the resistance of angles and channels. Future articles will cover the contents of the publication, and how the design data is to be used.