Lateral torsional buckling – additional Eurocode provisions

David Brown of the SCI discusses the Eurocode rules when the effect of LTB may be ignored, and the simplified rules for buildings.

All designers will appreciate that there is a range of slenderness known as the 'plateau length', where there is no reduction for lateral torsional buckling – illustrated in Figure 1. In the Eurocode, the plateau length is given by $\bar{\lambda}_{LT,0}$ and has the value of 0.2 if using clause 6.3.2.2 and the value of 0.4 if using clause 6.3.2.3 and the UK National Annex.

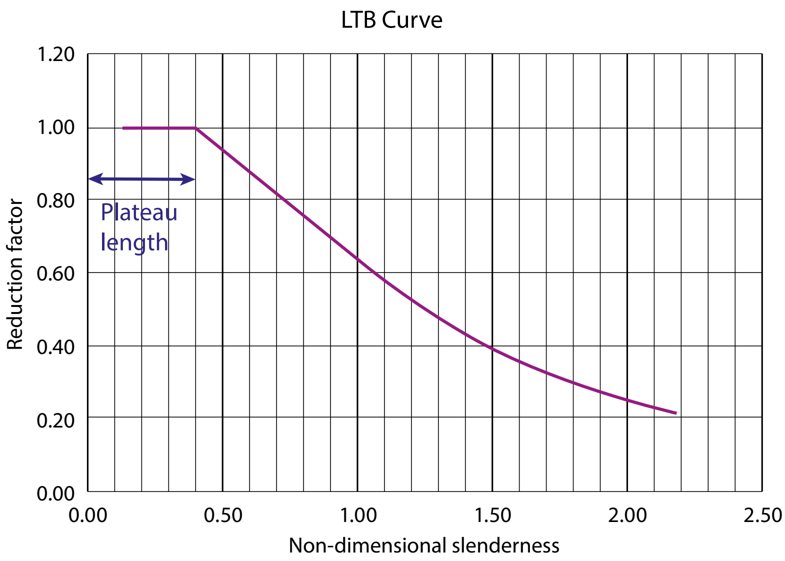

Figure 1: Typical LTB curve

If $\bar{\lambda}_{LT}$ is calculated, and found to be less than the plateau length, then there is no reduction for LTB. This (fairly obvious) point is confirmed in the first part of clause 6.3.2.2(4), which states that if $\bar{\lambda}_{LT} \leq \bar{\lambda}_{LT,0}$ lateral torsional buckling checks may be ignored and only cross sectional checks apply.

There is some uncertainty which value of $\bar{\lambda}_{LT,0}$ was intended in this clause (0.2 or 0.4), so it is hoped that the forthcoming revision will provide some clarity.

The second part of clause 6.3.2.2(4) is rather more interesting, stating that LTB may be ignored if $\frac{M_{Ed}}{M_{cr}} < \bar{\lambda}_{LT,0}^{\,2}$. M_{Ed} is the design moment, and M_{cr} the elastic critical buckling moment.

The expression flows from the definition of $\bar{\lambda}_{LT}$, which is given as $\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}}$. The numerator $W_y f_y$ is the cross sectional resistance, $M_{c,Rd}$, so by simple substitution, $\bar{\lambda}_{LT} = \sqrt{\frac{M_{c,Rd}}{M_{cr}}}$ or $\bar{\lambda}_{LT}^{\,2} = \frac{M_{c,Rd}}{M_{cr}}$. If $\bar{\lambda}_{LT} \leq \bar{\lambda}_{LT,0}$ and it is recognised that the applied moment M_{Ed} must always be less than the moment capacity, the expression becomes $\bar{\lambda}_{LT,0}^{\,2} \geq \frac{M_{Ed}}{M_{cr}}$, as given in the Standard.

This provision can have some interesting effects if the applied moment, M_{Ed} is low.

Example 1

533 × 210 × 92 UB, S355, 7 m long with a uniform bending moment. Using the tool for M_{cr} available from *steelconstruction.info*, M_{cr} = 362 kNm

Substituting the values into the expression, $0.4^2 \geq \frac{M_{Ed}}{362}$, or $M_{Ed} \leq 58$ kNm. If the applied moment is less than this value, LTB effects may be ignored. The slightly unsettling feature of this result is revealed if the normal process of calculating the non-dimensional slenderness is followed.

$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{838}{362}} = 1.52$ This value is much larger than the plateau length of 0.4, and one would naturally think there is a significant reduction in the LTB resistance. Completing the calculations, the reduction factor, $\chi = 0.38$ and the LTB resistance, $M_{b,Rd}$ = 319 kNm.

Considering this example, it is clear that clause 6.3.2.2(4) is not saying that there is no reduction due to LTB, just that if the expression is satisfied, the resistance is greater than the design moment. In this example, the design moment could be anything up to 319 kNm without a problem if the full procedure is followed, so perhaps the conservative limit of 58 kNm given by this clause is not very helpful.

Simplified assessment methods for beams with restraints in buildings

Many designers will conclude that the 'full' rules are easy enough, (especially if avoiding all calculations altogether by taking resistances directly from the Blue Book) so there is no value in simplified rules. The principles behind the simplified assessment in clause 6.3.2.4 are however of interest, and could be useful in unorthodox circumstances.

The basic approach is to consider only the compression part of a beam (the flange plus 1/3 of the compressed part of the web) and design this as a strut (Figure 2). This approach ignores the beneficial effects of the tension flange and the torsional rigidity of the beam.

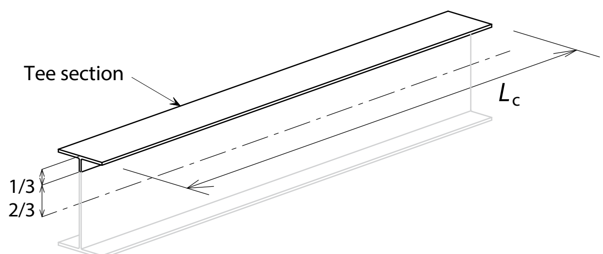

Figure 2: Simplified assessment concept

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▶28 The requirement is:

$$\bar{\lambda}_f = \frac{k_c L_c}{i_{f,z}\lambda_1} \le \bar{\lambda}_{c0}\frac{M_{c,Rd}}{M_{y,Ed}}$$

k_c depends on the shape of the bending moment diagram, from Table 6.6 or from $k_c = 1/\sqrt{C_1}$ (from the National Annex).

L_c is the unrestrained length

$i_{f,z}$ is the radius of gyration of the compression flange plus 1/3 of the compressed depth of the web, in the minor axis

$$\lambda_1 = 93.9\varepsilon = 93.9\sqrt{\frac{235}{f_y}}$$

$\bar{\lambda}_{c0}$ is the length of the plateau – which is specified in the UK National Annex as 0.4 (not the value recommended in the Eurocode)

Comparing the above with clause 6.3.1.3, the term $\frac{L_c}{i_{f,z}\lambda_1}$ is simply the non-dimensional slenderness of a strut. The clause is indicating that if the slenderness of the strut is less than the plateau length, there is no reduction due to LTB. This relationship is modified by $\frac{\text{moment resistance}}{\text{applied moment}}$

Example 2

533 × 210 × 92 UB, S355, with a uniform moment and $M_{y,Ed} = M_{c,Rd}$. This would imply that there is no reduction in resistance due to LTB, so the limiting length, L_c at the end of the plateau may be back-calculated.

The relevant dimensions of the tee section are shown in Figure 3. The depth between flanges is 501.9 mm, so 1/3 of the compressed part is 83.7 mm.

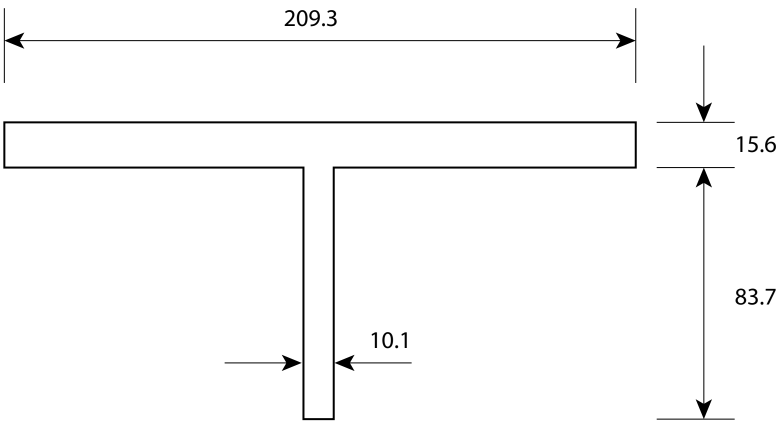

Figure 3: Tee dimensions

The radius of gyration, $i_{f,z}$ = 53.9 mm.

Because the moment is uniform, k_c = 1.0.

$\lambda_1 = 93.9 \times 0.814 = 76.4$

Then $\frac{1.0 \times L_c}{53.9 \times 76.4} \le 0.4 \times 1.0$

Rearranging, $L_c \le 1647$ mm if there is to be no reduction for LTB.

This length can be compared with that determined from clause 6.3.2.2.

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} \text{ or } 0.4 = \sqrt{\frac{838}{M_{cr}}} \text{ or } M_{cr} = 5238 \text{ kNm}$$

The painful expression to back-calculate the length to give this value of M_{cr} is not repeated here, but the physical length at the end of the plateau is found to be 1581 mm. At lengths longer than 1581 mm, there is some reduction due to LTB so, in this example, the simplified method is not conservative (by a trivial amount, admittedly).

Example 3

533 × 210 × 92 UB, S355, with a uniform moment and 4 m between restraints. The maximum applied moment $M_{y,Ed}$ can then be determined at which the beam remains stable.

$$\frac{1.0 \times 4000}{53.9 \times 76.4} \le 0.4 \times \frac{838}{M_{y,Ed}} \text{ or } M_{y,Ed} < 345 \text{ kNm}$$

Looking in the Blue Book, for C_1 = 1 and a length of 4m, M_b = 557 kNm, so the simplified approach is (quite) conservative.

The language of clause 6.3.2.4(1) perhaps could be improved. The clause describes the situations where the member is "not susceptible" to LTB, which is a bit misleading. The member does experience a reduction due to LTB, but the buckling resistance is more than the applied moment.

Example 4

533 × 210 × 92 UB, S355, with a uniform moment of 450 kNm and 4 m between restraints. The conditions of 6.3.2.4(1) are not met:

$$\frac{1.0 \times 4000}{53.9 \times 76.4} > 0.4 \times \frac{838}{450} \text{ or } 0.971 > 0.745\,;$$

the clause requirement is not satisfied.

Clause 6.3.2.4(2) allows a design bending moment resistance to be calculated, again based on the resistance of the tee section.

The bending resistance is given as $M_{b,Rd} = k_{fl}\chi M_{c,Rd}$

k_{fl} is a modification factor to account for the conservatism of the equivalent compression flange method. The recommended value is 1.1, but the UK National Annex limits this to 1.0 for hot rolled members.

χ is the reduction factor for flexural buckling, based on $\bar{\lambda}_f$, as calculated above.

$\bar{\lambda}_f$ = 0.971 (as above). According to clause 6.3.2.4(3), curve 'c' should be used. The imperfection factor α is therefore 0.49 and reduction factor χ is calculated as 0.56.

Therefore, $M_{b,Rd} = k_{fl}\chi M_{c,Rd}$ = 1.0 x 0.56 x 838 = 469 kNm

According to this simplified approach, the buckling resistance exceeds the applied moment, so the beam is stable. In fact, as previously noted, the actual buckling resistance is 557 kNm, so the calculated resistance is satisfactorily conservative.

Conclusions

Designers are unlikely to make much use of these simplifications. The use of software and look-up tables means that the simplifications are generally not required. The principle of conservatively taking just the compression part of a beam, and verifying the Tee as a strut can be a useful approach in particular situations, for example when checking the stability of a portal frame haunch.