LTB in the Eurocodes – Back to the Future

In Part 1, David Brown of the SCI looked at comparisons between lateral torsional buckling in BS 449 and BS 5950. In Part 2, the comparison is extended to the current Eurocode – and what might happen as the Eurocode is revised.

There have been several articles on BS EN 1993-1-1 and lateral torsional buckling, covering numerical examples and the calculation of the C_1 factor to deal with non-uniform bending moment diagrams. The emphasis has always been that the physics has not changed, a truth which should have been reinforced when the background to BS 449 and BS 5950 was reviewed in Part 1.

The Eurocode is perhaps clearer than previous steel design codes. LTB is always based on the elastic critical moment – it was in BS 449 and BS 5590; this is now explicit in EC3. The criticism of the European Standard is that expressions for M_{cr} are not given in the Standard – according to other Europeans, this is expected to be known by designers, or extracted from other resources – something that the Standard does not need to provide. The closed formula is complicated, just like the expression for the elastic critical stress in BS 449, but at least there are software tools and freely available software to calculate this moment.

The physics of a non-uniform moment is dealt with by the C_1 factor, with a second adjustment via the f factor (but only if using the special case for rolled sections in 6.3.2.3). Perhaps as expected, with more test data available and many more numerical simulations possible, the Eurocode allows more finesse within the buckling curves. Instead of the one single curve in BS 449 and BS 5950, four curves are available, depending on the cross-section. The Eurocode is further complicated with two families of buckling curves; the "general case" in clause 6.3.2.2 and a set of expressions for rolled sections (called "special" in this article). If verifying a rolled section, the "special" set of expressions in clause 6.3.2.3 are highly recommended, especially with a non-uniform bending moment, as the calculated resistance is significantly higher than that calculated using the "general case".

A comparison between the LTB curves from BS 5950, the "general case" and the "special case" is shown in Figure 5. For the particular beam examined, the "general case" and "special case" use curves c and d respectively.

The EC3 "special case" curve has a similar plateau length to BS 5950, but then provides a larger resistance at all slenderness. The increase in resistance in the Eurocode may appear small in Figure 5, but may be as much as 25% and more for some beam profiles. The increase in resistance is more significant as slenderness increases. The conservatism of the "general case" can also be seen in Figure 5; the plateau is short (limited to a slenderness of 0.2) and then a reduced resistance compared to the "special case".

The difference between the "general case" and the "special case" for rolled sections becomes more significant for non-uniform bending moments, since the beneficial effect of f from clause 6.3.2.3(2) can only be applied to the "special case". Figure 6 shows the comparison with a triangular bending moment diagram ($C_1 = 1.77$, $m_{LT} = 0.6$). In BS 5950, the influence of m_{LT} is outside the calculation of the bending resistance M_b; the curve shows the effective reduction factor after allowing for m_{LT}. The increase in resistance calculated using the "special case" is up to 50% higher than that determined using the "general case".

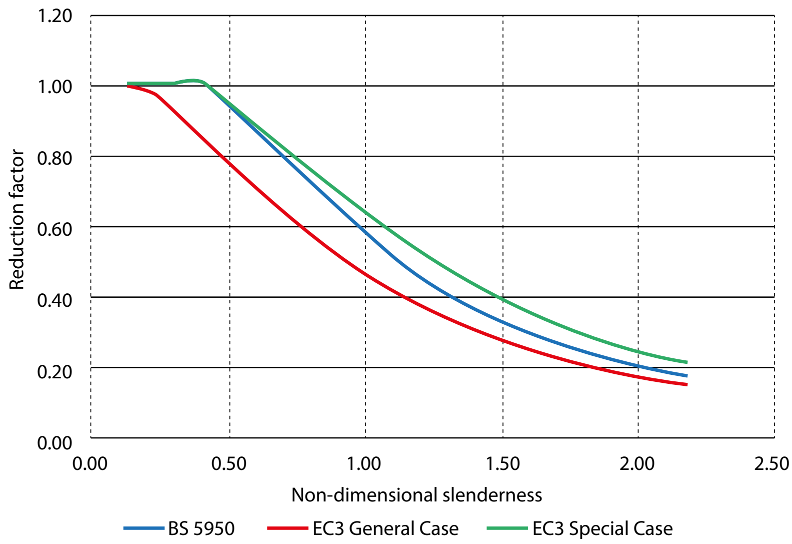

Figure 5: Comparison between BS 5950 and EC3; uniform bending moment diagram

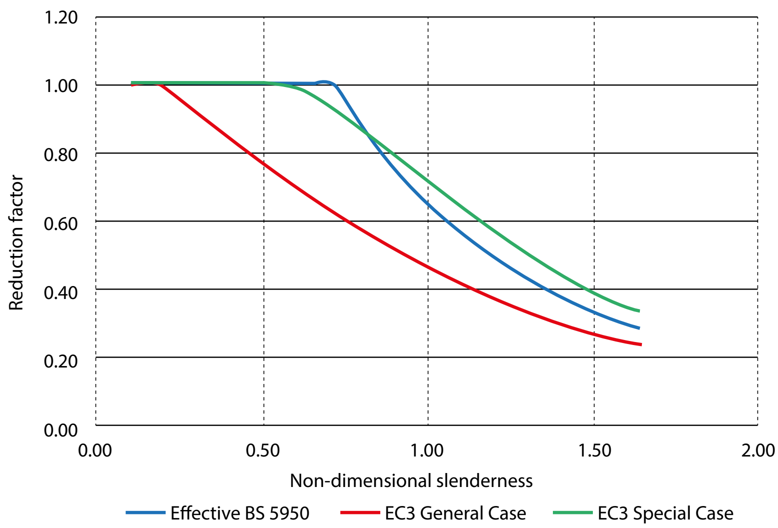

Figure 6: Comparison between BS 5950 and EC3; Triangular bending moment diagram

Where to next?

The Eurocodes are currently being revised, with a target date around 2020 for an amendment. It is likely that the LTB curves will be amended, though this is by no means certain. There is much discussion to be undertaken before the amendment is released. Accompanying the amended Standard will be a revised

Variable	Current ("Special Case")	Proposed
α_{LT}	0.34	$0.16\sqrt{W_{el,y}/W_{el,z}} \le 0.49$
ϕ_{LT}	$0.5\left[1+\alpha_{LT}(\bar{\lambda}_{LT}-\beta\bar{\lambda}_{LT,0})+\beta\bar{\lambda}_{LT}^{2}\right]$	$0.5\left[1+\varphi\left(\frac{\bar{\lambda}_{LT}^{2}}{\bar{\lambda}_{z}^{2}}\alpha_{LT}(\bar{\lambda}_{z}-0.2)\right)+\bar{\lambda}_{LT}^{2}\right]$
χ_{LT}	$\frac{1}{\phi_{LT}+\sqrt{\phi_{LT}^{2}-\beta\bar{\lambda}_{LT}^{2}}}$	$\frac{\varphi}{\phi_{LT}+\sqrt{\phi_{LT}^{2}-\varphi\bar{\lambda}_{LT}^{2}}}$
f	$1-0.5(1-k_{c})\left[1-2(\bar{\lambda}_{LT}-0.8)^{2}\right]$	

UK National Annex, which will mean the UK (where allowed) can influence the final outcome within our shores. The proposed buckling curves may have more theoretical justification than the current set of expressions. As with most work associated with the development of design Standards, the majority of the enthusiasm tends to come from those with an academic background. Perhaps academic colleagues have the time and opportunity to make a contribution, but it certainly influences the final output.

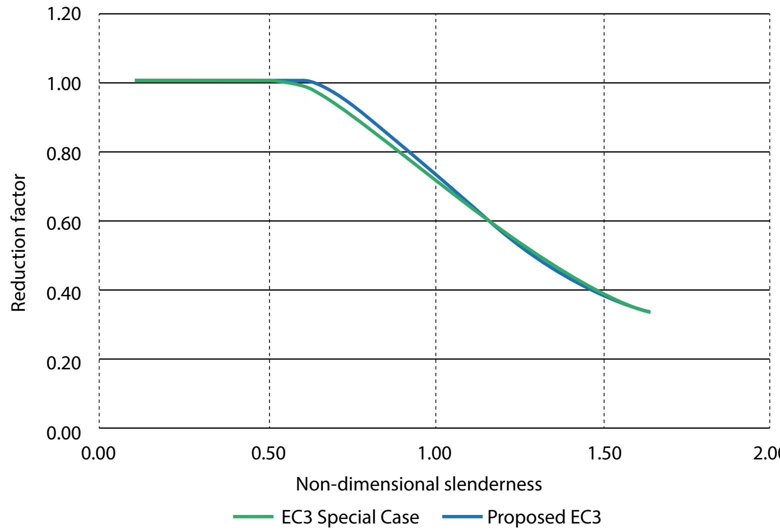

Figure 7: Comparison between existing and proposed EC3 rules; 457 × 191 × 98; triangular bending moment diagram

At present, it is far too early to be confident any detail in the amendment, so the discussion from now on becomes rather less reliable. The proposed amendment dispenses with the "general case" and the "special case" in favour of a single set of curves. A comparison between the two formulations is shown above, for beams where *h/b* < 2 (i.e. curve b in the current Standard).

In the proposed equations, φ depends on the shape of the bending moment diagram, rather like k_c in the current formulation. The value of the imperfection factor, α_{LT} becomes a variable which depends on the ratio between the major and minor axis elastic moduli rather than a constant, and approaches the value currently given for minor axis flexural buckling. In addition to the slenderness for lateral torsional buckling, the minor axis slenderness for flexural buckling, $\bar{\lambda}_z$, becomes an important part of the proposed process. A further notable change is that the plateau only extends to a slenderness of 0.2 (which is the same as the flexural buckling curve). The proposed LTB curves deliver higher resistances than the "general case", but are less attractive than the "special case".

A general comparison between the current rules and the proposed amendments is not possible, as the effect varies with the beam profile and the shape of the bending moment diagram. Figure 7 shows the comparison for a 457 × 191 × 98 UB with a triangular bending moment diagram; the difference between the "special case" and the proposed rules is marginal – what's not to like?

Figure 8 shows the comparison for the same beam with a uniform bending moment diagram. In this comparison the different plateau lengths are clearly seen; the proposed rules deliver a reduced resistance across the full range of slenderness, compared to the "special case".

Figure 9 also shows a rather less attractive comparison, for a 305 × 165 × 40 UB with a bending moment diagram due to a UDL. The proposed rules deliver less resistance than the "special case" across the whole range of slenderness. For this beam and loading, at high slenderness the proposed rules deliver only 84% of the current "special case" resistance, which is a significant reduction.

A perfect storm approaching?

At the same time as amendments to the resistance functions are being discussed, research is also underway considering the γ_{M1} value, which is used when calculating buckling resistance. The current recommended value in the Eurocode (which is adopted in the UK National Annex) is 1.0. It seems likely that some increase in reliability will be proposed – which may be to increase the γ_{M1} value directly, or the same effect may be achieved by further adjustments to the resistance functions. There remains much debate before agreement is reached, but there is a strong possibility that LTB resistances will be reduced in 2020 – a combination of the revised formulae and the effect of an increase in γ_{M1}.

The practical effect of changes to the resistance functions will mean that existing Eurocode design software and design aids, such as the Blue Book, will need to be updated, even if (in some circumstances) the change is small. As was demonstrated in Figure 9, the potential change in resistance could be significant – it would be inappropriate to continue to use out-of-date resources. LTB checks appear in very many SCI publications as part of worked examples, so the task of revision is certainly not trivial.

Perhaps the more significant concern is change to the Eurocodes when many designers are still not using them, or are in the early stages of transition. Although the Eurocodes have been available since 2005 (and so changes in 2020 after 15 years in use are perhaps not unreasonable), for many 'late adopters' the 2020 revisions may seem rather early.

A concluding reminder – the proposals are not yet agreed, so may well change before the amendment. The effect of the UK National Annex may also change the comparisons made in this article. No doubt nearer the time there will be plenty of articles looking at the impact of whatever is finally agreed.

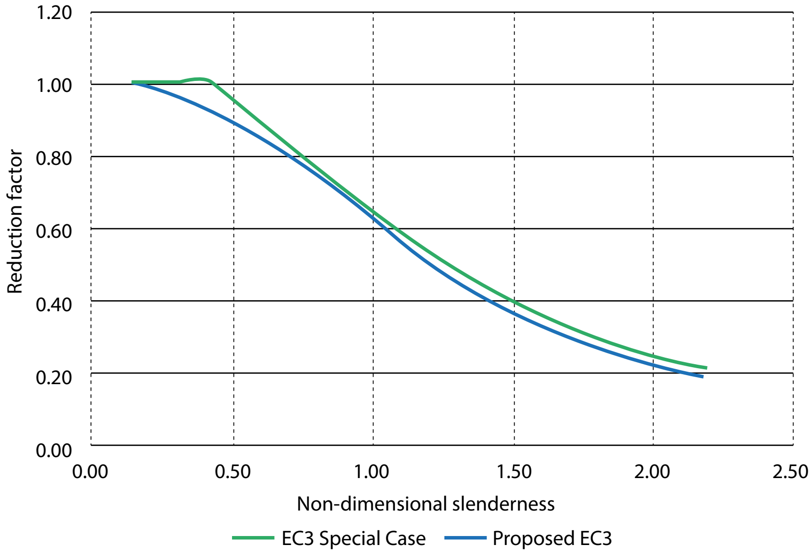

Figure 8: Comparison between existing and proposed EC3 rules; 457 × 191 × 98; uniform bending moment diagram

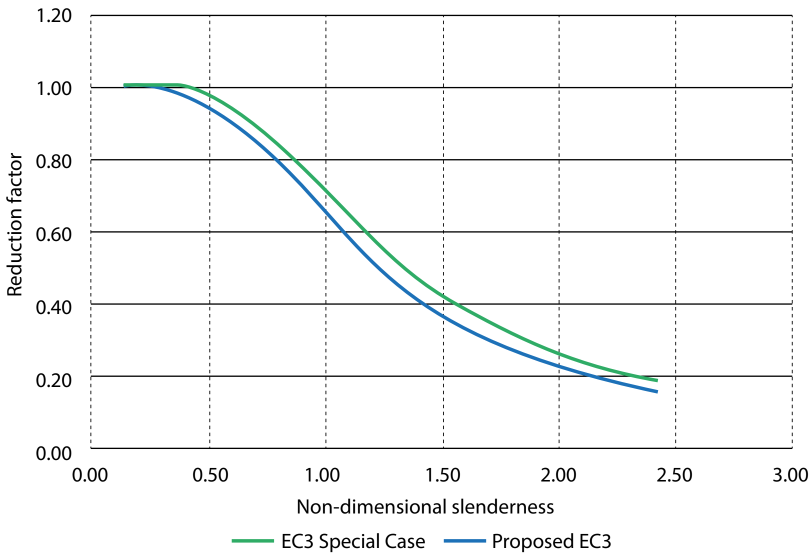

Figure 9: Comparison between existing and proposed EC3 rules; 305 × 165 × 40; bending moment diagram from a UDL