

The design of tee sections in bending

Although tees might not be an ideal choice to resist bending, sometimes they are selected for their architectural merit. To assist when tees must be used, David Brown of the SCI describes the design approach to BS 5950-1 and to BS EN 1993-1-1.

If members are subject to bending, structural engineers will probably recommend beams with flanges, or [hollow sections](#). Tees used to resist bending are unlikely to appear as a preferred solution, but if they *must* be used, they must be verified to the design Standard. This article looks at the verification of a Tee used as a cantilever, perhaps as the exposed steelwork supporting a canopy. Especially with Tees cut from [universal beams](#), the long narrow web means that the section is Class 4. The focus of this article is [lateral-torsional buckling](#), assuming that cross-sectional checks have been completed. Numerical examples are presented, considering Class 3 and Class 4 sections.

Structural model

In the scenario considered, the cantilever Tee section is fixed to a supporting steel column, by a [bolted connection](#). Although the connection is considered continuous, and thick plates, large [welds](#) and large bolts have been utilised in the connection, the thoughtful engineer will observe that there is still some (unquantified) flexibility – the connection is not truly “built in”. The cantilever Tee has lateral restraint at the tip – perhaps by some member attached to the tip of several cantilevers and braced back at some point to the support. The lateral restraint has a pinned connection to the Tee, so provides no torsional benefit. In this example, the applied loads are considered to be a UDL, even if in practice they may be applied via point loads from members acting as purlins. The stem of the tee is in compression and the loads are assumed to be applied on the top surface of the flange. In the first two examples, the loads are considered to be destabilising – that is they can move with the member as it buckles. The general arrangement is shown in Figure 1.

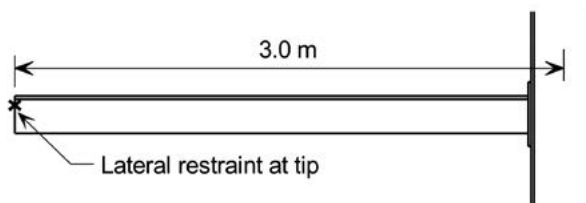


Figure 1: General arrangement of cantilever tee

Design to BS 5950

BS 5950 provides comprehensive coverage for the design of Tees, with Section B.2.8 providing rules for the lateral-torsional buckling resistance. Helpfully, some of the more involved terms have been calculated and presented in the “Blue Book”.

The first challenge is the slenderness and designers must refer to Table 14. Some engineering judgement is required in our

example. The tip is laterally restrained, but the support is not encastré. Row ‘c’ of Table 14 has therefore been selected, which means that with destabilising loads, $L_e = 2.5L$.

Example 1a – BS 5950

In this example, the selected section has been chosen to be Class 3, simply to avoid the complications of Class 4. In practice, it seems unlikely that such a heavy section might be chosen.

The selected section is $191 \times 229 \times 81$ in [S355](#) steel and 3 m long. The flange is 32 mm thick, so the design strength is 345 N/mm^2 .

Considering the classification limits of Table 11, the limiting D/t ratio for the stem of a Tee is 18ϵ . If the design strength is 345 N/mm^2 , then $\epsilon = 0.893$ and the limiting ratio is 16.07. The actual d/t ratio (note the difference in nomenclature) is 13.7, so the stem is Class 3.

The limiting ratio for the flange is 13.38, and the actual is 3.12, so the section is Class 3.

Following the guidance in B.2.8, the calculated values are as follows:

$$\gamma = 0.587$$

$$u = 0.573$$

$$x = 8.3$$

$$w = 0.0134$$

$\psi = -0.699$ (note that this value is given in section property tables as the monosymmetry index, but should be taken as negative when the flange of the Tee section is in tension.)

$$\lambda = 7500/45.5 = 165$$

$$v = 0.512$$

$\beta_w = 281/507 = 0.554$ (note that Z_{xx} is taken as the modulus for the stem)

$$\text{Therefore, } \lambda_{LT} = uv\lambda \sqrt{\beta_w} = 0.573 \times 0.512 \times 165 \times 0.744 = 36$$

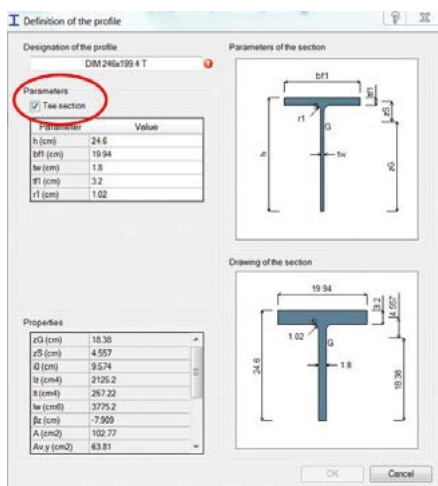
The bending strength p_b is determined from Table 16 as 331 N/mm^2 and the LTB resistance as $M_b = 331 \times 281 \times 10^{-3} = 93 \text{ kNm}$

Note that B.2.8.2 specifies that the equivalent uniform moment factor m_{LT} should be taken as 1.0.

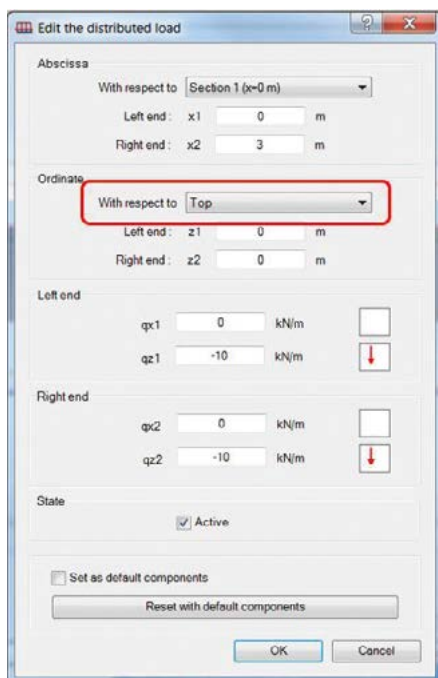
Example 1b – BS EN 1993-1-1

The determination of lateral-torsional buckling commences with the calculation of M_{cr} . Fortunately, the software *LTBeamN* allows designers to consider a wide variety of cross-sections, loading scenarios and restraint conditions, making the calculation of M_{cr} straightforward – assuming some familiarity with the software. The following screenshots illustrate the main settings for this example.

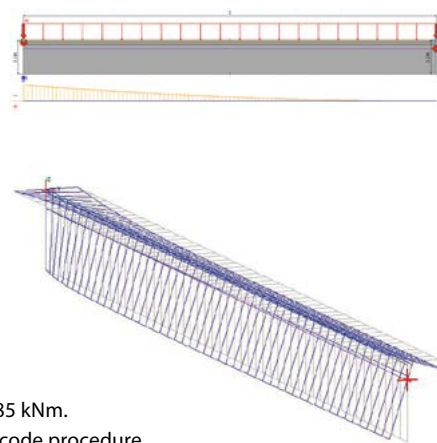
A cross-section must be defined at both ends of the member. Selecting the mono-symmetric option and choosing to "add" a definition, allows the option of a "Tee section" to be checked, and data entered. Helpfully, section properties are then calculated – which may be compared with the *Blue Book* values if required to confirm correct data entry.



Loading can be applied at any point, but in this example, the load has been applied at the top of the section. This is a destabilising load, as it is above the shear centre.



The support has been fixed at the left hand end (as drawn), and a lateral restraint introduced at the tip.



LTBeamN can then calculate M_{cr} , and present a 3-D view of the buckled shape.

In this example, $M_{cr} = 1085$ kNm. Following the usual Eurocode procedure,

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{281 \times 10^3 \times 345}{1085 \times 10^6}} = 0.299$$

Only the "General case" of 6.3.2.2 may be used, so from Table 6.4, curve 'd' is selected, which means in Table 6.3, $\alpha_{LT} = 0.76$.

Completing the maths, $\chi_{LT} = 0.924$

Therefore, $M_b = 0.924 \times 281 \times 10^3 \times 345 \times 10^{-6} = 89.6$ kNm – which compares well with the value of 93 kNm according to BS 5950.

Example 2a – BS 5950

In this example, the chosen section is 191 × 229 × 45 in *S355 steel* and 3 m long. The flange is 17.7 mm thick, so the design strength is 345 N/mm².

The d/t ratio for this section is 22.1, so the stem is Class 4. Advisory Desk note AD 311ⁱ gives advice for Class 4 sections, recommending the calculation of a reduced design strength – effectively making the section Class 3.

$$\text{The reduced design strength} = 345 \times \left(\frac{18 \times 0.893}{22.1} \right)^2 = 182.5 \text{ N/mm}^2$$

Following the same process as outlined in example 1a:

- $\gamma = 0.612$
- $u = 0.576$
- $x = 14.1$

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$$w = 0.00486$$

$$\psi = -0.706$$

$$\lambda = 7500/42.9 = 175$$

$$v = 0.682$$

$$\beta_w = 152/269 = 0.565$$

$$\text{Therefore, } \lambda_{LT} = uv\lambda \sqrt{\beta_w} = 0.576 \times 0.682 \times 175 \times 0.752 = 51.7$$

The bending strength p_b is determined by calculation from Annex B.2.1 as 169 N/mm² and the LTB resistance as $M_b = 169 \times 152 \times 10^{-3} = 25.7$ kNm

Example 2b – BS EN 1993-1-1

Introducing the revised cross section into *LTBeamN*, yields $M_{cr} = 231$ kNm

According to Table 5.2 of BS EN 1993-1-1, the limiting outstand for elements in compression is 14ϵ for a **Class 3 section**, where $\epsilon = 0.825$. Thus the limiting length of web in compression is $14 \times 0.825 \times 10.5 = 121$ mm from the neutral axis, making an overall depth of 175.7mm. The effective cross section is shown in Figure 2.

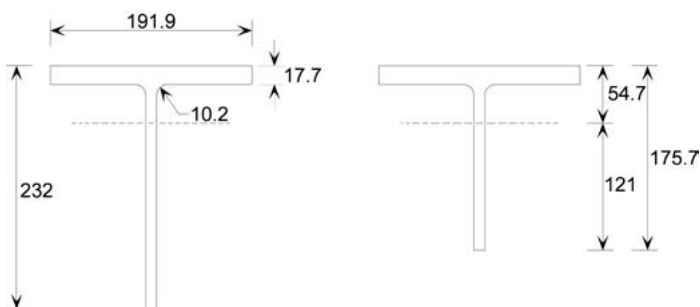


Figure 2: Gross and effective cross sections

The modulus of this reduced cross section can be determined by hand, or *LTBeamN* can be used to calculate the properties of the revised section. Simply reducing the overall depth of the section to 175.7 mm in *LTBeamN* gives the revised elastic modulus as 88.0×10^3 mm³.

$$\text{Proceeding in the usual way, } \bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{88.0 \times 10^3 \times 345}{231 \times 10^6}} = 0.363$$

Completing the maths, $\chi_{LT} = 0.877$

Therefore, $M_b = 0.877 \times 88.0 \times 10^3 \times 345 \times 10^{-6} = 26.6$ kNm – which compares with the value of 25.7 kNm according to BS 5950.

Example 3a – BS 5950

Example 3 is the same as example 2, but the loads are not destabilising. From Table 14, $L_E = 0.9L$.

Following the same process as outlined in example 2a:
 $\gamma, u, x, w, \psi, \beta_w$ all as example 2a
 $\lambda = 2700/42.9 = 62.9$
 $v = 1.392$

$$\text{Therefore, } \lambda_{LT} = uv\lambda \sqrt{\beta_w} = 0.576 \times 1.392 \times 62.9 \times 0.752 = 37.9$$

At this short slenderness, there is no reduction for lateral-torsional buckling, so the bending strength is the reduced design strength, 182.5 N/mm².

The LTB resistance is therefore $M_b = 182.5 \times 152 \times 10^{-3} = 27.7$ kNm

Example 3b – BS EN 1993-1-1

With the loads applied at the shear centre, *LTBeamN* gives $M_{cr} = 235$ kNm, which leads to $M_b = 26.7$ kNm

Observations

The contrast between examples 2 and 3 is possibly the most surprising, as the huge difference in the effective length does not result in a significant difference in the resistance. Although the effective length varies in the BS 5950 approach, the influence of the factor v means that the slenderness for lateral-torsional buckling does not change so significantly. Within the Eurocode approach, the difference between the two examples is simply the location of the applied loads, which only varies by 9 mm. The loads are only slightly destabilising, so the limited change in lateral-torsional buckling resistance is to be expected.

Conclusions

As expected, both design Standards give a reasonably consistent result. With access to appropriate software, some designers may find the Eurocode approach more straightforward, though specifying the correct supports, restraints and loading is essential.

i AD 311: T-sections in bending – stem in compression
 Available from <http://www.steelbiz.org/>

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