The management of destabilising loads

Although destabilising loads on unrestrained beams may be infrequent in orthodox building structures, they are sometimes found in domestic construction and can be quite common in steelwork supporting industrial equipment. David Brown looks at the provisions in BS 5950 and BS EN 1993-1-1.

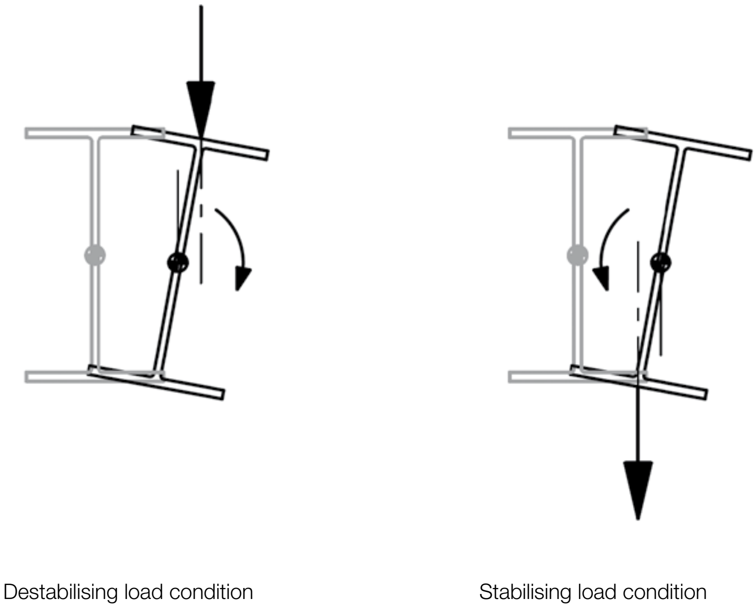

Figure 1: Load arrangements

Is the load destabilising?

The common definition of a destabilising load is if the load is free to move with the flange, it's a destabilising load. BS 5950 describes the situation in clause 4.3.4 as when both the load and the flange are free to deflect laterally. The situation is shown in Figure 1.

In the destabilising load condition, the vertical load has moved with the compression flange, which is deflecting laterally. The vertical load is eccentric to the shear centre and the resulting moment encourages further lateral deflection of the flange. The stress due to the lateral bending of the flange is increased, which means the beam is closer to buckling than it would be without the additional moment.

Figure 1 also shows the effect of a load applied which is a stabilising load. In this case, the load produces a restoring moment, which serves to reduce the lateral bending of the compression flange; the load may be increased before the onset of buckling.

Destabilising loads are relatively common in steelwork supporting equipment, where there may be no floor to provide restraint. Equipment supported on multiple beams may still be a destabilising load, if all the beams can buckle in the same direction and the load can move, as shown in Figure 2.

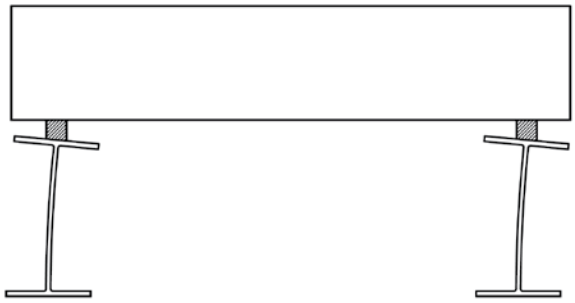

Figure 2: Possible load arrangements supporting equipment

BS 5950 provisions

BS 5950 deals with destabilising loads by increasing the effective length, L_E, as specified in Table 13. The effective length of the beam is really the effective length of the all-important unrestrained compression flange. With a beam loaded in the conventional sense, it is easy to visualise the compression flange from a bird's eye view, and consider the fixity at the end of the beam flange. Full rotational fixity leads to shorter effective lengths and less fixity leads to larger effective lengths. For a comparison with BS EN 1993-1-1, it will be assumed that both flanges are free to rotate on plan. Sometimes this is known as a fork end support, as indicated in Figure 3 – the beam has vertical and lateral support, but nothing stops the flanges rotating on plan.

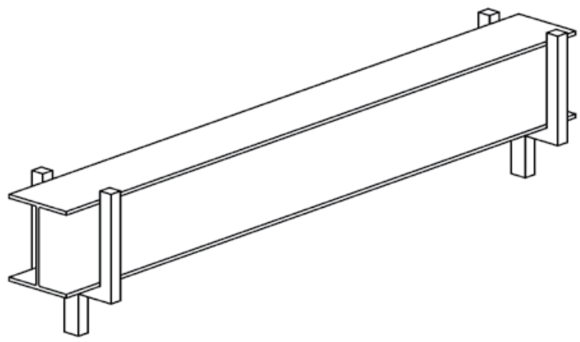

Figure 3: Beam with fork end supports

With a beam supported in this way, Table 13 of BS 5950 indicates that the effective length L_E is 1.0 L_{LT} under normal conditions, and 1.2 L_{LT} if the loads are destabilising.

This is the only provision that BS 5950 makes for destabilising loads; from then on, the process of determining a lateral torsional buckling resistance follows the normal rules.

Before leaving Table 13, the condition with the compression flange unrestrained should be noted. This is the case often encountered in domestic construction when beams sit on padstones. Two options are offered in Table 13; when the bottom flange is positively connected to the support and secondly when the beam simply sits on the support with no positive connection. If one imagines looking again with a bird's eye view of the top flange, an unrestrained compression flange can deform laterally even at the support. As shown in Figure 4, the effective length is increased in this situation. Table 13 specifies 1.2 L_{LT} + 2D for the normal loading condition and 1.4 L_{LT} + 2D when loads are destabilising.

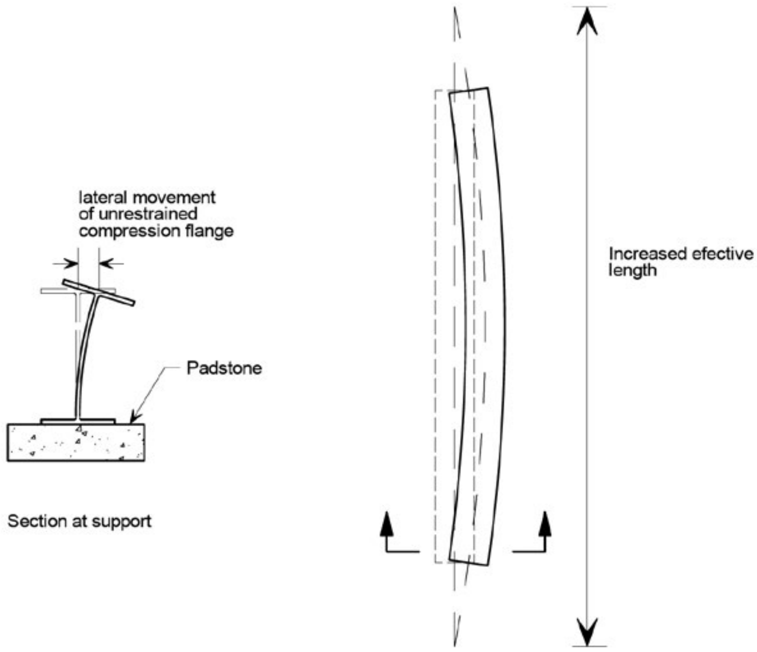

Figure 4: Unrestrained compression flange at supports

Finally, note that clause 4.3.4 alerts the designer to the possibility of destabilising loads, but in all other cases specifies that the normal loading condition be assumed. In BS 5950 therefore, there is no way of allowing for the beneficial effects of stabilising loads.

BS EN 1993-1-1 provisions

Within the Eurocode approach, the impact of the load position is accounted for in the determination of M_{cr} which may be calculated by a closed expression or determined using software. If designers conclude that the loads *are* destabilising, the general form of the closed expression (for a beam with fork end supports) is shown below.

$$M_{cr} = C_1 \frac{\pi^2 EI_z}{L^2}\left(\sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_T}{\pi^2 EI_z} + (C_2 z_g)^2} - C_2 z_g\right)$$

This expression is fully defined in NCCI ; of interest to this discussion is the C_2 value and the z_g dimension.

Rather like the C_1 value, the C_2 value depends on the shape of the bending moment diagram. Values for both factors can be obtained from NCCI. Two simple loading conditions and the values of C_1 and C_2 are given in Table 1, for a simply supported beam.

Loading condition	C_1	C_2
UDL	1.13	0.45
Central point load	1.35	0.63

Table 1: C_1 and C_2 values for standard cases

The dimension z_g is the distance from the shear centre to the point of load application. As shown in Figure 5, in the conventional orientation, if the load is applied to the top flange (a destabilising load), z_g is positive. If the load is stabilising, applied below the shear centre, z_g is negative.

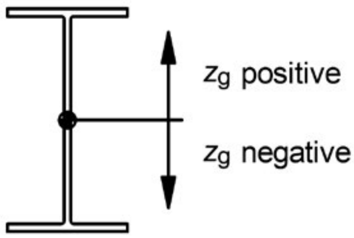

Figure 5: Sign convention for z_g

In Figure 6, *LTBeam* has been used to consider a destabilising load. Of note, the z_g dimension (highlighted) is positive and subtly, the load sketch shows the loading applied *above* the beam.

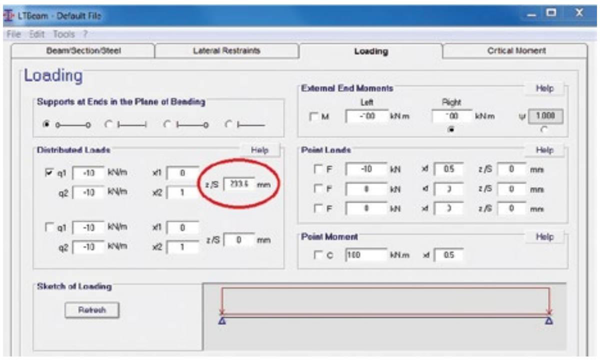

Figure 6: LTBeam software – destabilising load

In Figure 7, the same load has been applied as a stabilising load. The dimension z_g is negative.

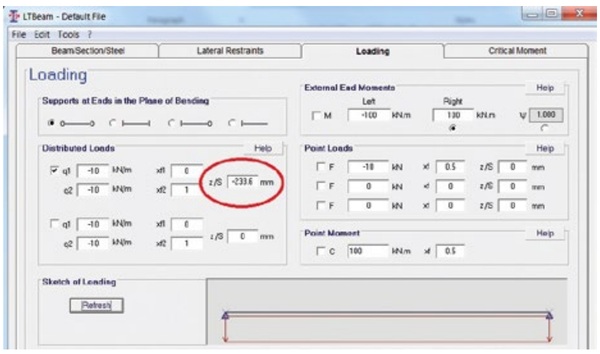

Figure 7: LTBeam software – stabilising load

What difference does it make?

The objective of this comparison is not to compare BS 5950 with BS EN 1993-1-1; the Eurocode is expected to deliver a larger resistance. Rather, the following example is presented to demonstrate the danger of ignoring destabilising loads – the resistance may be significantly lower.

The example is a 457 × 191 × 98 UB in S355. It is 6 m long, and subject to a UDL. It is assumed that the beam has fork end supports – i.e. the flanges are free to rotate on plan.

BS 5950

The intermediate values and final buckling resistances for both loading conditions are shown in Table 2.

	Normal load conditions	Destabilising loads
Effective length, L_E (m) (Table 13)	6	7.2
λ	138.6	166.3
λ/x	5.37	6.44
v (Table 19)	0.80	0.75
$\lambda_{LT} = uv\lambda$	97.7	109.9
p_b (Table 16 for p_y = 345 N/mm^2)	142.5	119.0
M_b (kNm)	**317.8**	**265.4**
m_{LT} (Table 18)	0.925	0.925
M_{max} (kNm)	343.6	286.9

Table 2: Member capacities according to BS 5950

	Normal load (applied at shear centre)	Destabilising load (applied at top flange)	Stabilising load (applied at bottom flange)
Dimension z_g (mm)	0	223.6	-223.6
M_{cr} (kNm) (*LTBeam*)	537	398	724
M_{cr} (kNm) (*expression*)	535	402	712
λ_{LT}	1.20	1.39	1.03
χ_{LT} (α_{LT} = 0.49)	0.525	0.434	0.621
$\chi_{LT,Mod}$	0.536	0.440	0.632
M_b (kNm)	**412.4**	**338.5**	**486.2**

Table 3: Member resistance according to BS EN 1993-1-1

The buckling resistances may be compared directly with the resistances in P202[ii]. The quoted resistance at 6 m is 318 kNm, so the calculations above appear to be correct!

Note that the maximum moment in the destabilising condition is only 83% of the value if normal load conditions had been assumed.

BS EN 1993-1-1

A similar exercise may be completed for BS EN 1993-1-1, as shown in Table 3 for three loading conditions. The load is assumed to be applied at the outside of the flange for both the stabilising and destabilising conditions. M_{cr} was calculated using *LTBeam* and by the expression above; both values are shown in Table 3.

In this case, if loads are destabilising, the resistance is again only 82% of the resistance if the loads are applied at the shear centre. Note that if the loads were stabilising, the resistance shows an enhancement of 17%.

General observations

This article has attempted to warn designers about the dangers of undiagnosed destabilising loads – whichever Standard is used, the lateral torsional buckling resistance is reduced significantly. The Eurocode allows the benefit of stabilising loads to be calculated, which may be an advantage in that relatively uncommon design situation.

This exercise also demonstrates that the BS 5950 approach of increasing the effective length by 20% is a good approximation to allow for the effect of destabilising loads. If M_b is recalculated according to the Eurocode, but with a buckling length of 7.2 m, the resistance is 348 kNm, which compares favourably with the precise calculation of 338 kNm. To increase the buckling length by 20% is a good rule of thumb when selecting an initial section, as the Eurocode resistance tables can then be used directly. To verify members to the Eurocode, an initial section is necessary, so that the dimension z_g can be determined.

Finally, this exercise considered destabilising loads applied to the top flange. If equipment is supported from stools, themselves on top of the beams, it may be prudent to increase the z_g dimension further, to allow for the increased destabilising effect.

[i] AD 311: T-sections in bending – stem in compression
Available from *http://www.steelbiz.org/*
[ii] P202 Section properties and member capacities to BS 5950-1