Steel Design to Eurocode 3

Unrestrained Beams

Beams without continuous lateral restraint are prone to buckling about their major axis, this mode of buckling is called **lateral torsional buckling (LTB).**

This handout is a continuation of the 'Restrained Beams' one and covers the design of unrestrained beams that are prone to lateral torsional buckling.

Lateral torsional buckling can be discounted when:

- The section is bent about its minor axis
- Full lateral restraint is provided
- Closely spaced bracing is provided making the slenderness of the weak axis low
- The compressive flange is restrained again torsion
- The section has a high torsional and lateral bending stiffness
- The non-dimensional slenderness, $\bar{\lambda}_{LT}$< 0.2

Eurocode 3 Approach

There are three methods for calculating the LTB resistance of a member in Eurocode 3:

1. Primary method (Clauses 6.3.2.2 and Clauses 6.3.2.3)
2. Simplified assessment method (Clause 6.3.2.4)
3. General method (Clause 6.3.4)

Note: This handout will only deal with the primary method.

General and Special Cases

When using the primary method, there are two cases which are available for you to use. The first case is the 'General Case' which can be used for all sections, and the second case is the 'Special Case' which is specifically for rolled sections of standard dimensions.

The methods for both cases are very similar with the addition of a few extra parameters in the Special Case. This small amount of extra work for the Special Case is worthwhile as it provides greater resistance of the section.

LTB Resistance

EN 1993-1-1 Clause 6.3.2.1 Equation 6.54 states that the design moment (M_{Ed}) must be less than the design buckling resistance moment ($M_{b,Rd}$)

$$\frac{M_{Ed}}{M_{b,Rd}} \le 1.0 \qquad (6.54)$$

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}} \qquad (6.55)$$

where γ_{M1} =1.0 (from UK NA)

Section Modulus W_y

For Class 1 and 2 cross-sections:

$$W_y = W_{pl,y}$$

For Class 3 cross-sections:

$$W_y = W_{el,y}$$

For Class 4 cross-sections:

$$W_y = W_{eff,y}$$

Yield Strength, f_y

The UK National Annex says that we should obtain the value of the yield strength from the product standards.

Extract from EN 10025-2 - f_y (yield strength) values for hot rolled steel:

Steel Grade	f_y (N/mm^2) nominal thickness of element, t (mm)			
	t≤16	16< t ≤ 40	40 < t ≤ 63	63 < t ≤ 80
S 275	275	265	255	245
S 355	355	345	335	325

Extract from EN 10025-2 (Table 7)

Reduction Factor, χ_{LT}

General Case:

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \bar{\lambda}_{LT}^2}} \qquad (6.56)$$

$$but\ \chi_{LT} \le 1.0$$

where

$$\phi_{LT} = 0.5[1 + \alpha_{LT}(\bar{\lambda}_{LT} - 0.2) + \bar{\lambda}_{LT}^2]$$

To get α_{LT}, determine the buckling curve that you need to use from table 6.4 and then refer to table 6.3 to get the corresponding value of α_{LT}

Cross-section	Limits	Buckling Curve
Rolled I sections	h/b ≤ 2 h/b >2	a s
Welded I sections	h/b ≤ 2 h/b >2	c d
Other	-	d

EN 1993-1-1 Table 6.4

Buckling curve	a	b	c	d
α_{LT}	0.21	0.34	0.49	0.76

EN 1993-1-1 Table 6.3

Special Case (for rolled sections):

$$\chi_{LT} = \frac{1}{\phi_{LT} + \sqrt{\phi_{LT}^2 - \beta\bar{\lambda}_{LT}^2}} \qquad (6.57)$$

$$\chi_{LT} \leq 1.0 \qquad \chi_{LT} \leq \frac{1}{\bar{\lambda}_{LT}}$$

where

$$\phi_{LT} = 0.5[1 + \alpha_{LT}(\bar{\lambda}_{LT} - \bar{\lambda}_{LT,0}) + \beta\bar{\lambda}_{LT}^2]$$

UK NA sets β = 0.75 and $\bar{\lambda}_{LT,0}$ = 0.4

To get α_{LT}, determine the buckling curve that you need to use from the table from the National Annex NA.2.17 Clause 6.3.2.3(1) and then refer to table 6.3 to get the corresponding value of α_{LT}

Cross-section	Limits	Buckling Curve
Rolled bi-symmetric I and H sections and hot-finished hollow sections	h/b ≤ 2 2.0 < h/b ≤ 3.1	b c
Angles (for moments in the major principal plane) and other hot-rolled sections		d
Welded bi-symmetric sections and cold-formed hollow sections	h/b ≤ 2 h/b > 2	c d

Table from NA.2.17 Clause 6.3.2.3(1)

Buckling curve	a	b	c	d
α_{LT}	0.21	0.34	0.49	0.76

EN 1993-1-1 Table 6.3

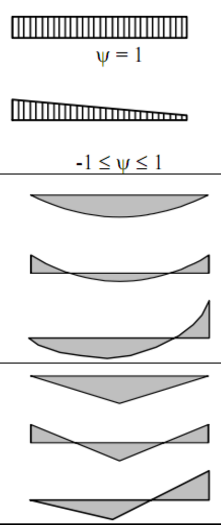
You can use a modified value of χ_{LT} in the special case to give some extra resistance:

$$\chi_{LT,mod} = \frac{\chi_{LT}}{f} \qquad (6.58)$$

f= 1- 0.5(1 - k_c)[1-2.0($\bar{\lambda}_{LT}$ - 0.8)^2]

but f ≤1.0

k_c can be obtained from Table 6.6 in the Eurocodes:



Moment distribution	k_c
ψ = 1	1,0
-1 ≤ ψ ≤ 1	$\frac{1}{1,33 - 0,33\psi}$
	0,94
	0,90
	0,91
	0,86
	0,77
	0,82

EN 1993-1-1 Table 6.6

$\bar{\lambda}_{LT}$

You will need the value of $\bar{\lambda}_{LT}$ for both the general and special cases.

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} \qquad (6.56)$$

M_{cr}

Refer to SN003 document (NCCI) for detailed description of how to get Mcr

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

where

L is the distance between points of lateral restraint (L_{cr})

E is the Young's Modulus = 210000 N/mm^2

G is the shear modulus = 80770 N/mm^2

I_z is the second moment of area about the weak axis

I_t is the torsion constant

I_w is the warping constant

k is an effective length factor (usually 1.0)

k_w is an effective length factor (usually 1.0)

z_g is the distance between the point of load application and the shear centre. The value will be positive or negative depending on where the load is applied as shown in figure 1.

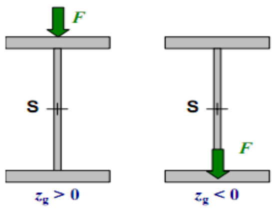
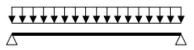
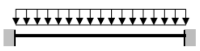
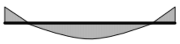
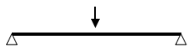


Figure 1 (from SN003 document)

C_1 and C_2 are coefficients.

For transverse loading, C1 and C2 are obtained from Table 5.2 in SN003:

Table 3.2 Values of factors C_1 and C_2 for cases with transverse loading (for k = 1)

Loading and support conditions	Bending moment diagram	C_1	C_2
		1,127	0,454
		2,578	1,554
		1,348	0,630
		1,683	1,645

Note : the critical moment M_{cr} is calculated for the section with the maximal moment along the member

Table 5.2 from SN003 (C1 and C2 values for transverse loading)

For members with end moments, the value of C1 is obtained from Table 3.1 in SN003:

ψ	C_1
+1,00	1,00
+0,75	1,14
+0,50	1,31
+0,25	1,52
0,00	1,77
-0,25	2,05
-0,50	2,33
-0,75	2,57
-1,00	2,55

Table 3.1 from SN003 (Values of C1 for members with end moments)

where

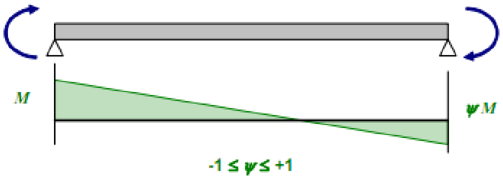


Figure 3.1 from SN003

Summary

1. Draw the bending moment diagram to obtain the value of the maximum bending moment, M_{Ed}
2. Determine f_y (UK NA recommends you use the product standards) and calculate the class of the section. Once you know the class of the section then you will know which value of the section modulus you will need to use in the equation 6.55.
3. Work out the effective length, L_{cr}
4. Refer to SN003 document and work out the value of M_{cr}, the critical moment
5. Work out $\bar{\lambda}_{LT}$ using expression 6.56.
6. Determine the values of α_{LT}
   a. For the **general case** use Table 6.4 to work out the buckling curve and then refer to Table 6.3 to get a value of α_{LT}
   b. For the **special case**, refer to the table in the National Annex (NA.2.17 Clause 6.3.2.3(1)) to get the buckling curve and then refer to Table 6.3 to get the value of α_{LT}
7. Work out Φ_{LT}
   a. For the **general case** use expression 6.56
   b. For the **special case**, use expression 6.57
8. Work out χ_{LT}
   a. For the **general case** use expression 6.56
   b. For the **special case**, use expression 6.57
9. Calculate the design buckling resistance $M_{c,Rd}$ using equation 6.55.
10. Carry out the buckling resistance check in expression 6.54.