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Benchmark Example No. 15

Buckling Resistance of Steel Members

VERiFiCATION
DCE-EN15 Buckling Resistance of Steel Members

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The user of the program is solely responsible for the applications. We strongly encourage the user to test the correctness of all calculations at least by random sampling.

Front Cover

6th Street Viaduct, Los Angeles Photo: Tobias Petschke

Overview

Design Code Family(s):	EN
Design Code(s):	EN 1993-1-1
Module(s):	BDK
Input file(s):	buckling_steel.dat

1 Problem Description

The problem consists of a simply supported beam with a steel I-section subject to uniform end moments, as shown in Fig. 1. The cross-section is checked against buckling.

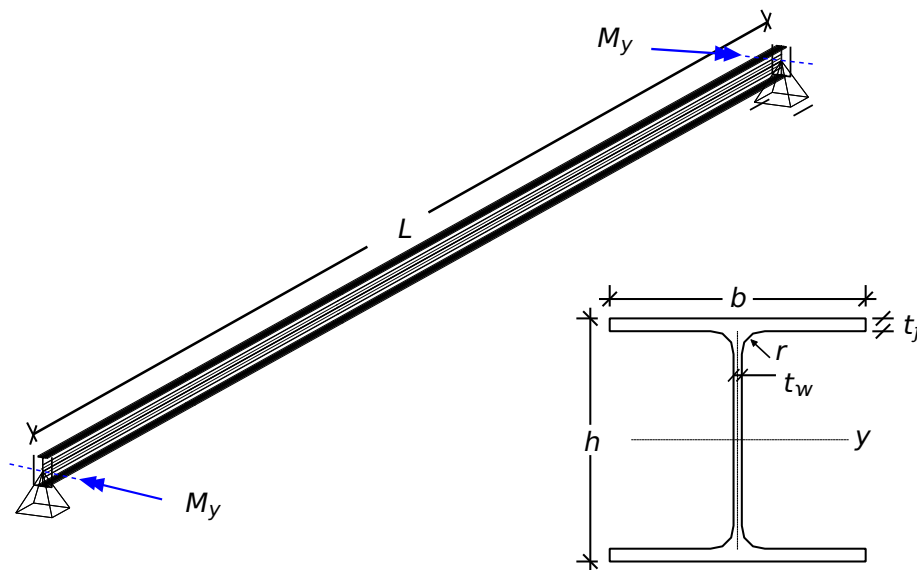


Figure 1: Problem Description

2 Reference Solution

This example is concerned with the buckling resistance of steel members. Lateral torsional buckling occurs in unrestrained, or inadequately restrained beams bent about the major axis and this causes the compression flange to buckle and deflect sideways, thus inducing twisting of the section. The content of this problem is covered by the following parts of EN 1993-1-1:2005 [1]:

- Structural steel (Section 3.2)
- Classification of cross-sections (Section 5.5)
- Buckling resistance of members (Section 6.3)

3 Model and Results

The I-section, a UB 457x152x74, with properties as defined in Table 1, is to be checked for buckling, with respect to EN 1993-1-1:2005 [1]. The calculation steps [2] are presented below and the results are given in Table 2.

Table 1: Model Properties

Material Properties	Geometric Properties	Loading
S 275	$L = 8 \text{ m}$	$M_y = 150 \text{ kNm}$
$E = 210000 \text{ N/mm}^2$	UB 457x152x74	
	$h = 462.0 \text{ mm}$	
	$b = 154.4 \text{ mm}$	
	$t_f = 17.0 \text{ mm}$	
	$t_w = 9.6 \text{ mm}$	
	$r = 10.2 \text{ mm}$	
	$A = 94.48 \text{ cm}^2$	
	$I_z = 1046.5 \text{ cm}^4$	
	$I_T = 66.23 \text{ cm}^4$	
	$I_w = 516297.12 \text{ cm}^6$	

Table 2: Results

	SOF.	Ref.
$M_{cr} [\text{kNm}]$	154.17	154.26
$\bar{\lambda}_{LT}$	1.703	1.703
Φ_{LT}	1.907	1.907
χ_{LT}	0.321	0.321
$M_{Ed}/M_{b,Rd} \text{ (BDK)}$	1.045	1.045

4 Design Process¹

Material:

Structural Steel S 275

$$f_y = 275 \text{ N/mm}^2 \text{ for maximum thickness } \leq 40 \text{ mm}$$

$$\epsilon = \sqrt{235/f_y} = 0.924$$

Design Load:

$$M_{Ed} = 150 \text{ kNm}$$

The cross-section is classified as **Class 1**, as demonstrated in Benchmark DCE-EN14.

$$M_{c,Rd} = M_{pl,Rd,y} = \frac{W_{pl,y} \cdot f_y}{\gamma_{M0}} = 447.31 \text{ kNm}$$

$$M_{cr} = \frac{\pi \sqrt{EI_z GI_T}}{L} \sqrt{\left(1 + \frac{\pi^2 EI_w}{GI_T L^2}\right)}$$

$$M_{cr} = \frac{3.14 \cdot \sqrt{2197.74 \cdot 53.496}}{8} \sqrt{\left(1 + \frac{3.14^2 \cdot 108.42}{53.496 \cdot 8^2}\right)}$$

$$M_{cr} = 154.26 \text{ kNm}$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{447.31}{154.26}} = 1.703$$

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

$$h/b = 462/154.4 = 2.99 > 2$$

for rolled I-sections and $h/b > 2 \rightarrow$ buckling curve c

for buckling curve c $\rightarrow \alpha_{LT} = 0.49$

$$\Phi_{LT} = 0.5 \left[1 + 0.49 (1.703 - 0.4 + 0.75 \cdot 1.703^2)\right] = 1.907$$

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \beta \bar{\lambda}_{LT}^2}} = 0.321$$

$$\text{but } \chi_{LT} = 0.321 \leq 1.0 \text{ and } \chi_{LT} = 0.321 \leq \frac{1}{\bar{\lambda}_{LT}^2} = 0.345$$

$$M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}} = 143.587 \text{ kNm}$$

$$\frac{M_{Ed}}{M_{b,Rd}} = 1.045 \rightarrow \text{Beam fails in LTB}$$

Tab. 3.1 : Nominal values of yield strength f_y and ultimate tensile strength f_u for hot rolled structural steel.

Tab. 5.2: Maximum width-to-thickness ratios for compression parts

Tab. 5.5: Classification of cross-section

6.2.5 (2):Eq. 6.13: Bending resistance $M_{c,Rd}$ for Class 1 cross-section

6.1 (1): $\gamma_{M0} = 1.00$

6.3.2.2 (2): M_{cr} , the elastic critical moment for ltb is based on gross cross sectional properties

Various empirical or approximate formulae exist for the determination of M_{cr}

6.3.2.2 (1): $\bar{\lambda}_{LT}$ non dimensional slenderness for lateral torsional buckling

6.3.2.3 (1): Φ_{LT} for rolled sections in bending. Recommended values:

$\bar{\lambda}_{LT,0} = 0.4$ (maximum value)

$\beta = 0.75$ (minimum value)

6.3.2.3 (1): Table 6.5: Recommendation for the selection of ltb curve for cross-sections using Eq. 6.57

6.3.2.2 (2): Table 6.5: Recommendation values for imperfection factors α_{LT} for ltb curves

6.3.2.3 (1): Eq. 6.57: χ_{LT} reduction factor for ltb

6.3.2.1 (3): Eq. 6.55: $M_{b,Rd}$ The design buckling resistance moment of laterally unrestrained beam

For Class 1 section $W_y = W_{pl,y}$

6.1 (1): $\gamma_{M1} = 1.00$ recommended value

¹The sections mentioned in the margins refer to EN 1993-1-1:2005 [1] unless otherwise specified.

5 Conclusion

This example shows the check for lateral torsional buckling of steel members. It has been shown that the results are reproduced with excellent accuracy.

6 Literature

- [1] *EN 1993-1-1: Eurocode 3: Design of steel structures, Part 1-1: General rules and rules for buildings*. CEN. 2005.
 - [2] *Structural Eurocodes - Extracts from the structural Eurocodes for students of structural design*. BSI - British Standards Institution. 2007.
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