The Second Generation Eurocodes

Key changes and benefits through design examples

Online, 3-5 June 2025

Copyright in BSI publications

EN 1999 ‘Eurocode 9: Design of aluminium structures’

Antonio Formisano

EUROCODES

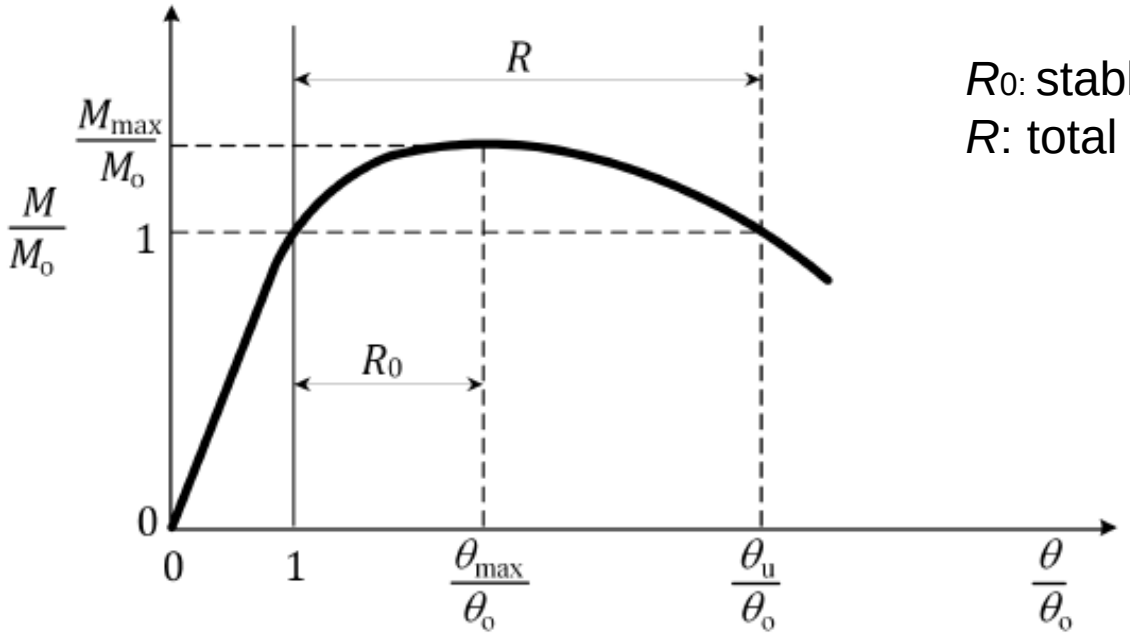
EUROCODES

EN 1999

Design of aluminium structures

Cross-sectional ductility and rotation capacity

According to Annex L, the Moment-Rotation curve of a double T aluminium alloy beam is evaluated through empirical relationships based on available experimental results and/or numerical simulation results.



*

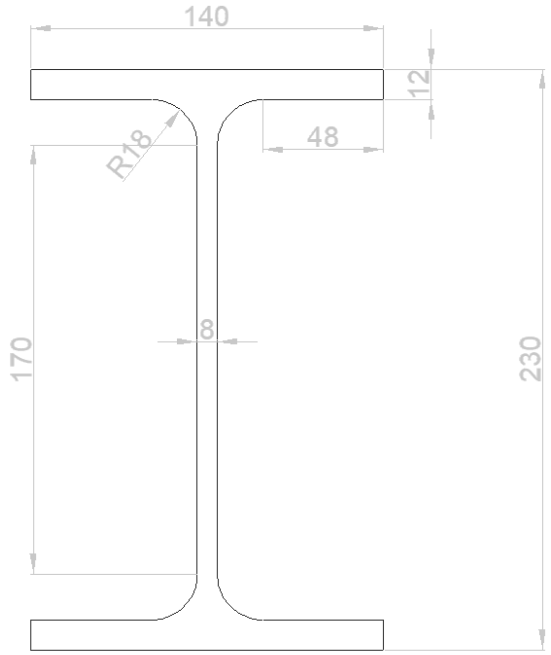
R_0: stable part of rotation capacity
R: total rotation capacity

$$R_0 = \frac{\theta_{max}}{\theta_o} - 1$$

$$R = \frac{\theta_u}{\theta_o} - 1$$

Cross-sectional ductility and rotation capacity

A simple supported beam with length of 5 m, having double T cross-section and made of EN AW 6061-T6 aluminium alloy, is investigated under an uniformly distributed load to assess its Moment-Rotation curve.



Alloy EN AW	Product form	Temper	Thick-ness, t, mm[a, c]	f_o[a]	f_u[a]	A[e, b]	$f_{o,haz}$[d]	$f_{u,haz}$[d]	HAZ-factor[d]		BC[f]	n_p[g]
				N/mm²		%	N/mm²		$\rho_{o,haz}$	$\rho_{u,haz}$		
6061	EP, ET, ER/B	T4	$t \le 25$	110	180	15	95	150	0,86	0,83	C	10
	DT		$t \le 20$	110	205	16				0,73	C	8
	EP, ET, ER/B	T6	$t \le 25$	240	260	8	115	175	0,48	0,67	A	55
	DT		$t \le 20$	240	290	10				0,60	A	23

*

Cross-sectional ductility and rotation capacity

CLASSIFICATION OF THE CROSS-SECTION

- Web

For internal parts with a stress gradient that results in a neutral axis at the centre:

$\beta = 0{,}40 \times b/t = 0{,}40 \times 170/8 = 8{,}5$

$$\varepsilon = \sqrt{\frac{250}{f_o}} = \sqrt{\frac{250}{240}} = 1{,}02$$

	Buckling Class according to Table 5.3 and Table 5.4	Internal part		Outstand part	
		β_2/ε	β_3/ε	β_2/ε	β_3/ε
Without welds	A	16	22	4,5	6
	B	16	20	4,5	5,5
	C	16	18	4,5	5
With welds	A	13	18	4,0	5
	B	13	16,5	3,8	4,5
	C	13	15	3,5	4

*

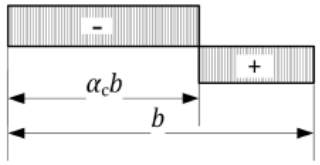
$\beta_2 = 16\varepsilon = 16 \times 1{,}02 = 16{,}32$ $\beta_3 = 22\varepsilon = 22 \times 1{,}02 = 22{,}44$ $\beta < \beta_2$ **Class 1**

Cross-sectional ductility and rotation capacity

CLASSIFICATION OF THE CROSS-SECTION

- Web

The values of permissible b/t-ratios for class 1 cross section parts without welds should be obtained from Table 8.2 “Permissible values of b/t for cross-section part without welds”



Cross-section	Internal part		Outstand part	
	$\alpha_c \le 0{,}5$	$\alpha_c > 0{,}5$	Peak compression at supported edge	Peak compression at unsupported edge
Class 1	$\le \frac{16\varepsilon}{\alpha_c}$	$\le \frac{56\varepsilon}{5{,}5\alpha_c - 1}$	$\le \frac{4\varepsilon}{\alpha_c}$	$\le \frac{4\varepsilon}{\alpha_c^{1,5}}$

$\alpha_c = 0{,}5$

$$\frac{b}{t} \le \frac{16\varepsilon}{\alpha_c} = \frac{16 \cdot 1{,}02}{0{,}5} = 32{,}6$$

$$\frac{b}{t} = \frac{170}{8} = 21{,}25 < 32{,}6$$ **Class 1** *

Cross-sectional ductility and rotation capacity

CLASSIFICATION OF THE CROSS-SECTION

- Flange

For flat outstands with no stress gradient:

$\beta = b/t = 48/12 = 4$

$$\varepsilon = \sqrt{\frac{250}{f_o}} = \sqrt{\frac{250}{240}} = 1{,}02$$

	Buckling Class according to Table 5.3 and Table 5.4	Internal part		Outstand part	
		β_2/ε	β_3/ε	β_2/ε	β_3/ε
Without welds	A	16	22	4,5	6
	B	16	20	4,5	5,5
	C	16	18	4,5	5
With welds	A	13	18	4,0	5
	B	13	16,5	3,8	4,5
	C	13	15	3,5	4

*

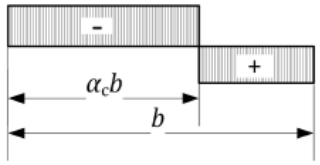
$\beta_2 = 4{,}5\varepsilon = 4{,}5 \times 1{,}02 = 4{,}59$ $\beta_3 = 6\varepsilon = 6 \times 1{,}02 = 6{,}12$ $\beta < \beta_2$ **Class 1**

Cross-sectional ductility and rotation capacity

CLASSIFICATION OF THE CROSS-SECTION

- Flange

The values of permissible b/t-ratios for class 1 cross section parts without welds should be obtained from Table 8.2 “Permissible values of b/t for cross-section part without welds”



Cross-section	Internal part		Outstand part	
	$\alpha_c \le 0{,}5$	$\alpha_c > 0{,}5$	Peak compression at supported edge	Peak compression at unsupported edge
Class 1	$\le \frac{16\varepsilon}{\alpha_c}$	$\le \frac{56\varepsilon}{5{,}5\alpha_c - 1}$	$\le \frac{4\varepsilon}{\alpha_c}$	$\le \frac{4\varepsilon}{\alpha_c^{1,5}}$

$\alpha_c = 1$

$$\frac{b}{t} \le 4\varepsilon = 4 \cdot 1{,}02 = 4{,}08$$

$$* \quad \frac{b}{t} = \frac{48}{12} = 4 < 4{,}08$$ **Class 1**

Cross-sectional ductility and rotation capacity

EMPIRICAL RELATION FOR ULTIMATE RESISTANCE

In case of a beam made of temper T6, the ratio between the ultimate moment resistance and the conventional elastic limit moment M_o can be calculated as a function of the non-dimensional geometrical parameters describing the cross-section and the shear length:

- Flange slenderness parameter

$$\lambda_f = 0,807 \frac{b}{t_f}\sqrt{\frac{f_o}{E}}$$ for outstand cross-section part * $\lambda_f = 0{,}807 \cdot \frac{140}{12} \cdot \sqrt{\frac{240}{70000}} = 0{,}55$

- Web restraining action (flange-to-web slenderness ratio)

$$\alpha_s = \frac{bt_w}{2ht_f}$$ for I (double T) cross-section * $a_s = \frac{140 \cdot 8}{2 \cdot 230 \cdot 12} = 0{,}203$

Cross-sectional ductility and rotation capacity

EMPIRICAL RELATION FOR ULTIMATE RESISTANCE

In case of a beam made of temper T6, the ratio between the ultimate moment resistance and the conventional elastic limit moment M_o can be calculated as a function of the non-dimensional geometrical parameters describing the cross-section and the shear length:

- The non-dimensional shear length, Ls/b, i.e. the parameter accounting for the influence of the moment gradient, where:
  - L_s is the distance between the point of zero moment and the critical section where the development of the plastic hinge is expected;
  - b is the flange width of the cross-sections.

Cross-sectional ductility and rotation capacity

EMPIRICAL RELATION FOR ULTIMATE RESISTANCE

In case of alloys whose stress-strain constitutive law is characterised by a value of the exponent n of the Ramberg-Osgood formula ranging from 8 to 55 and for values of f_o ranging from 110 MPa to 260 MPa, the following relation for calculating the ultimate resistance can be used:

$$\frac{M_{max}}{M_o} = \frac{1}{C_0}\left\{\left[C_1\left(\frac{L_s}{b}\right)+C_2\right]\alpha_s+\left(C_3 n^{C_4}\right)\left(\frac{L_s}{b}\right)^{(C_5 n+C_6)}\right\}\left(\lambda_f\right)^{C_7 ln(n)+C_8}$$

*

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
RHS	1,03	-0,00 076	-0,092 82	1,031 8	0,0725 5	-0,0005 9	-0,003 83	0,087 22	-0,426 5
I, H	1,03	0,000 8	-0,376 6	1,498 2	-0,014 9	0,000 2	-0,068 4	0,084 3	-0,471 9

*

$$M_o = (I_y/z_f)f_o$$

*

I_y: inertia moment evaluated with reference to the mid-line thickness model of the cross section

z_f: the distance from the neutral axis to the mid-line of the compression flange.

Cross-sectional ductility and rotation capacity

EMPIRICAL RELATION FOR ULTIMATE RESISTANCE

$$\frac{M_{max}}{M_o} = \frac{1}{C_0}\left\{\left[C_1\left(\frac{L_s}{b}\right)+C_2\right]\alpha_s+\left(C_3 n^{C_4}\right)\left(\frac{L_s}{b}\right)^{(C_5 n+C_6)}\right\}\left(\lambda_f\right)^{C_7 ln(n)+C_8} \quad *$$

The above formula is the outcome of the fitting with numerical results obtained by advanced finite element simulations so that it should be used within the following ranges of the performed parametric analysis:

— for I (double T) sections:

$0{,}52 \le \lambda_f \le 1{,}24$	$\lambda_f = 0{,}55$	
$0{,}20 \le \alpha_s \le 0{,}50$	$\alpha_s = 0{,}203$	Satisfied checks
$6{,}25 \le L_s/b \le 18{,}75$ *	$\frac{L_s}{b} = \frac{2500}{140} = 17{,}9$	

Cross-sectional ductility and rotation capacity

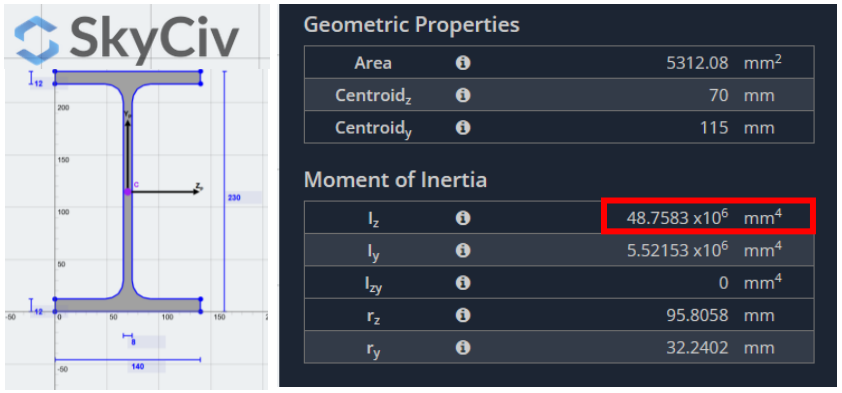
EMPIRICAL RELATION FOR ULTIMATE RESISTANCE

$$\frac{M_{max}}{M_o} = \frac{1}{C_0}\left\{\left[C_1\left(\frac{L_s}{b}\right)+C_2\right]\alpha_s+\left(C_3 n^{C_4}\right)\left(\frac{L_s}{b}\right)^{(C_5 n+C_6)}\right\}\left(\lambda_f\right)^{C_7 ln(n)+C_8}$$

*

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
RHS	1,03	-0,00 076	-0,092 82	1,031 8	0,0725 5	-0,0005 9	-0,003 83	0,087 22	-0,426 5
I, H	1,03	0,000 8	-0,376 6	1,498 2	-0,014 9	0,000 2	-0,068 4	0,084 3	-0,471 9

*



$$I_y = 48{,}76 \cdot 10^6 mm^4$$

$$z_f = \frac{230}{2} - \frac{12}{2} = 109mm$$

$$M_o = \frac{I_y}{z_f} \cdot f_o = \frac{48{,}76 \cdot 10^6}{109} \cdot 240 = 107{,}4kNm$$

$$\lambda_f = 0{,}55$$

$$a_s = 0{,}203$$

$$\frac{L_s}{b} = \frac{2500}{140} = 17{,}9$$

$$\frac{M_{max}}{M_o} = \mathbf{1{,}18}$$

$$\boldsymbol{M_{max} = 126{,}7\ kNm}$$

Cross-sectional ductility and rotation capacity

EMPIRICAL RELATIONS FOR ROTATION CAPACITY

The stable part of the rotation capacity R_0 can be derived from the following formula:

$$R_0 = \frac{1}{C_0} C_1 \left(\frac{L_s}{b}\right)^{C_2} \exp\left[\alpha_s C_3 \left(\frac{L_s}{b}\right)^{C_4} - \alpha_s \lambda_f - \lambda_f C_5 n^{C_6} \left(\frac{L_s}{b}\right)^{C_7}\right] *$$

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
RHS	1,80	793,8	-0,947 0	-5,769	-1,702 6	4,506	0,241 4	-0,144 5
I, H	1,22	82,83	-0,166 3	1,942	-0,286 8	1,789	0,165 6	0,254 3

*

$\boldsymbol{R_0 = 0,83}$

$\lambda_f = 0{,}55$ $\quad a_s = 0{,}203$ $\quad \frac{L_s}{b} = 17{,}9$

Cross-sectional ductility and rotation capacity

EMPIRICAL RELATIONS FOR ROTATION CAPACITY

The total rotation capacity *R* can be derived from the following formula:

$$R = \frac{1}{C_0}\sqrt{\alpha_s}\left[C_1 n^{C_2}\left(\frac{L_s}{b}\right)^{C_3}\right]\exp\left\{C_4\alpha_s - \left[C_5\left(\frac{L_s}{b}\right) + C_6\ln(n) + C_7\right]\lambda_f\right\}$$ *

	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7
RHS	1,55	117 800	-1,376 5	-0,912 9	-0,815 5	-0,000 45	-2,008 3	11,40
I, H	1,21	222 100	-0,890 8	-1,645 3	-0,775 2	-0,003 6	-0,000 5	4,560

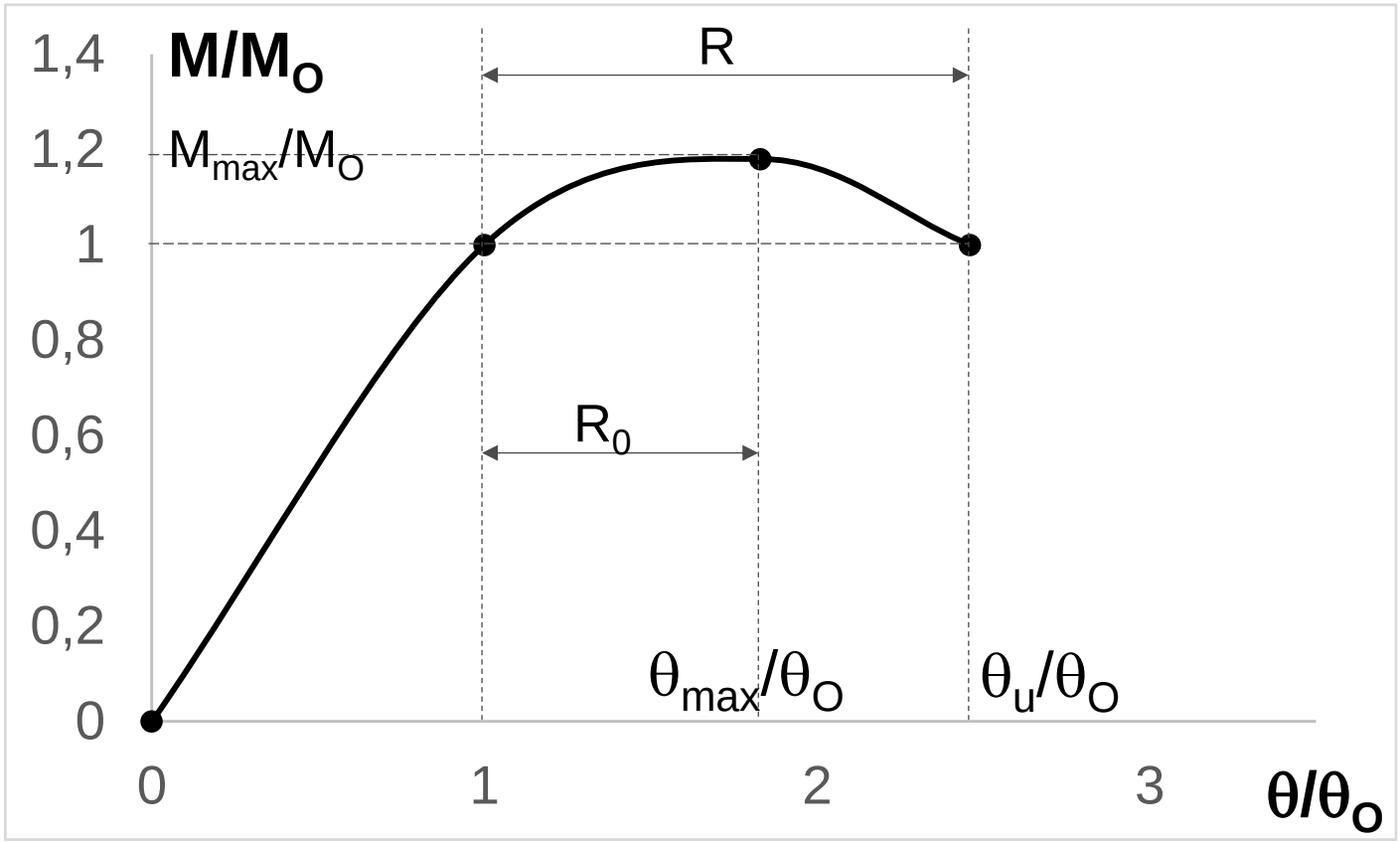
*

$$\boxed{R = 1,46}$$

$$\lambda_f = 0{,}55 \qquad a_s = 0{,}203 \qquad \frac{L_s}{b} = 17{,}9$$

Cross-sectional ductility and rotation capacity

MOMENT-ROTATION CURVE OF THE EXAMINED BEAM



Thank you!