7 SECTION CLASSIFICATION

7.1 GENERAL

Cross-sections subject to compression due to axial load or bending moment should be classified into Class 1 plastic, Class 2 compact, Class 3 semi-compact or Class 4 slender, depending on their width to thickness ratios of section elements and hence, their susceptibility against local buckling. Cross-sections should be classified to determine whether local buckling influences their section capacity, without calculating their local buckling resistance. This section covers steel grades with design strength not greater than 690 N/mm^2 and its extension to higher steel grades should be justified.

The classification of each element of a cross-section subject to compression should be based on its width-to-thickness ratio. The dimensions of these compression elements should be taken as shown in Figure 7.1. The elements of a cross-section are generally of constant thickness. For elements taper in thickness, the thickness specified in the relevant standard should be used.

A distinction should be made between the following two types of element,

(a) Outstand elements are attached to adjacent elements at one edge only while the other edge being free.

(b) Internal elements are attached to other elements on both longitudinal edges and including:

- *Webs* comprising internal elements perpendicular to the axis of bending
- *Flanges* comprising internal elements parallel to the axis of bending

All compression elements should be classified in accordance with clause 7.2. Generally, the complete cross-section should be classified according to the highest (least favourable) class of its compression elements. Alternatively, a cross-section may be classified with its compression flange and its web in different classes.

Circular hollow sections should be classified separately for axial compression and for bending.

For the design of compression elements with longitudinal stiffeners, acceptable reference should be made.

Formulae in this clause shall be applicable to high strength steel, provided that it meets the requirements in strength, resistance to brittle fracture, ductility and weldability required in clause 3.1.3.

7.2 CLASSIFICATION

Class 1 plastic:

Cross-sections with plastic hinge rotation capacity. A plastic hinge can be developed with sufficient rotation capacity to allow redistribution of moments within the structure. Elements subject to compression that meet the limits for Class 1 given in Table 7.1 or Table 7.2 should be classified as Class 1 plastic.

Class 2 compact:

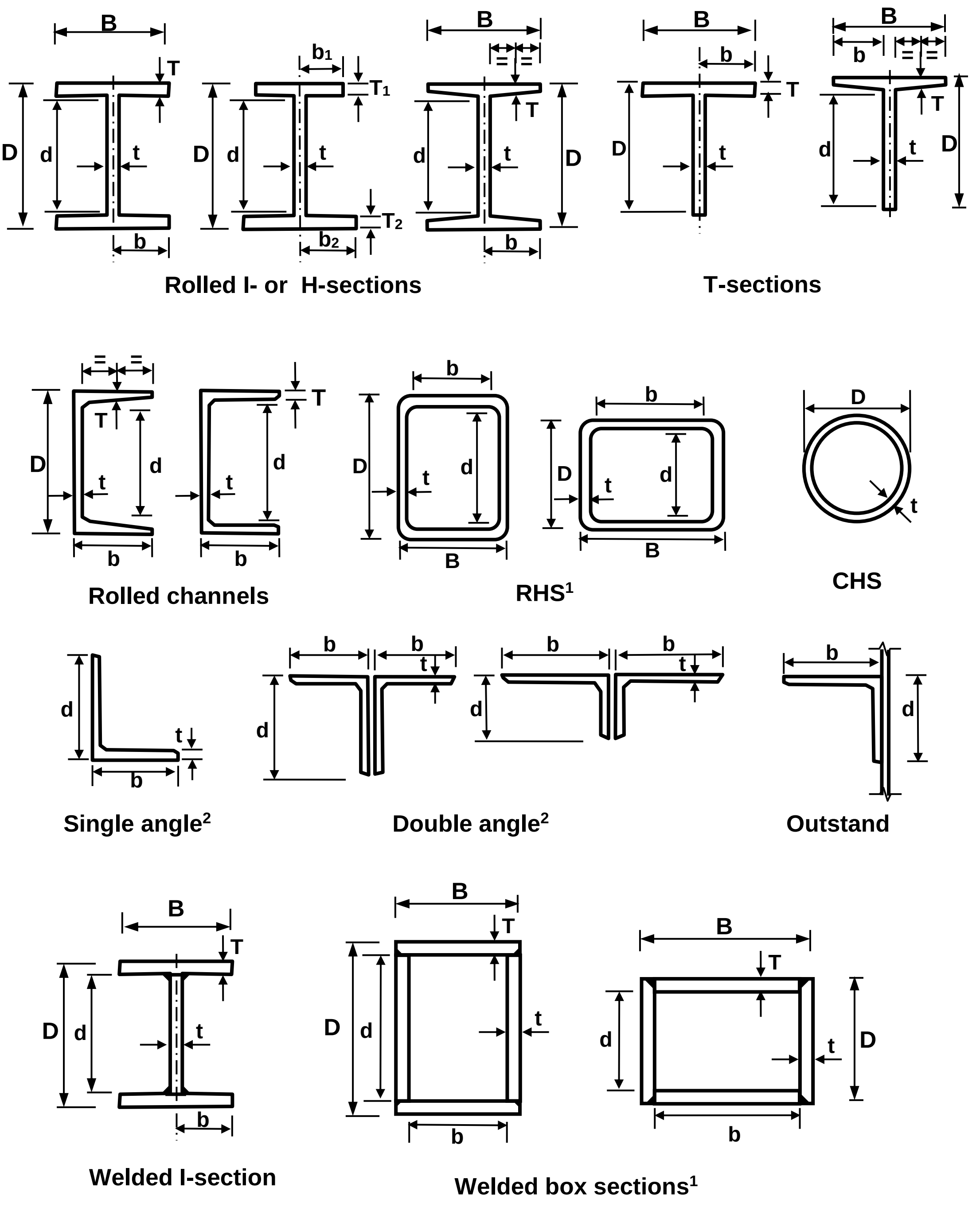
Cross-sections with plastic moment capacity. The plastic moment capacity can be developed, but local buckling may prevent the development of plastic hinge with sufficient rotation capacity at the section. Elements subject to compression that meet the limits for Class 2 given in Table 7.1 or Table 7.2 should be classified as Class 2 compact.

Class 3 semi-compact:

Cross-sections in which the stress at the extreme compression fibre can reach the design strength, but the plastic moment capacity cannot be developed. Elements subject to compression that meet the limits for Class 3 given in Table 7.1 or Table 7.2 should be classified as Class 3 semi-compact.

Class 4 slender:

Cross-sections in which it is necessary to make explicit allowance for the effects of local buckling which prevents the development of the elastic capacity in compression and/or bending. Elements subject to compression that do not meet the limits for Class 3 semi-compact given in Table 7.1 or Table 7.2 should be classified as Class 4 slender. In these cross-sections, the stress at the extreme compression fibre cannot reach the design strength.



[1] For a RHS or box section, B and b are flange dimensions and D and d are web dimensions. The distinction between webs and flanges depends upon whether the member is bent about its major axis or minor axis, see clause 7.1.
For a RHS, dimensions b and d are defined in footnote a to c Table 7.2.

[2] For an angle, b is the dimension of the outstand leg and d is the dimension of the connected leg.
Special care should be taken in sections fabricated by thick plates to avoid lamellar tearing.

Figure 7.1 - Dimensions of compression elements

Table 7.1 - Limiting width-to-thickness ratios for sections other than CHS and RHS

Compression element				Ratio [a]	Limiting value [b]		
					Class 1 plastic	Class 2 compact	Class 3 semi-compact
Flange	Outstand element	Compression due to bending	Rolled section	*b/T*	9ε	10ε	15ε
			Welded section		8ε	9ε	13ε
		Axial compression		*b/T*	Not applicable		13ε
	Internal element	Compression due to bending		*b/T*	28ε	32ε	40ε
		Axial compression		*b/T*	Not applicable		
Web of an I-, H- or Box section [d]	Neutral axis at mid-depth			*d/t*	80ε	100ε	120ε
	Generally [c]	r_1 is negative		*d/t*	$\frac{80\varepsilon}{1+r_1}$ but $\geq 40\varepsilon$	$\frac{100\varepsilon}{1+r_1}$	$\frac{120\varepsilon}{1+2r_2}$ but $\geq 40\varepsilon$
		r_1 is positive		*d/t*		$\frac{100\varepsilon}{1+1.5r_1}$ but $\geq 40\varepsilon$	
	Axial compression [c]			*d/t*	Not applicable		
Web of a channel				*d/t*	40ε	40ε	40ε
Angle, compression due to bending (Both criteria should be satisfied)				*b/t* *d/t*	9ε 9ε	10ε 10ε	15ε 15ε
Single angle, or double angles with the components separated, axial compression (All three criteria should be satisfied)				*b/t* *d/t* *(b+d)/t*	Not applicable		15ε 15ε 24ε
Outstand leg of an angle in contact back-to-back in a double angle member				*b/t*	9ε	10ε	15ε
Outstand leg of an angle with its back in continuous contact with another component							
Stem of a T-section, rolled or cut from a rolled I- or H-section				*D/t*	8ε	9ε	18ε

[a] Dimensions *b*, *D*, *d*, *T* and *t* are defined in Figure 7.1. For a box section *b* and *T* are flange dimensions and *d* and *t* are web dimensions, where the distinction between webs and flanges depends upon whether the box section is bent about its major axis or its minor axis, see clause 7.1.

[b] The parameter $\varepsilon = \sqrt{\frac{275}{p_y}}$ where p_y is in N/mm^2

[c] The stress ratios r_1 and r_2 are defined in clause 7.3.

[d] For the web of a hybrid section ε should be based on the design strength p_{yf} of the flanges.

Table 7.2 - Limiting width-to-thickness ratios for CHS and RHS

Compression element			Ratio [a]	Limiting value [b]		
				Class 1 plastic	Class 2 compact	Class 3 semi-compact
CHS	Compression due to bending		D/t	$40\varepsilon^2$	$50\varepsilon^2$	$140\varepsilon^2$
	Axial compression		D/t	Not applicable		$80\varepsilon^2$
HF RHS	Flange	Compression due to bending	b/t	28ε but $\leq 80\varepsilon - d/t$	32ε but $\leq 62\varepsilon - 0.5d/t$	40ε
		Axial compression	b/t	Not applicable		
	Web	Neutral axis at mid-depth	d/t	64ε	80ε	120ε
		Generally [c]	d/t	$\frac{64\varepsilon}{1+0.6r_1}$ but $\geq 40\varepsilon$	$\frac{80\varepsilon}{1+r_1}$ but $\geq 40\varepsilon$	$\frac{120\varepsilon}{1+2r_2}$ but $\geq 40\varepsilon$
		Axial compression [c]	d/t	Not applicable		
CF RHS	Flange	Compression due to bending	b/t	26ε but $\leq 72\varepsilon - d/t$	28ε but $\leq 54\varepsilon - 0.5d/t$	35ε
		Axial compression	b/t	Not applicable		
	Web	Neutral axis at mid-depth	d/t	56ε	70ε	105ε
		Generally [c]	d/t	$\frac{56\varepsilon}{1+0.6r_1}$ but $\geq 35\varepsilon$	$\frac{70\varepsilon}{1+r_1}$ but $\geq 35\varepsilon$	$\frac{105\varepsilon}{1+2r_2}$ but $\geq 35\varepsilon$
		Axial compression [c]	d/t	Not applicable		

Abbreviations

- CF — Cold formed;
- CHS — Circular hollow section — including welded tube;
- HF — Hot finished;
- RHS — Rectangular hollow section — including square hollow section.

[a] For an RHS, the dimensions b and d should be taken as follows:
— for HF RHS: $b = B - 3t$; $d = D - 3t$
— for CF RHS: $b = B - 5t$; $d = D - 5t$
and B, D and t are defined in Figure 7.1. For an RHS subject to bending, B and b are always flange dimensions, and D and d are always web dimensions, but the definition of which sides of the RHS are webs and which are flanges changes according to the axis of bending, see clause 7.1.

[b] The parameter $\varepsilon = \sqrt{\frac{275}{p_y}}$ where p_y is in N/mm^2

[c] The stress ratios r_1 and r_2 are defined in clause 7.3.

7.3 STRESS RATIOS FOR CLASSIFICATION

The stress ratios r_1 and r_2 used in Tables 7.1 and 7.2 should be calculated from the following:

(a) I- or H-sections with equal flanges:

$$r_1 = \frac{F_c}{dtp_{yw}} \quad \text{but} \quad -1 < r_1 \leq 1 \tag{7.1}$$

$$r_2 = \frac{F_c}{A_g p_{yw}} \tag{7.2}$$

(b) I- or H-sections with unequal flanges:

$$r_1 = \frac{F_c}{dtp_{yw}} + \frac{(B_t T_t - B_c T_c) p_{yf}}{dtp_{yw}} \quad \text{but} \quad -1 < r_1 \leq 1 \tag{7.3}$$

$$r_2 = \frac{f_1 + f_2}{2p_{yw}} \tag{7.4}$$

(c) RHS or welded box sections with equal flanges:

$$r_1 = \frac{F_c}{2dtp_{yw}} \quad \text{but} \quad -1 < r_1 \leq 1 \tag{7.5}$$

$$r_2 = \frac{F_c}{A_g p_{yw}} \tag{7.6}$$

where

A_g = gross cross-sectional area;
B_c = width of the compression flange;
B_t = width of the tension flange;
d = web depth;
F_c = axial compression (negative for tension);
f_1 = maximum compressive stress in the web, see Figure 7.2;
f_2 = minimum compressive stress in the web (negative for tension), see Figure 7.2;
p_{yf} = design strength of the flange;
p_{yw} = design strength of the web (but $p_{yw} \leq p_{yf}$);
T_c = thickness of the compression flange;
T_t = thickness of the tension flange;
t = web thickness.

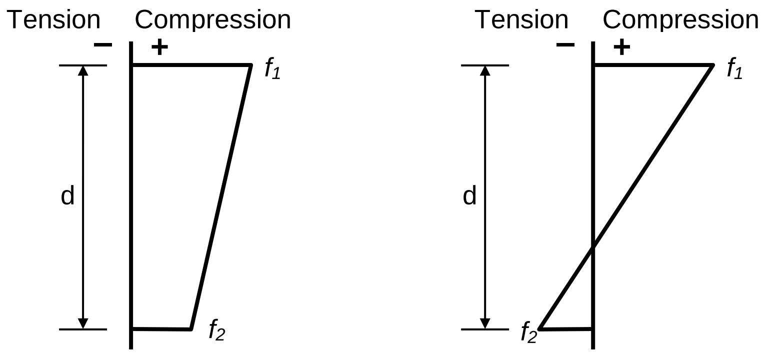


Figure 7.2 - Stress ratio for a semi-compact web

7.4 FLANGES OF COMPOUND I- OR H-SECTIONS

The classification of the compression flange of a compound section, fabricated by welding a flange plate to a rolled I- or H-section should take into account of the width-to-thickness ratios shown in Figure 7.3 as follows:

(a) The ratio of the outstand *b* of the compound flange, as shown in Figure 7.3(a), to the thickness *T* of the original flange should be classified under "<u>outstand element of compression flange-rolled section</u>", see Table 7.1.

(b) The ratio of the internal width b_p of the plate between the lines of welds or bolts connecting it to the original flange, as shown in Figure 7.3(b), to the thickness t_p of the plate should be classified under "<u>internal element of compression flange</u>", see Table 7.1.

(c) The ratio of the outstand b_o of the plate beyond the lines of welds or bolts connecting it to the original flange, as shown in Figure 7.3(c), to the thickness t_p of the plate should be classified under "<u>outstand element of compression flange-welded section</u>", see Table 7.1.

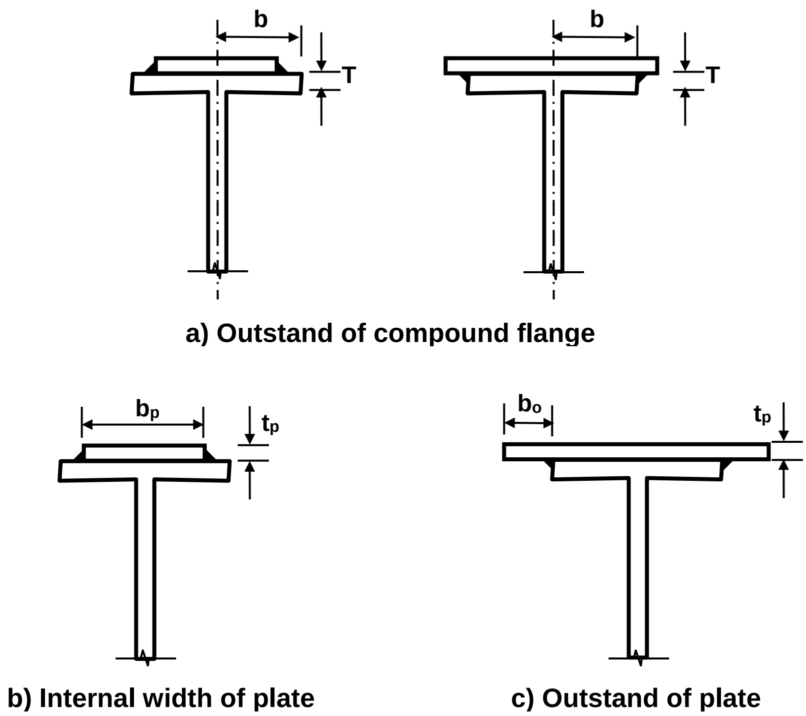


Figure 7.3 - Dimensions of compound flanges

The equivalent uniform moment factor m_{LT} for beams and the moment equivalent factor m for flexural buckling can be referred to Tables 8.4 a & b and Table 8.9.

7.5 EFFECTIVE PLASTIC MODULUS

7.5.1 General

Class 3 semi-compact sections subject to bending should be designed using either the section modulus Z or the effective plastic modulus S_{eff}.

For I- or H-sections with equal flanges, RHS and CHS, the effective plastic modulus should be determined from clause 7.5.2, 7.5.3 or 7.5.4 respectively.

For I- or H-sections with unequal flanges subject to bending in the plane of the web, acceptable reference should be made.

For other cross-sections S_{eff} should be taken as equal to the section modulus Z.

7.5.2 I- or H-sections with equal flanges

For Class 3 semi-compact I- or H-sections with equal flanges, the effective plastic modulus $S_{x,eff}$ and $S_{y,eff}$ for major and minor axes bending may be obtained from:

$$S_{x,eff} = Z_x + \left(S_x - Z_x\right)\left[\frac{\left(\dfrac{\beta_{3w}}{d/t}\right)^2 - 1}{\left(\dfrac{\beta_{3w}}{\beta_{2w}}\right)^2 - 1}\right] \text{ and } S_{y,eff} = Z_y + \left(S_y - Z_y\right)\left[\frac{\dfrac{\beta_{3f}}{b/T} - 1}{\dfrac{\beta_{3f}}{\beta_{2f}} - 1}\right] \qquad (7.7\ \&\ 7.8)$$

but
$$S_{x,eff} \le Z_x + \left(S_x - Z_x\right)\left[\frac{\dfrac{\beta_{3f}}{b/T} - 1}{\dfrac{\beta_{3f}}{\beta_{2f}} - 1}\right] \qquad (7.9)$$

where

b, d, T and *t* are defined in Figure 7.1

S_x = plastic modulus about the major axis

S_y = plastic modulus about the minor axis

Z_x = section modulus or elastic modulus about the major axis

Z_y = section modulus or elastic modulus about the minor axis

β_{2f} = limiting value of *b/T* from Table 7.1 for Class 2 compact flange

β_{2w} = limiting value of *d/t* from Table 7.1 for Class 2 compact web

β_{3f} = limiting value of *b/T* from Table 7.1 for Class 3 semi-compact flange

β_{3w} = limiting value of *d/t* from Table 7.1 for Class 3 semi-compact web

7.5.3 Rectangular hollow sections

For Class 3 semi-compact rectangular hollow sections (RHS), the effective plastic moduli $S_{x,eff}$ and $S_{y,eff}$ for major and minor axis bending may both be obtained by considering bending about the respective axis, using the following:

$$S_{eff} = Z + \left(S - Z\right)\left[\frac{\dfrac{\beta_{3w}}{d/t} - 1}{\dfrac{\beta_{3w}}{\beta_{2w}} - 1}\right] \qquad (7.10)$$

but
$$S_{eff} \le Z + \left(S - Z\right)\left[\frac{\dfrac{\beta_{3f}}{b/t} - 1}{\dfrac{\beta_{3f}}{\beta_{2f}} - 1}\right] \qquad (7.11)$$

where

b, d and *t* of RHS are defined in Table 7.2

β_{2f} = limiting value of *b/t* from Table 7.2 for Class 2 compact flange

β_{2w} = limiting value of *d/t* from Table 7.2 for Class 2 compact web

β_{3f} = limiting value of *b/t* from Table 7.2 for Class 3 semi-compact flange

β_{3w} = limiting value of *d/t* from Table 7.2 for Class 3 semi-compact web

For a RHS subject to bending, *B* and *b* are always flange dimensions and *D* and *d* are always web dimensions, but the definition of which sides of the RHS are webs and which are flanges changes according to the axis of bending, see clause 7.1.

7.5.4 Circular hollow sections

For Class 3 semi-compact circular hollow sections (CHS) of overall diameter *D* and thickness *t*, the effective plastic modulus S_{eff} may be obtained from:

$$S_{eff} = Z + 1.45\left[\left(\sqrt{\frac{140}{D/t}}\right)\varepsilon - 1\right](S - Z) \tag{7.12}$$

7.6 EFFECTIVE WIDTH METHOD FOR SLENDER CROSS-SECTIONS

Local buckling in Class 4 slender cross-sections may be allowed for in design by adopting effective section properties. Due allowance should be made for the possible effects of any shift of the centroid of the effective cross-section. Effective section properties can be obtained from Chapter 11 or any acceptable reference.

7.7 EFFECTIVE STRESS METHOD FOR SLENDER CROSS-SECTIONS

Effective stress method is an alternative method to the effective width method detailed in clause 7.6. Effective stress method reduces the design strength p_{yr} that may be calculated at which the cross-section would be Class 3 semi-compact. The reduced design strength p_{yr} should then be used in place of p_y in the checks on section capacity and member buckling resistance. The value of this reduced design strength p_{yr} may be obtained from:

$$p_{yr} = \left(\frac{\beta_3}{\beta}\right)^2 p_y \tag{7.13}$$

in which β is the value of *b/T*, *b/t*, *D/t* or *d/t* that exceeds the limiting value β_3 given in Table 7.1 or Table 7.2 for a Class 3 semi-compact section.

It should be noted that unless the Class 3 semi-compact limit is exceeded by only a small margin, the use of this alternative method can be rather conservative.

7.8 SHIFT OF THE CENTROID OF THE EFFECTIVE CROSS-SECTION

Local buckling is a major consideration in the design of Class 4 slender cross-sections. The main effect of local buckling is to cause a redistribution of the longitudinal stress in which the greatest portion of the load is carried near the plate junctions, as shown for a channel section in Figures 7.4(a) and 7.4(b). The redistribution produces increased stresses near the plate junctions and high bending stresses as a result of plate flexure, leading to ultimate loads below the squash load of the section.

For singly symmetric cross-sections, the redistribution of longitudinal stress caused by local buckling also produces a shift of the centroid of the effective cross-section, as shown in Figures 7.4(a) and 7.4(b). The shift of effective centroid caused by local buckling does not induce overall bending in fixed-ended singly symmetric columns as it does in pin-ended singly symmetric columns. For fixed-ended singly symmetric columns, the applied load always passes through the effective centroid of the cross-section. Hence, the effect of the shift in the line of action of the internal force due to local buckling shall be ignored in the checks on section capacity and member buckling resistance. For pin-ended singly symmetric columns, the shift of the effective centroid introduces an eccentricity and caused applied moment to the member. This shift must be taken into account in the checks on section capacity and member buckling resistance, in which the applied moment is calculated as a product of the axial force and its eccentricity.

The design eccentricity can be determined using the effective widths of each component plate and thus an effective cross-section with distinct centroid, referred to as the “effective centroid”, as shown in Figure 7.4(c). The design eccentricity is determined as the distance from the effective centroid to the applied force.

For doubly symmetric cross-sections subjected to compression, there is no shift of the centroid of the effective cross-section, as shown in Figure 7.5; whereas for doubly symmetric cross-sections subjected to bending, a shift of the centroid of the effective cross-section needs to be considered, as shown in Figure 7.6.

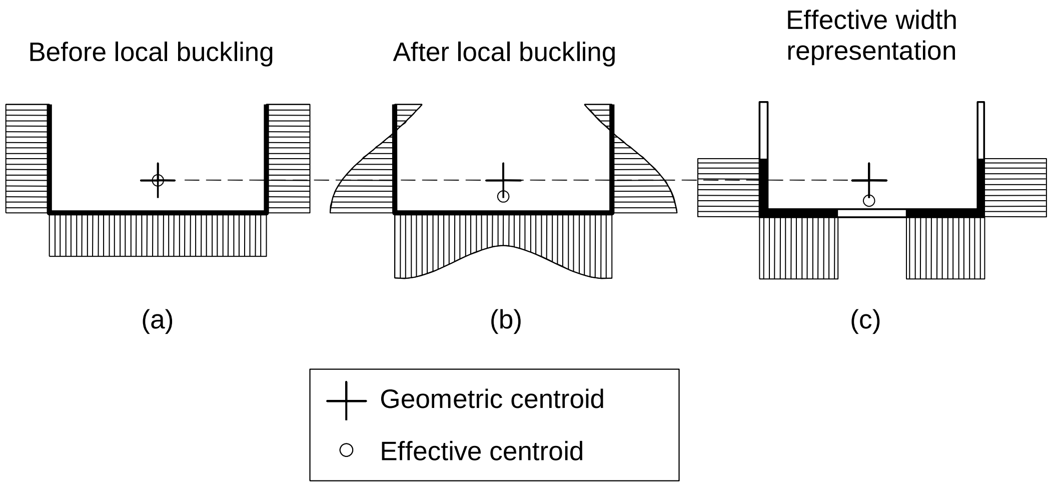


Figure 7.4 - Stress redistribution of singly symmetric slender cross-section subjected to compression

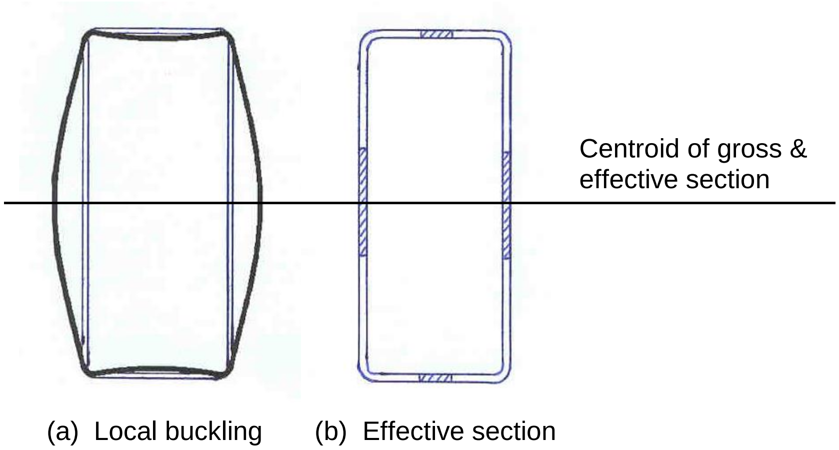


Figure 7.5 - Doubly symmetric slender cross-section subjected to compression

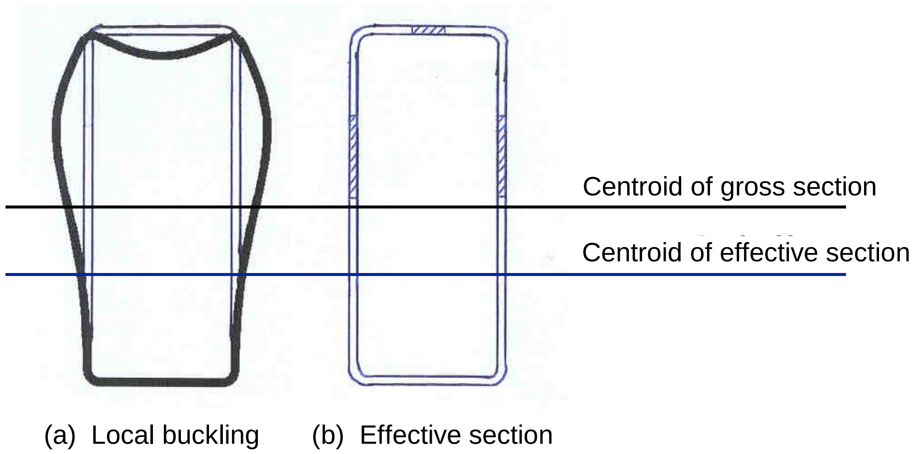


Figure 7.6 - Doubly symmetric slender cross-section subjected to bending