CLASSIFICATION OF CROSS SECTIONS

The cross-section of most structural members is considered as an assemblage of individual parts. As these parts are plate elements and are relatively thin, they may buckle locally when subjected to compression (**local buckling**). In turn, this may limit the compression resistance and the bending resistance. This phenomenon is independent of the length of the member and hence is termed local buckling. It is dependent upon a number of parameters:

local buckling

The following are of particular importance:

- **Width to thickness ratio** of the individual compression elements. This is often termed the aspect ratio. Wide, thin compression elements are more prone to buckling.
- **Support condition**. This is dependent upon the edge restraint to the individual compression element. If the compression element is supported by other elements along both edges parallel to the direction of the member, then it is called an **internal part** as both edges are prevented from deflecting out of plane. If this condition only occurs along one edge, it is said to be **an outstand part** as the free edge is able to deflect out of plane. Each half of the flange of an I section is an outstand part; the web is an internal compression part.

- **Yield strength of the material**. The higher the yield strength of the material, the greater is the likelihood of local buckling before yielding is reached.
- **Stress distribution across the width of the plate element**. The most severe form of stress distribution is uniform compression, which will occur throughout a cross-section under axial compression or in the compression flange of an I section in bending. The web of an I section under flexure will be under a varying stress, which is a less severe condition. This is because the maximum compressive stress will only occur at one location and the stress level will reduce across the width of the element, possibly even changing to a tensile value.

BS EN 1993-1-1 (see Clause 5.5 and Table 5.2) sets out a practical and conservative approach suitable for most design situations to ensure that local buckling does not occur. The standard introduces four classes of cross-section which are defined below:

Class 1

Class 1 cross-sections are those which have compression elements that are sufficiently stocky that the material yield strength may be attained throughout the cross-section. The bending resistance is therefore equal to the design value of the plastic moment, $W_{pl} f_y / \gamma_{M0}$, and this resistance can be maintained whilst rotation required for plastic design occurs at that cross-section.

Class 2

Class 2 cross-sections are those which can attain the design value of the plastic moment but which do not necessarily have the rotation capacity required for plastic design.

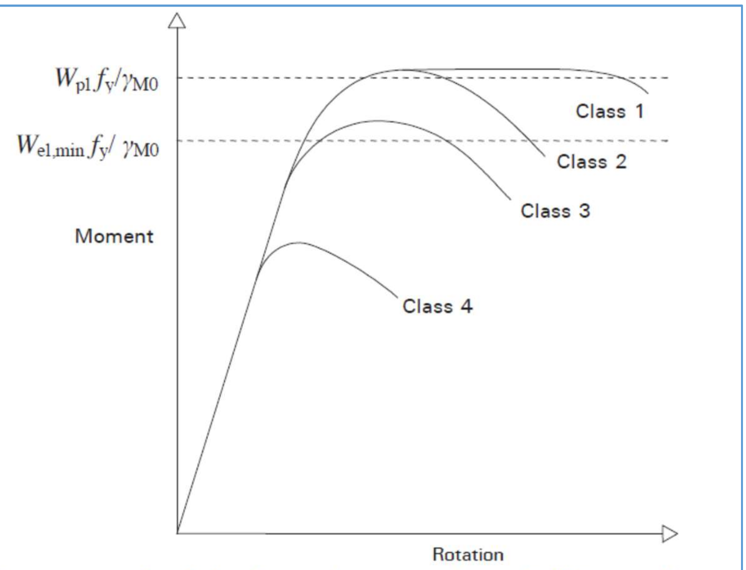
Class 3

Class 3 cross-sections are those in which the material yield strength is attainable in the extreme compression fibres of the cross-section assuming an elastic distribution of stress without necessarily being able to attain that stress throughout the cross-section. Such a cross-section can resist the design value of the elastic moment, $W_{el,min} f_y / \gamma_{M0}$.

Class 4

Class 4 cross-sections are those which contain elements that are so slender that local buckling is likely to occur before the attainment of the material yield strength on the extreme fibers. Reference to BS EN 1993-1-5[39] is needed to evaluate the resistance of these cross-sections.

The differences in behaviour of the four classes may be seen in the Figure below, which illustrates the moment-rotation behaviour of the cross-section.



Moment rotation behaviour of cross-sections of different classes

The classification process of a cross section depends on the following parameters:

1-width to thickness ratio **c/t** of the parts subjected to compression (clause 5.5.2(3)),

2-type of element (**internal part or an outstand part)**

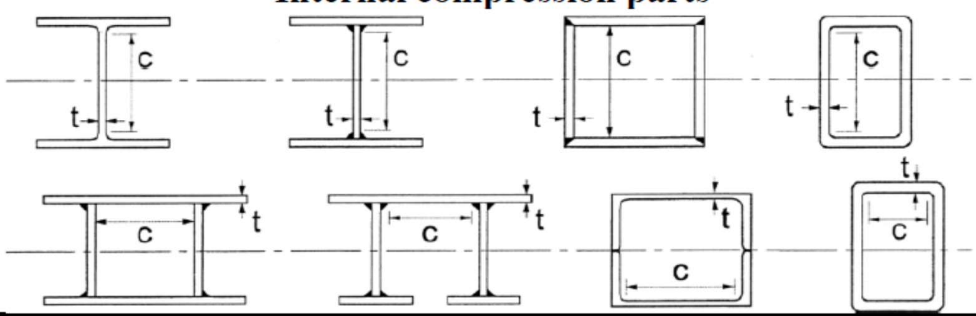
3-the applied internal forces,

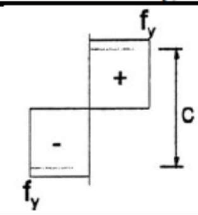
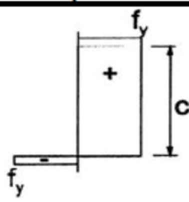
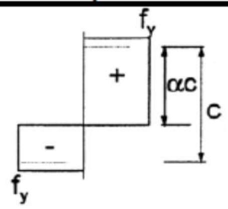
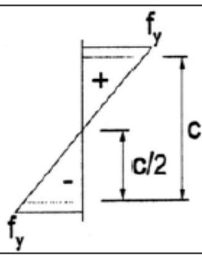
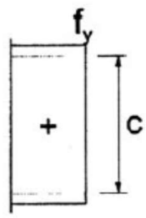
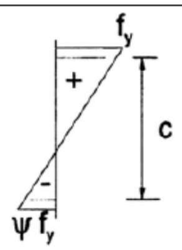
4-the steel grade

The limiting values of the ratios **c/t** of the compressed parts are indicated in Tables 2.21, 2.22 and 2.23 (textbook Page 111) which reproduced from Table 5.2 of EC3-1-1. To apply the classification limits from Table 5.2 of BS EN 1993-1-1 for a section under combined axial load and bending requires the calculation of the parameter **(α)** for Class 1 and 2 cross-sections and **(ψ)** For the case of an I or H section.

Table 2.21 – Maximum width-to-thickness ratios for internal compression parts

Internal compression parts



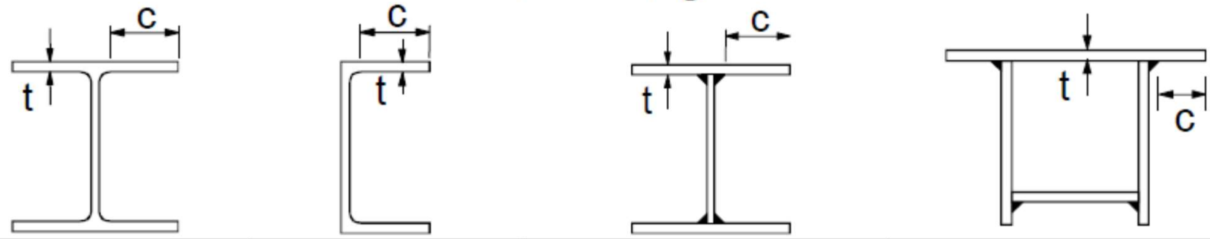
Class	Part subjected to bending	Part subjected to compression	Part subjected to bending and compression
Stress distribution (compression +ve)			
1	$c/t \le 72\,\varepsilon$	$c/t \le 33\,\varepsilon$	if $\alpha > 0.5$, $c/t \le \dfrac{396\,\varepsilon}{13\alpha - 1}$ if $\alpha \le 0.5$, $c/t \le \dfrac{36\,\varepsilon}{\alpha}$
2	$c/t \le 83\,\varepsilon$	$c/t \le 38\,\varepsilon$	if $\alpha > 0.5$, $c/t \le \dfrac{456\,\varepsilon}{13\alpha - 1}$ if $\alpha \le 0.5$, $c/t \le \dfrac{41.5\,\varepsilon}{\alpha}$
Stress distribution (compression +ve)			
3	$c/t \le 124\,\varepsilon$	$c/t \le 42\,\varepsilon$	if $\Psi > -1$, $c/t \le \dfrac{42\,\varepsilon}{0.67 + 0.33\Psi}$ if $\Psi \le -1$ *), $c/t \le 62\,\varepsilon(1-\Psi)\sqrt{(-\Psi)}$

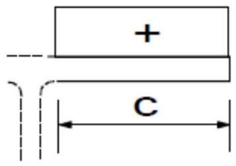
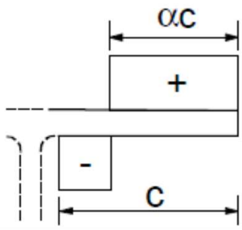
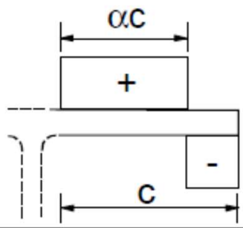
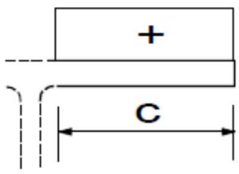
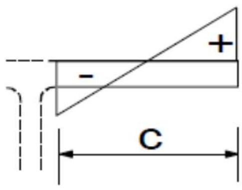
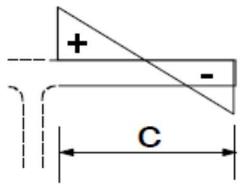
$\varepsilon = \sqrt{235/f_y}$	f_y (N/mm^2)	235	275	355	420	460
	ε	1.00	0.92	0.81	0.75	0.71

*) $\Psi \le -1$ applies where either the compression stress $\sigma < f_y$ or the tensile strain $\varepsilon_y > f_y/E$.

Table 2.22 – Maximum width-to-thickness ratios of outstand flanges

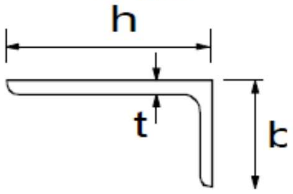
Outstand flanges

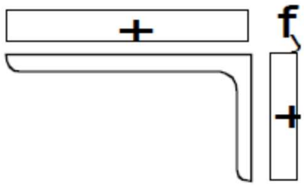


	Rolled sections	Welded sections	
		Part subjected to bending and compression	
Class	Part subjected to compression	Tip in compression	Tip in tension
Stress distribution (compression +ve)			
1	$c/t \leq 9\varepsilon$	$c/t \leq \frac{9\varepsilon}{\alpha}$	$c/t \leq \frac{9\varepsilon}{\alpha\sqrt{\alpha}}$
2	$c/t \leq 10\varepsilon$	$c/t \leq \frac{10\varepsilon}{\alpha}$	$c/t \leq \frac{10\varepsilon}{\alpha\sqrt{\alpha}}$
Stress distribution (compression +ve)			
3	$c/t \leq 14\varepsilon$	$c/t \leq 21\varepsilon\sqrt{k_\sigma}$ For k_σ see EN 1993-1-5	

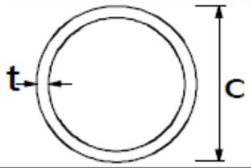
$\varepsilon = \sqrt{235/f_y}$	f_y (N/mm^2)	235	275	355	420	460
	ε	1.00	0.92	0.81	0.75	0.71

Table 2.23 – Maximum width-to-thickness ratios of angles and tubular sections

See also Table 2.22	**Angles** 	Does not apply to angles in continuous contact with other components

Class	Section in compression
Stress distribution (compression +ve)	
3	$h/t \le 15\,\varepsilon: \ \frac{b+h}{2t} \le 11.5\,\varepsilon$

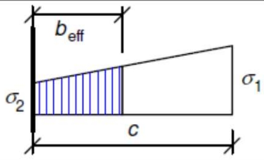
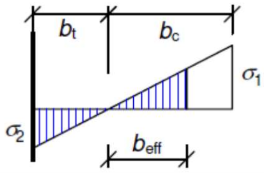
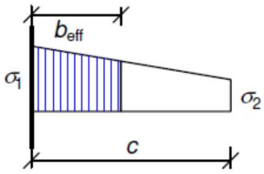
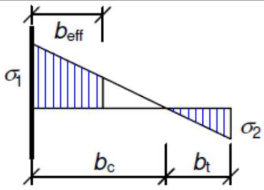
Tubular sections



Class	Section in bending and/or compression
1	$d/t \le 50\,\varepsilon^2$
2	$d/t \le 70\,\varepsilon^2$
3	$d/t \le 90\varepsilon^2$ **NOTE:** For $d/t > 90\,\varepsilon^2$ see EN 1993-1-6

$\varepsilon = \sqrt{235/f_y}$	f_y (N/mm^2)	235	275	355	420	460
	ε	1.00	0.92	0.81	0.75	0.71
	ε^2	1.00	0.85	0.66	0.56	0.51

Table 4.2: Outstand compression elements

<table>
<tr><th colspan="3">Stress distribution (compression positive)</th><th colspan="3">Effective[p] width b_{eff}</th></tr>
<tr><td colspan="3">
</td><td colspan="3">$1 > \psi \geq 0$:
$b_{eff} = \rho\, c$</td></tr>
<tr><td colspan="3">
</td><td colspan="3">$\psi < 0$:
$b_{eff} = \rho\, b_c = \rho\, c\,/\,(1\text{-}\psi)$</td></tr>
<tr><td>$\psi = \sigma_2/\sigma_1$</td><td>1</td><td>0</td><td>-1</td><td colspan="2">$1 \geq \psi \geq -3$</td></tr>
<tr><td>Buckling factor k_σ</td><td>0,43</td><td>0,57</td><td>0,85</td><td colspan="2">$0{,}57 - 0{,}21\psi + 0{,}07\psi^2$</td></tr>
<tr><td colspan="3">
</td><td colspan="3">$1 > \psi \geq 0$:
$b_{eff} = \rho\, c$</td></tr>
<tr><td colspan="3">
</td><td colspan="3">$\psi < 0$:
$b_{eff} = \rho\, b_c = \rho\, c\,/\,(1\text{-}\psi)$</td></tr>
<tr><td>$\psi = \sigma_2/\sigma_1$</td><td>1</td><td>$1 > \psi > 0$</td><td>0</td><td>$0 > \psi > -1$</td><td>-1</td></tr>
<tr><td>Buckling factor k_σ</td><td>0,43</td><td>$0{,}578\,/\,(\psi + 0{,}34)$</td><td>1,70</td><td>$1{,}7 - 5\psi + 17{,}1\psi^2$</td><td>23,8</td></tr>
</table>

For the case of an I or H section subject to combined axial compression and major axis bending and where the neutral axis is within the web of the member, **(α)** can be calculated from the following expression:

$$\alpha = \frac{1}{c}\left(\frac{h}{2} + \frac{1}{2}\frac{N_{Ed}}{t_w f_y} - (t_f + r)\right) \leq 1$$

where:

- c is shown in Table 2.1
- h is the depth of the section
- t_w is the thickness of the web
- t_f is the thickness of the flange
- r is the root radius
- f_y is the yield strength
- N_{Ed} is the design axial force (+ve for compression and -ve for tension)

Example:

A 457 x 191 x 67 UB in steel grade S355 is to be used under the three conditions described below. Classify the section for each case.

i) Under bending

ii) Under axial compression

iii) Under bending about the major axis and an axial compression of 250 kN.

The section properties are:

h = 453.4 mm
b = 189.9 mm t_f = 12.7 mm
d = 407.6 mm t_w = 8.5 mm
r = 10.2 mm
A = 85.5 cm^2 W_{pl} = 1470 cm3 Wel = 1300 cm^3

Ratios for local buckling:

For the flange:

$c = (b - t_w - 2r)/2$ = (189.9 – 8.5 – 2 x 10.2)/2 = 80.5 mm
$t = t_f = 12.7$ *mm*
$c/t = 6.34$

For the web:

c = d = 407.6 mm
$t = t_w$ = 8.5 mm
c/t = 48.0

Influence of material strength

For thickness = 12.7 mm
fy = 355 N/mm2
Hence, $\varepsilon = [235/355]^{0.5} = 0.81$

(i) Bending

Flanges (Table 2.21, sheet 2 of 3)
Limiting value of c/t for Class 1 in compression is $9\varepsilon = 7.29$.
Actual $c/t = 6.34 <$ limiting c/t (7.29)
Therefore, the flanges are Class 1.

Web (Table 2.21, sheet 1 of 3)
The limiting value of c/t for Class 1 in bending is $72\varepsilon = 58.32$. The actual value is 48, therefore the web is Class 1.

The entire cross-section is classified as Class 1 and therefore the design strength of the material can be attained throughout the section.

ii) Under axial compression

Flanges (Table 2.21, sheet 2 of 3)

Limiting value of *c/t* for Class 1 in compression is $9\varepsilon = 7.29$.
Actual $c/t = 6.34 <$ limiting c/t (7.29)
Therefore, the flanges are Class 1.

Web (Table 2.21, sheet 1 of 3)

limiting value of *c/t* for Class 3 in compression is $42\varepsilon = 34.02$.

The actual value is 48.0, therefore the web is Class 4.

The entire cross-section therefore may be treated as Class 4 under pure axial compression.

(iii) Bending about the major axis and an axial compression of 250 kN

Web (Table 2.21, Sheet 1 of 3)

For a Class 2 element under varying stress, the limiting value of *c/t* is given by:

$$\text{When } \alpha > 0.5: \ \frac{c}{t} \leq \frac{456\varepsilon}{13\alpha - 1}$$

$$\text{When } \alpha \leq 0.5: \ \frac{c}{t} \leq \frac{41.5\varepsilon}{\alpha}$$

$$\alpha = \frac{1}{c}\left(\frac{h}{2} + \frac{1}{2}\frac{N_{\mathrm{Ed}}}{t_{\mathrm{w}} f_{\mathrm{y}}} - (t_{\mathrm{f}} + r)\right) \leq 1$$

$$\alpha = \frac{1}{407.6}\left(\frac{453.4}{2} + \frac{1}{2} \times \frac{250000}{8.5 \times 355} - (12.7 + 10.2)\right)$$

$$\alpha = 0.602$$

The limit for a Class 2 web is:

$$\frac{456\varepsilon}{13\alpha - 1} = \frac{456 \times 0.81}{13 \times 0.602 - 1} = 54.11$$

The actual value is 48, therefore the web is Class 2. The overall section under combined bending and an axial compression of 250 kN is therefore a Class 2.