جَامعة
المَنارة
MANARA UNIVERSITY

# Steel Structures 1
# Sem. 2
# 2025-2024

أ.د. نايل محمد حسن

- ✓ المحاضرة الأولى: مفاهيم أساسية
- ✓ المحاضرة الثانية: مدخل إلى المنشآت الفولاذية
- ✓ المحاضرة الثالثة: العناصر الخاضعة للشد المركزي
- ✓ المحاضرة الرابعة: أمثلة عملية
- ✓ المحاضرة الخامسة: العناصر الخاضعة للضغط المركزي
- ✓ المحاضرة السادسة: العناصر الخاضعة للضغط المركزي (تتمة)

تصنيف المقطع Section Classification

- ✓ المحاضرة السابعة: العناصر الخاضعة للضغط المركزي (تتمة)

✓ تحنيب عناصر الضغط

- ✓ المحاضرة الثامنة: العناصر الخاضعة للضغط المركزي (تتمة)

✓ تحنيب عناصر الضغط

**المحاضرة التاسعة: العناصر الخاضعة للضغط المركزي (تتمة)**

**تحنيب عناصر الضغط (مسائل)**

# المحاضرة التاسعة

# العناصر الخاضعة للضغط المركزي (تتمة)

# تحنيب عناصر الضغط (مسائل)

# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3 (المنهجية)

# Design of compression members

تخضع عناصر الضغط لـ

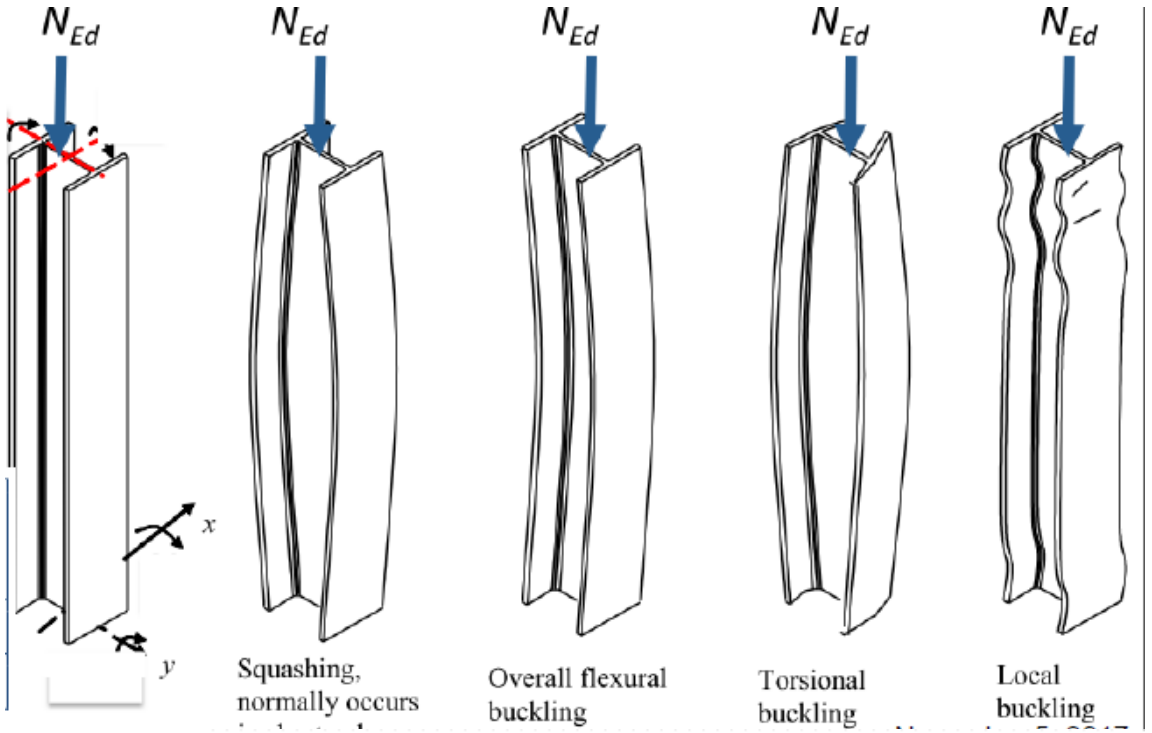
- ضغط محوري فقط
- بدون انعطاف

تخضع الأعمدةعمليا لـ

- لامركزية الاحمال المحورية
- القوى العرضية

خلال التعامل مع الاعمدة سيتم التفريق بين

- الاعمدة القصيرة و
- الاعمدة النحيفة




| | Slender column $\bar{\lambda}$> 0.2 | Stocky Column $\bar{\lambda}$< 0.2 |
|---|---|---|
| Cross-section Resistance check, $N_{c,Rd}$ | ✓ | ✓ |
| Buckling Resistance Check, $N_{b,Rd}$ | ✓ | |

# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3 (الاعمدة النحيفة)

# Design of compression members

## الخصائص الأساسية للاعمدة النحيفة

- تكون الاعمدة المتوسطة النحافة حساسة جداً لتأثيرات العيوب imperfections
- يحدث التحنيب غير المرن قبل حمولة تحنيب اويلر بسبب العيوب المختلفة:
  - عدم استقامة بدئية
  - اجهادات متبقية
  - لامركزية الحمولات المحورية المطبقة
  - حالة التصلب التشوهي

# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3 (المقاومة)

# Design of compression members

- يجب تحقيق علاقة المقاومة على التحنيب $N_{b,Rd}$ للعناصر المضغوطة وهي عادة تتحكم بالتصميم:

$$N_{Ed} \le N_{b,Rd}$$

$$\begin{cases} N_{b,Rd} = \chi \dfrac{A \cdot f_y}{\gamma_{M1}} & \text{cross-sections of class 1, 2 or 3:,} \\ N_{b,Rd} = \chi \dfrac{A_{eff} \cdot f_y}{\gamma_{M1}} & \text{cross-sections of class 4} \end{cases}$$

- $\chi$ هي عامل تخفيض تبعا لنمط التحنيب الموافق. نحصل عليها من العلاقات:

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \overline{\lambda}^2}}, \text{ but } \chi \le 1.0$$

$$\phi = 0.5\left[1 + \alpha\left(\overline{\lambda} - 0.2\right) + \overline{\lambda}^2\right]$$

$$\overline{\lambda} = \sqrt{Af_y / N_{cr}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1} \rightarrow \text{cross-sections of class 1, 2 or 3:,}$$

$$\overline{\lambda} = \sqrt{A_{eff} f_y / N_{cr}} = \frac{L_{cr}}{i}\frac{\sqrt{A_{eff}/A}}{\lambda_1} \rightarrow \text{cross-sections of class 4}$$

$\overline{\lambda}$ هي عامل النحافة النسبية اللابعدية

# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3 (المقاومة)

# Design of compression members

- $\alpha$ عامل العيوب
- $N_{cr}$ الحمولة الحرجة المرنة (حمولة اويلرالحرجة) لنمط التحنيب الموافق
- $L_{cr}$ طول نمط التحنيب الموافق
- $i$ نصف قطر الدوران للمقطع العرضي و

$$\lambda_1 = \pi\sqrt{(E / f_y)} = 93.9\varepsilon;$$

$$\varepsilon = \sqrt{235 / f_y} \quad \text{with } f_y \text{ in } N/mm^2$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \overline{\lambda}^2}}, \text{ but } \chi \le 1.0$$

$$\phi = 0.5\left[1 + \alpha\left(\overline{\lambda} - 0.2\right) + \overline{\lambda}^2\right]$$

$$\overline{\lambda} = \sqrt{Af_y / N_{cr}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1}$$

$$\overline{\lambda} = \sqrt{A_{eff} f_y / N_{cr}} = \frac{L_{cr}}{i}\frac{\sqrt{A_{eff} / A}}{\lambda_1}$$

cross-sections of class 1, 2 or 3:,

cross-sections of class 4

$\overline{\lambda}$ هي عامل النحافة النسبية اللابعدية

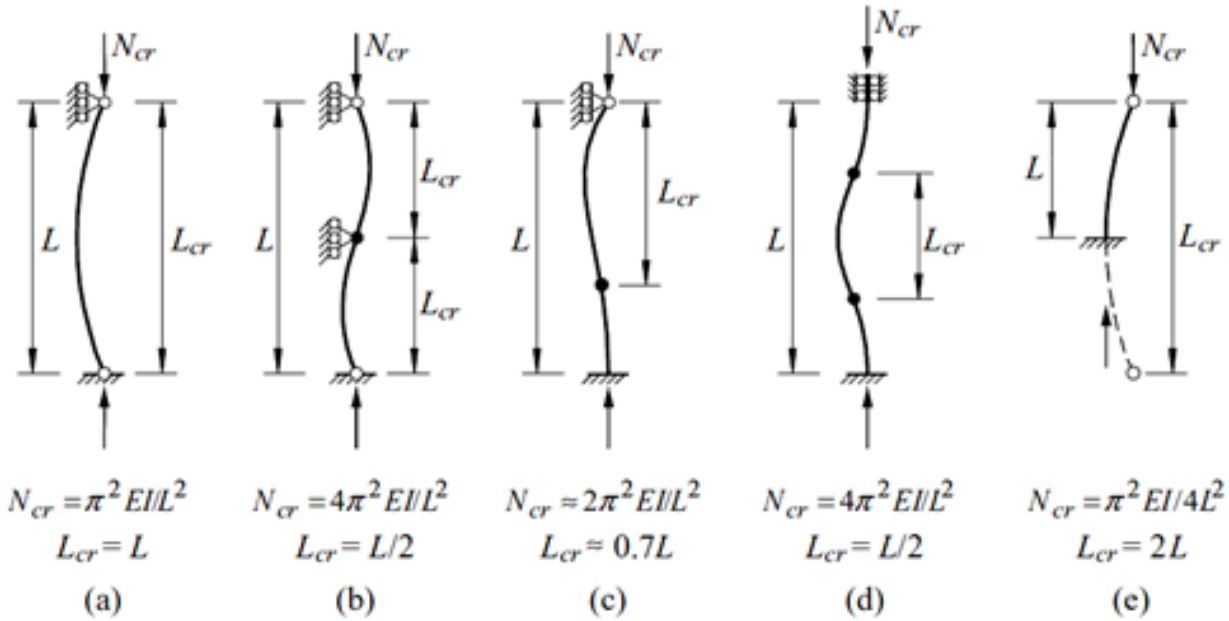
# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3
## (حمولة التحنيب المرنة وطول التحنيب)

تتغير حمولة التحنيب $N_{cr}$ حسب

- ابعاد وشكل العنصر،الحمولة،التقييد

تحسب حمولة التحنيب $N_{cr}$ من العلاقة التالية $$N_{cr} = \frac{\pi^2 EI}{L_{cr}}$$

يعطى طول التحنيب $L_{cr}$ للحالات الفردية حسب التقييد من الشكل التالي




من المهم اعتبار سلوك العنصر في كل مستو رئيسي، وعندها يمكن أن يختلف طول التحنيب $L_{cr.y}$ و $L_{cr.y}$ كذلك $i_y$ و $i_z$

# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3 (منحنيات التحنيب التصميمية)

- يدخل تاثير العيوب بواسطة العامل α

يبين الشكل التالي مقاومات التحنيب التصميمية اللابعدية على الضغط $N_{b,Rd}/N_y$ من أجل:

$\alpha = 0.13, 0.21, 0.34, 0.49, 0.76$،

والتي تمثل منحنيات

(a0 ), (a), (b), (c), (d), لعناصر الضغط في كود EC3.

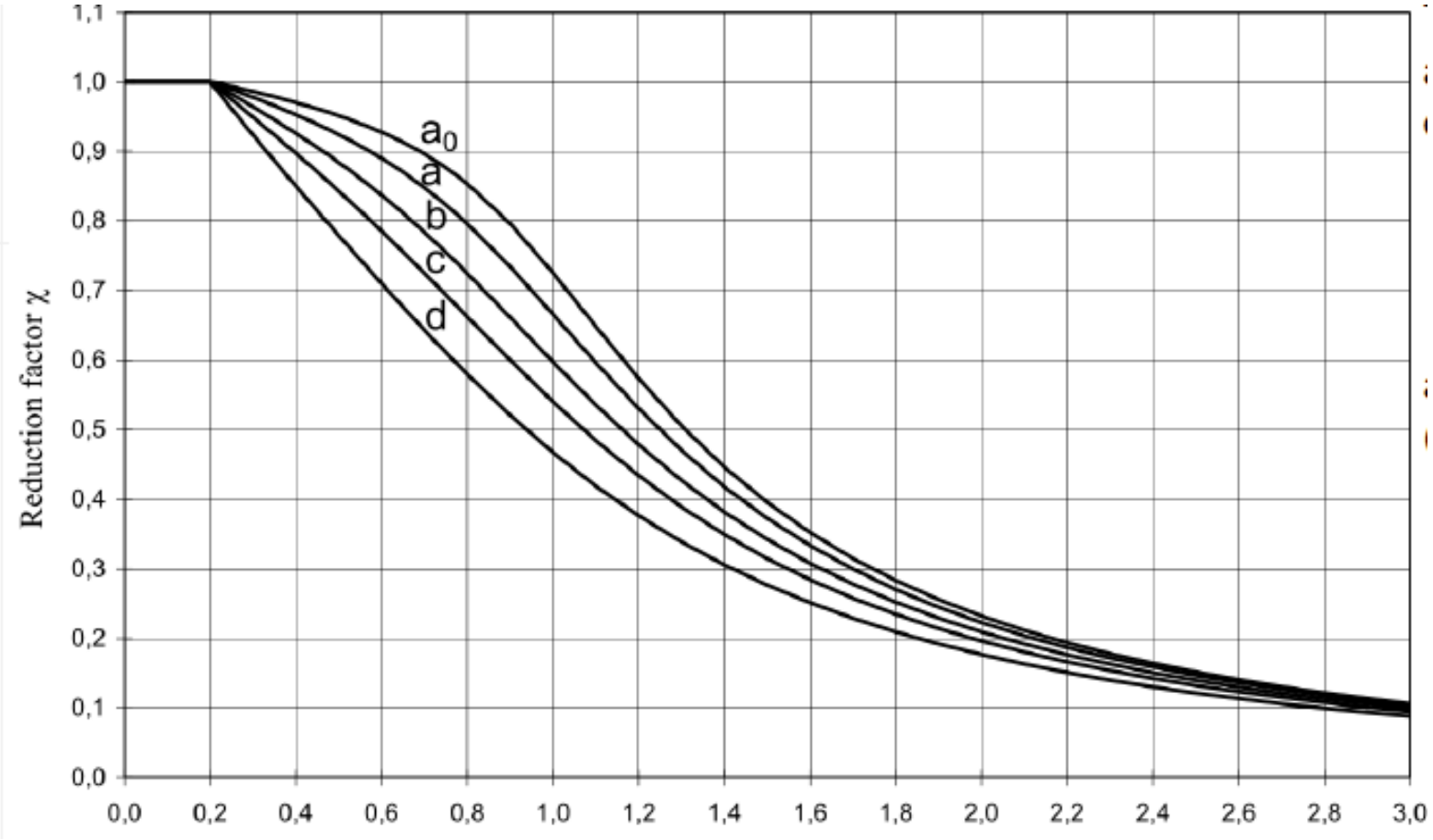
- تملك العناصر ذات العيوب الأولية العالية مقاومات أخفض نتيجة الخضوع المبكر، وتكون هذه موافقة لقيم α عالية.
- من ناحية أخرى لاتتأثر عناصر الضغط ذات التشوه الأولي القليل بالخضوع الأولي، وتكون قيم α المحددة لها اصغر.

# تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3
# (منحنيات التحنيب التصميمية)

يعتمد والعامل α ومنحنيات التصميم الموافقة له على:

- شكل وابعاد المقطع العرضي
- صنف الفولاذ
- عمليةالتصنيع
- مستوى التحنيب الموافق

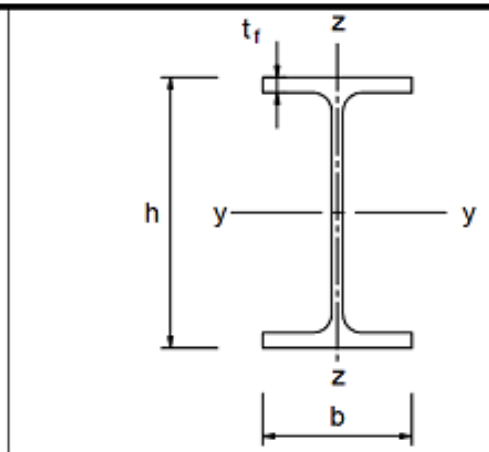
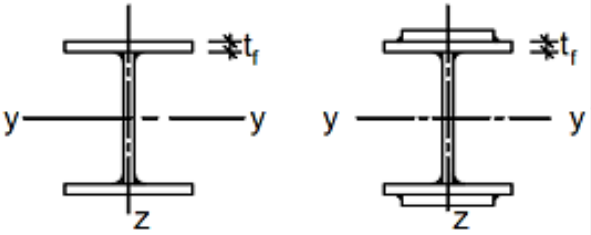
توضح الجداول اللاحقة ذلك



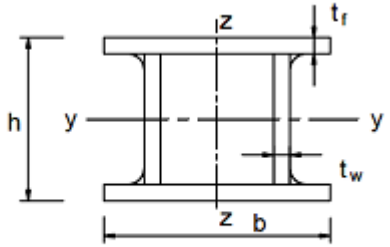
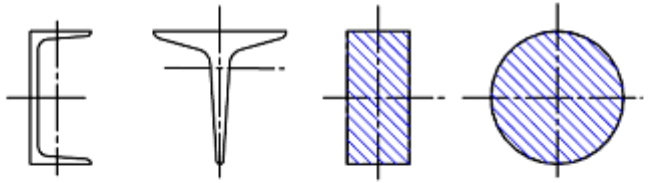
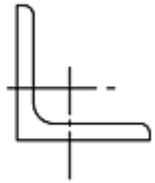

| Buckling curve | $a_0$ | a | b | c | d |
|---|---|---|---|---|---|
| Imperfection factor $\alpha$ | 0,13 | 0,21 | 0,34 | 0,49 | 0,76 |

## منحنيات التحنيب وعوامل العيوب a

# اختيار منحني التحنيب حسب نوع المقطع

| Cross section | | Limits | | Buckling about axis | Buckling curve | |
|---|---|---|---|---|---|---|
| | | | | | S 235<br>S 275<br>S 355<br>S 420 | S 460 |
| Rolled sections |  | h/b > 1,2 | $t_f \le 40$ mm | y – y<br>z – z | a<br>b | $a_0$<br>$a_0$ |
| | | | 40 mm < $t_f \le 100$ | y – y<br>z – z | b<br>c | a<br>a |
| | | h/b ≤ 1,2 | $t_f \le 100$ mm | y – y<br>z – z | b<br>c | a<br>a |
| | | | $t_f > 100$ mm | y – y<br>z – z | d<br>d | c<br>c |
| Welded I-sections |  | $t_f \le 40$ mm | | y – y<br>z – z | b<br>c | b<br>c |
| | | $t_f > 40$ mm | | y – y<br>z – z | c<br>d | c<br>d |
| Hollow sections | | hot finished | | any | a | $a_0$ |
| | | cold formed | | any | c | c |

# اختيار منحني التحنيب حسب نوع المقطع

| Cross section | | Limits | Buckling about axis | Buckling curve | |
|---|---|---|---|---|---|
| | | | | S 235<br>S 275<br>S 355<br>S 420 | S 460 |
| Welded box sections |  | generally (except as below) | any | b | b |
| | | thick welds: $a > 0{,}5t_f$<br>$b/t_f < 30$<br>$h/t_w < 30$ | any | c | c |
| U-, T- and solid sections |  | | any | c | c |
| L-sections |  | | any | b | b |

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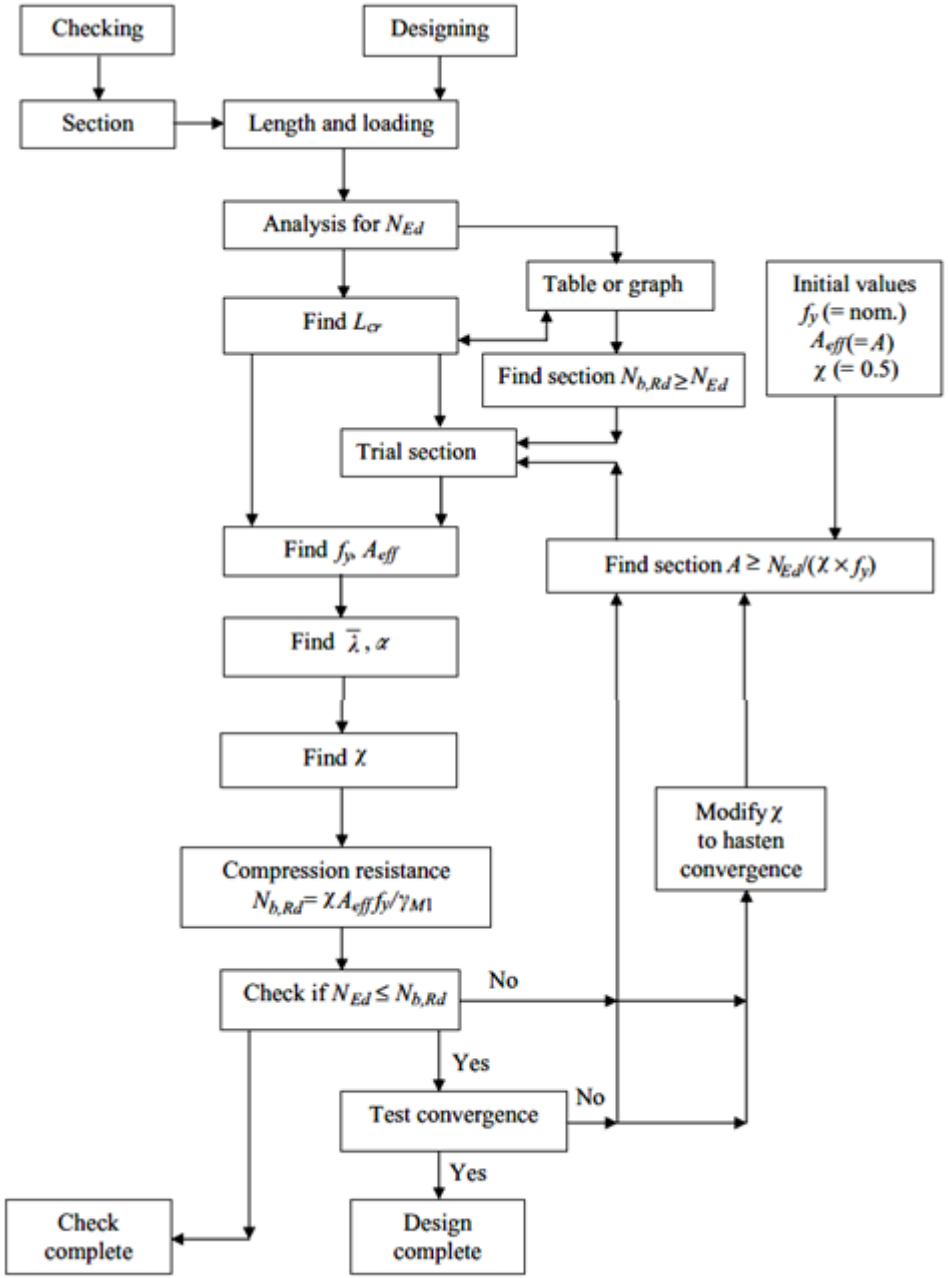
# ملخص التصميم والتحقيق للعناصر المضغوطة



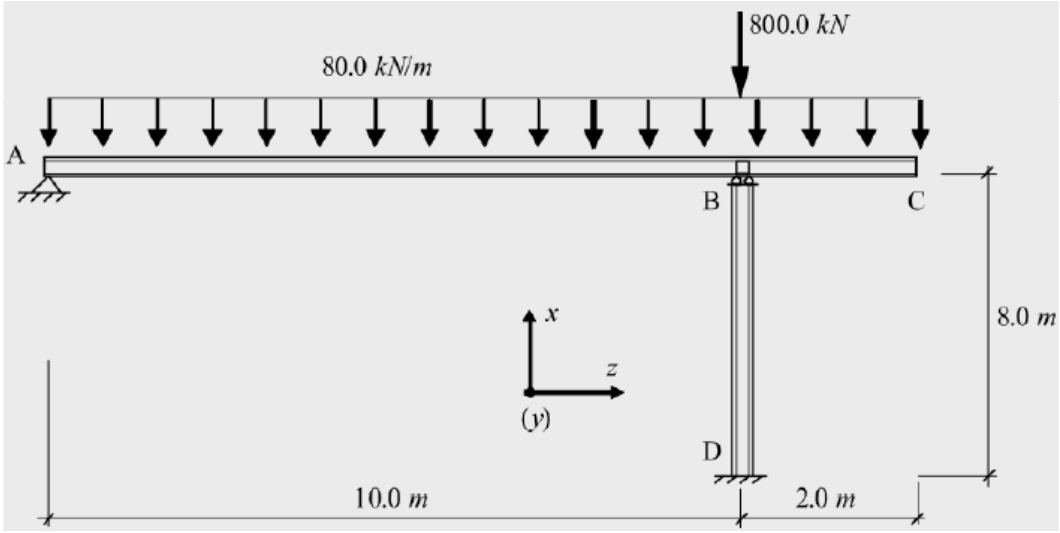
# Example on resistance in compression against buckling

Example 3.2. Design the column BD of the steel structure represented in the figure below, using a HEB cross section in S 355 steel, according to EC1993-1-1. The column is fixed at the base and hinged at section B (with respect to the two principal axis of the cross section). Cross section B is fixed in both horizontal directions, in the plane of the structure (due to the beam itself) and in the perpendicular plane (because of secondary bracing members).

Loading s already factored for ULS.

S 335 for t≤40mm Material Properties:

- $f_y$ = 355 MPa
- $f_u$ = 510 MPa
- E = 210 GPa




Solution

Step1: Compute the design applied compressive axial force $N_{Ed}$.

$$N_{Ed} = \frac{80.0}{10} \times \frac{12^2}{2} + 800 = 1376.0\,kN$$

# Example on resistance in compression against buckling

Step2: Select a preliminary cross section.

Assuming class 1,2 or 3 cross sections, and considering minimum cross sectional resistance.

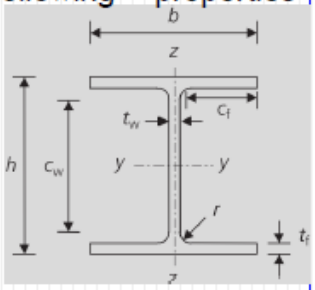
$$N_{Ed} = 1376.0\,kN \le N_{c,Rd} = A f_y / \gamma_{M0} = A \times 355 \times 10^3 / 1.0$$

$$A \ge 38.76 \times 10^{-4}\ m^2 = 38.76\,cm^2$$

As it is expected that buckling resistance will govern the member design, a HEB 240 in S 355 steel is proposed (class 1 in pure compression), with the following properties (geometrical and mechanical):

HEB 240

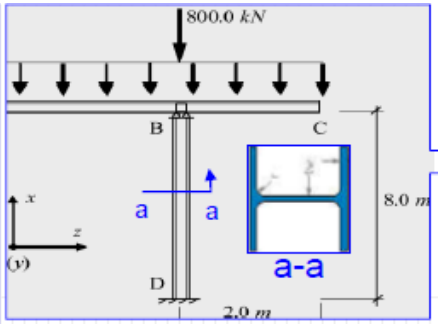
- h = 254.1mm
- b = 254.6mm
- $t_w$ = 10mm
- $t_f$ = 17mm
- r = 10mm
- A = 106cm²
- $I_y$ = 11260cm⁴
- $I_z$ = 3923cm⁴
- $i_y$ = 10.31cm
- $i_z$ = 6.08cm




Step3: Check for instability.

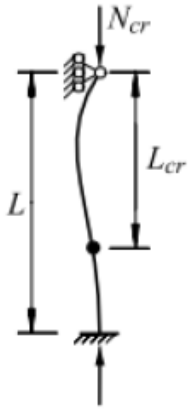
Step3.1: Identify the Buckling length in both direction.

According to the support conditions, the buckling lengths are equal in both planes, given by:




(plane $x$-$z$) - $L_{Ey} = 0.7 \times 8.0 = 5.6\,m$.

(plane $x$-$y$) - $L_{Ez} = 0.7 \times 8.0 = 5.6\,m$.




$$N_{cr} = 2\pi^2 EI/L^2$$

$$L_{cr} = 0.7L$$

Because the buckling lengths are equal in both planes, the orientation of the cross section is arbitrary. For constructional reasons, the section is placed as shown in the Figure, with the strong axis (y axis) in the perpendicular direction to the plane of the structure.

**Step3.3:** Determine the slenderness coefficients.

Since the selected section is section of class 1:

About axis y-y

$$\overline{\lambda_y} = \frac{L_{cry}}{i_y}\frac{1}{\lambda_1}$$

$$\overline{\lambda_y} = \frac{5.6}{10.31\times10^{-2}}\times\frac{1}{76.4} = 0.71$$

$$\lambda_1 = \pi\sqrt{(E/f_y)}$$

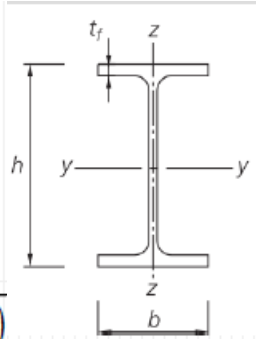
$$\lambda_1 = \pi\sqrt{(210\times10^6/355\times10^3)}$$

$$\lambda_1 = 76.4$$

About axis z-z

$$\overline{\lambda_z} = \frac{L_{crz}}{i_z}\frac{1}{\lambda_1}$$

$$\overline{\lambda_z} = \frac{5.6}{6.08.\times10^{-2}}\times\frac{1}{76.4} = 1.21$$




| | | | | |
|---|---|---|---|---|
| $h/b > 1.2$ | $t_f \le 40$ mm | y–y<br>z–z | a<br>b | $a_0$<br>$a_0$ |
| | 40 mm $< t_f \le 100$ | y–y<br>z–z | b<br>c | a<br>a |
| $h/b \le 1.2$ | $t_f \le 100$ mm | y–y<br>z–z | b<br>c | a<br>a |
| | $t_f > 100$ mm | y–y<br>z–z | d<br>d | c<br>c |

$$\chi_z = \frac{1}{\phi_z + \sqrt{\phi_z^2 - \overline{\lambda}_z^2}}$$

$$\chi_z = \frac{1}{1.48 + \sqrt{1.48^2 - 1.21^2}}$$

$$\chi_z = 0.43$$

$$\phi_z = 0.5\left[1 + \alpha\left(\overline{\lambda_z} - 0.2\right) + \overline{\lambda_z}^2\right]$$

$$\phi_z = 0.5\times\left[1 + 0.49\times(1.21 - 0.2) + 1.21^2\right]$$

$$\phi_z = 1.48$$

**Step3.4:** Calculation of the reduction factor $X_{min}$

$$\frac{h}{b} = 1.0 < 1.2 \quad \text{and} \quad t_f = 17mm < 100mm$$

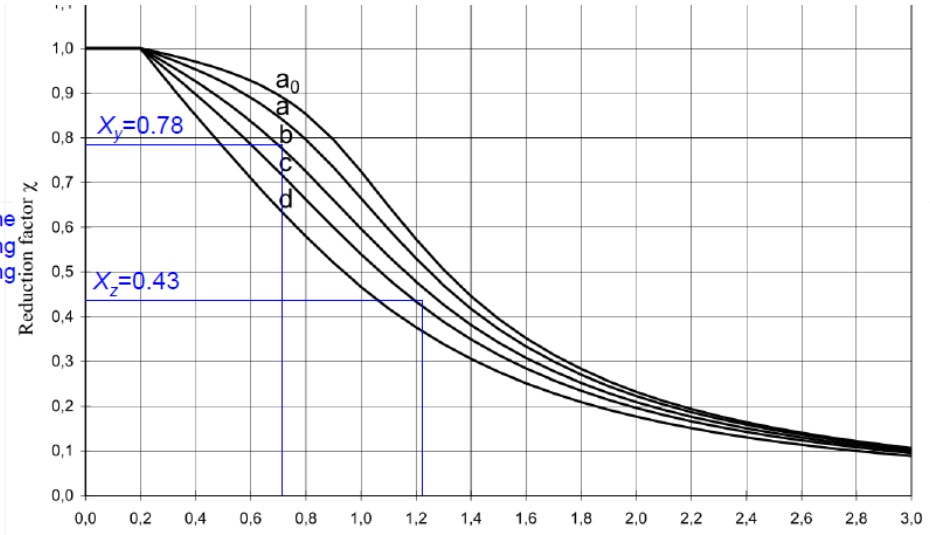
As $\overline{\lambda}_z > \overline{\lambda}_y$ and $\alpha_{curve\ c} > \alpha_{curve\ b} \Rightarrow \chi_{min} => \chi_z$.

**Step4:** Section Verification.

$$N_{b,Rd} = \chi A f_y/\gamma_{M1} = 0.43\times106\times10^{-4}\times355\times10^3/1.0 = 1618.1kN$$

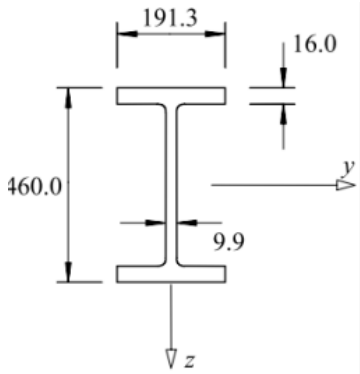
$$N_{Ed} = 1376.0kN < N_{b,Rd} = 1618.1kN$$

Alternatively and conservatively the reduction factor, $X$ ,for each buckling axis can be calculated from the buckling curve provided in EC1993-1-1



# Example on checking a UB compression member

Example 3.3. The 457 × 191 UB 82 compression member of S275 steel of is simply supported about both principal axes at each end ($L_{cr,y}$ = 12.0 m), and has a central brace which prevents lateral deflections in the minor principal plane ($L_{cr,z}$ = 6.0 m). Check the adequacy of the member for a factored axial compressive load corresponding to a nominal dead load of 160 kN and a nominal imposed load of 230kN.




457 × 191 UB 82
$I_z = 1871\ cm^4$
$A = 104\ cm^2$
$i_y = 18.8$ cm
$i_z = 4.23$ cm
$r = 10.2$ mm

S 275 for t≤40mm Material Properties:

- $f_y$ = 275 MPa
- $f_u$ = 430 MPa
- E = 210 GPa

Solution

Step1: Compute the design applied compressive axial force $N_{Ed}$.

$$N_{Ed} = (1.35 \times 160) + (1.5 \times 230) = 561 \text{ kN}$$

Step2: Classify the cross-section.

Flange = external or outstand element.

Web = internal or stiffened element.

$$\varepsilon = (235/275)^{0.5} = 0.924$$

Flange = external or outstand element.

$$\frac{c}{t} = \frac{b - t_w - (2 \cdot r)}{2 \cdot t_f} = \frac{191.3 - 9.9 - (2 \times 10.4)}{2 \times 16.0} = 5.026$$

$$\frac{c}{t} = 5.026 < 9\varepsilon \Rightarrow \text{Class 1}$$

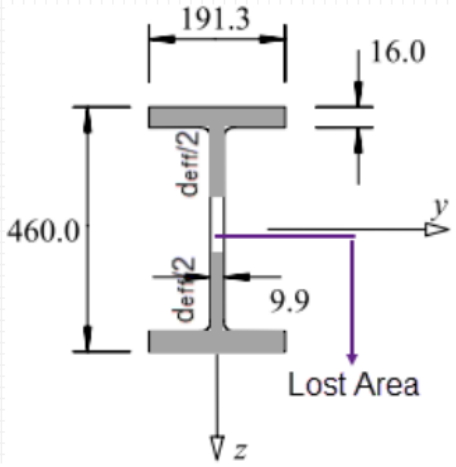
Web = internal or stiffened element.

$$\frac{c}{t} = \frac{h - (2 \cdot t_f) - (2 \cdot r)}{t_w} = \frac{460 - (2 \times 16.0) - (2 \times 10.2)}{9.9} = 41.118$$

$$\frac{c}{t} = 41.118 > 42\varepsilon \Rightarrow \text{Class 4}$$

and so the cross section is Class 4 (slender).

Step3: Compute the Effective area. the cross-section $A_{eff}$ .




$$\bar{\lambda}_p = \sqrt{\frac{f_y}{\sigma_{cr}}} = \frac{\bar{b}/t}{28.4\varepsilon\sqrt{k_\sigma}} = \frac{407.6/9.9}{28.4 \times 0.924 \times \sqrt{4.0}} = 0.784$$

$$\rho = \frac{\bar{\lambda}_p - 0.055(3+\psi)}{\bar{\lambda}_p^2} = \frac{0.784 - 0.055(3+1)}{0.784^2} = 0.918$$

$$d - d_{eff} = (1 - 0.918) \times 407.6 = 33.6 \text{ mm}$$

$$A_{eff} = 104 \times 10^2 - 33.6 \times 9.9 = 10\,067 \text{ mm}^2$$

Step4: Compute the Cross-section compression resistance $N_{c,Rd}$.

$$N_{c,Rd} = \frac{A_{eff} \cdot f_y}{\gamma_{M0}}$$ cross-sections of class 4

$$N_{c,Rd} = \frac{10067 \times 275}{1.0} = 2768kN > 561kN = N_{Ed}$$

Step5: Compute the Buckling resistance of the Member $N_{b,Rd}$.

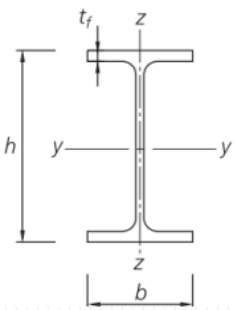
Since the selected section is section of class 4: Slenderness coefficient

$$\bar{\lambda}_y = \sqrt{\frac{A_{eff} f_y}{N_{cr,y}}} = \frac{L_{cr,y}}{i_y}\frac{\sqrt{A_{eff}/A}}{\lambda_1} = \frac{12\,000}{(18.8 \times 10)}\frac{\sqrt{10\,067/10\,400}}{93.9 \times 0.924} = 0.724$$

$$\bar{\lambda}_z = \sqrt{\frac{A_{eff} f_y}{N_{cr,z}}} = \frac{L_{cr,z}}{i_z}\frac{\sqrt{A_{eff}/A}}{\lambda_1} = \frac{6000}{(4.23 \times 10)}\frac{\sqrt{10\,067/10\,400}}{93.9 \times 0.924}$$

$$= 1.608 > 0.724$$

Select the buckling curve and corresponding "α" value




| | | | | |
|---|---|---|---|---|
| $h/b > 1.2$ | $t_f \le 40$ mm | y–y | a | $a_0$ |
| | | z–z | b | $a_0$ |
| | 40 mm $< t_f \le 100$ | y–y | b | a |
| | | z–z | c | a |
| $h/b \le 1.2$ | $t_f \le 100$ mm | y–y | b | a |
| | | z–z | c | a |
| | $t_f > 100$ mm | y–y | d | c |
| | | z–z | d | c |

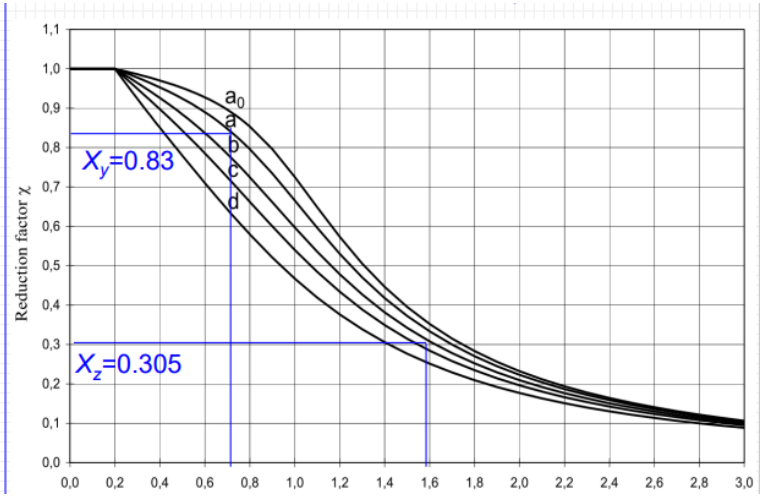
Buckling will occur about the minor (z) axis. For a rolled UB section (with h/b > 1.2 and $t_f \le 40$mm), buckling about the z-axis, use buckling curve (b) with α = 0.34.

$$\Phi_z = 0.5[1 + 0.34(1.608 - 0.2) + 1.608^2] = 2.032$$

$$\chi_z = \frac{1}{2.032 + \sqrt{2.032^2 - 1.608^2}} = 0.305$$

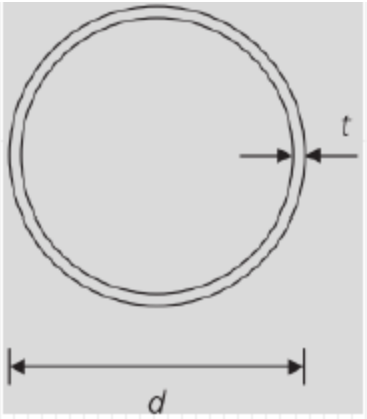
$$N_{b,z,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}} = \frac{0.305 \times 10\,067 \times 275}{1.0} = 844 \text{ kN} > 561 \text{ kN} = N_{Ed}$$

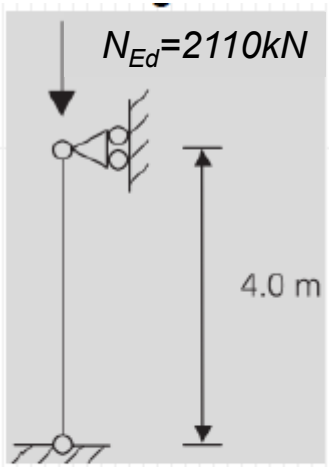
and so the member is satisfactory!



# Example on buckling resistance of CHS compression member

Example 3.4. A hot finished circular hollow section (CHS) member is to be used as an internal column in a multi-storey building. The column has pinned boundary conditions at each end, and the inter-storey height is 4m, as shown. The critical combination of actions results in a design axial force of 2110kN. Assess the suitability of a hot-rolled 244.5 x 10 CHS in grade S355 steel for this application.




$d = 244.5$ mm

$t = 10.0$ mm

$A = 7370$ mm$^2$

$W_{el,y} = 415\,000$ mm$^3$

$W_{pl,y} = 550\,000$ mm$^3$

$I = 50\,730\,000$ mm$^4$

S 355 for t≤40mm

Material Properties:

- $f_y$ = 355 MPa
- $f_u$ = 510 MPa
- E = 210 GPa

Solution

Step1: Classify the cross-section.

$$\varepsilon = \sqrt{235/f_y} = \sqrt{235/355} = 0.81$$

Tubular sections (Table 5.2, sheet 3):

$$d/t = 244.5/10.0 = 24.5$$

$$33 > 24.5 \quad \therefore \text{ section is Class 1}$$

Step2: Compute the Cross-section compression resistance $N_{c,Rd}$.

$$N_{c,Rd} = \frac{Af_y}{\gamma_{M0}} \quad \text{for Class 1, 2 or 3 cross-sections}$$

$$\therefore N_{c,Rd} = \frac{7370 \times 355}{1.00} = 2616 \times 10^3 \text{ N} = 2616 \text{ kN}$$

$2616 > 2110$ kN $\quad \therefore$ cross-section resistance is acceptable

Step3: Compute the Buckling resistance of the Member $N_{b,Rd}$.

$$N_{b,Rd} = \frac{\chi Af_y}{\gamma_{M1}} \quad \text{for Class 1, 2 and 3 cross-sections}$$

# Example on buckling resistance of CHS compression member

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \qquad \text{but } \chi \le 1.0$$

where

$$\Phi = 0.5[1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2]$$

and

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} \qquad \text{for Class 1, 2 and 3 cross-sections}$$

| Buckling curve | $a_0$ | a | b | c | d |
|---|---|---|---|---|---|
| Imperfection factor $\alpha$ | 0.13 | 0.21 | 0.34 | 0.49 | 0.76 |

## Elastic critical force and nondimensional slenderness or flexural buckling

$$N_{cr} = \frac{\pi^2 EI}{L_{cr}^2} = \frac{\pi^2 \times 210\,000 \times 50\,730\,000}{4000^2} = 6571\ \text{kN}$$

$$\therefore \bar{\lambda} = \sqrt{\frac{7370 \times 355}{6571 \times 10^3}} = 0.63$$

$$\Phi = 0.5[1 + 0.21 \times (0.63 - 0.2) + 0.63^2] = 0.74$$

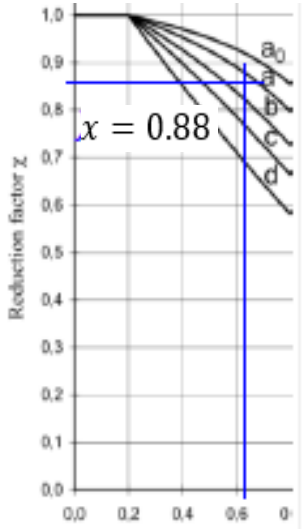
$$\chi = \frac{1}{0.74 + \sqrt{0.74^2 - 0.63^2}} = 0.88$$

$$\therefore N_{b,Rd} = \frac{0.88 \times 7370 \times 355}{1.0} = 2297 \times 10^3\ \text{N} = 2297\ \text{kN}$$

$2297 > 2110\ \text{kN}$ $\therefore$ buckling resistance is acceptable.

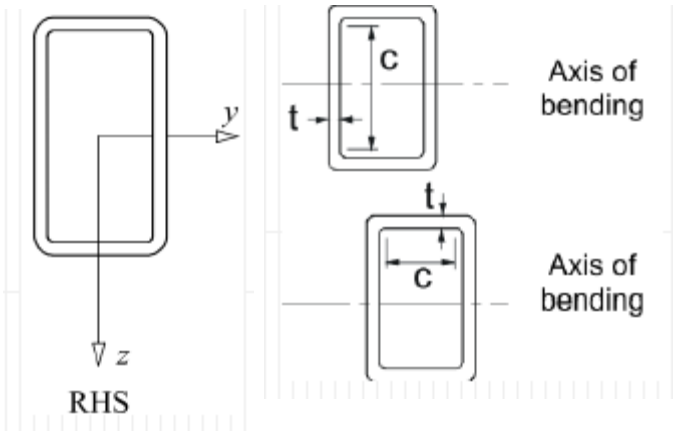
## For a hot-rolled CHS, use buckling curve a (table (6-5) (table 6-2 of EN 1993-1-1)) for buckling curve a , α=0.21

| | | | | |
|---|---|---|---|---|
| Hollow sections | hot finished | any | *a* | $a_0$ |
| | cold formed | any | *c* | *c* |



# Example on Designing an RHS compression member

Example 3.5. Design a suitable hot-finished RHS of S355 steel to resist the loading of example 3.3.




S 355 for t≤40mm Material Properties:

- $f_y$ = 355 MPa
- $f_u$ = 510 MPa
- E = 210 GPa

Solution

Step1: Compute the design applied compressive axial force $N_{Ed}$.

$$N_{Ed} = (1.35 \times 160) + (1.5 \times 230) = 561 \text{ kN}$$

Step2: Select a cross section based on an assumed reduction value. Guess $\chi = 0.3$

$$A \geq 561 \times 10^3/(0.3 \times 355) = 5268 \text{ mm}^2$$

Try a **250 × 150 × 8 RHS**, with A = 60.8cm², $i_y$ = 9.17cm, $i_z$ = 6.15cm, t = 8.0mm, r=4.0mm.

Step3: Classify the cross-section.

$$\varepsilon = (235/355)^{0.5} = 0.814$$

All plate members = internal or stiffened element.

$$\frac{c}{t} = \frac{h-(2\cdot t)-(2\cdot r)}{t} = \frac{25.0-(2\times 8.0)-(2\times 4.0)}{8.0} = 28.25$$

$$\frac{c}{t} = 33\varepsilon < 28.25 < 38\varepsilon \Rightarrow \text{Class 2}$$

and so the cross section is Class 2.

Hence, verification is only required for buckling resistance

| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 250x150 | 5.0 | 30.4 | 38.7 | 47.0 | 27.0 | 3360 | 1530 | 9.31 | 6.28 | 269 | 204 | 324 | 228 | 3280 | 337 | 0.787 | 25.9 |
| | 6.3 | 38.0 | 48.4 | 36.7 | 20.8 | 4140 | 1870 | 9.25 | 6.22 | 331 | 250 | 402 | 283 | 4050 | 413 | 0.784 | 20.6 |
| | 8.0 | 47.7 | 60.8 | 28.3 | 15.8 | 5110 | 2300 | 9.17 | 6.15 | 409 | 306 | 501 | 350 | 5020 | 506 | 0.779 | 16.3 |

(1) For local buckling calculation $c_w$ = h - 3t and $c_f$ = b - 3t.

# Example on Designing an RHS compression member

Step4: Verify the Buckling resistance of the Member $N_{b,Rd}$ Vs $N_{b,Ed}$

Since the selected section is section of class 2: Slenderness coefficient

$$\bar{\lambda}_y = \sqrt{\frac{Af_y}{N_{cr,y}}} = \frac{L_{cr,y}}{i_y}\frac{1}{\lambda_1} = \frac{12\,000}{(9.18 \times 10)}\frac{1}{93.9 \times 0.814} = 1.710$$

$$\bar{\lambda}_z = \sqrt{\frac{Af_y}{N_{cr,z}}} = \frac{L_{cr,z}}{i_z}\frac{1}{\lambda_1} = \frac{6000}{(6.15 \times 10)}\frac{1}{93.9 \times 0.814} = 1.276 < 1.710$$

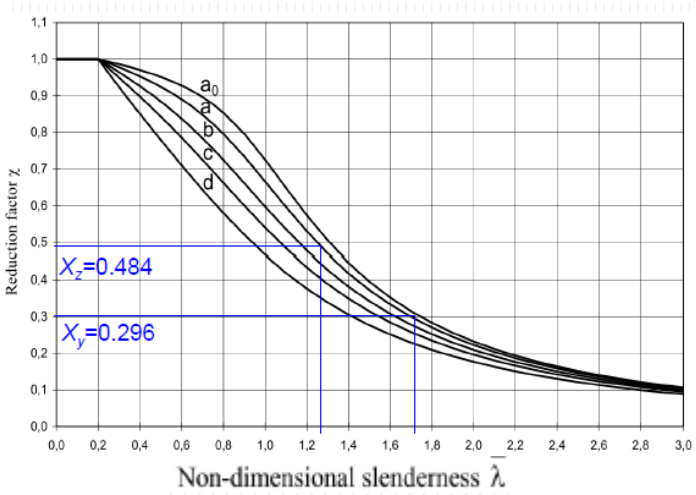
Select the buckling curve and corresponding "α" value

| | | | |
|---|---|---|---|
| Hollow sections | hot finished | any | a |
| | cold formed | any | c |

Buckling will occur about the major (y) axis. For a hot-finished RHS, use buckling curve (a) with α = 0.21

$$\Phi_y = 0.5[1 + 0.21(1.710 - 0.2) + 1.710^2] = 2.121$$

$$\chi_y = \frac{1}{2.121 + \sqrt{2.121^2 - 1.710^2}} = 0.296$$

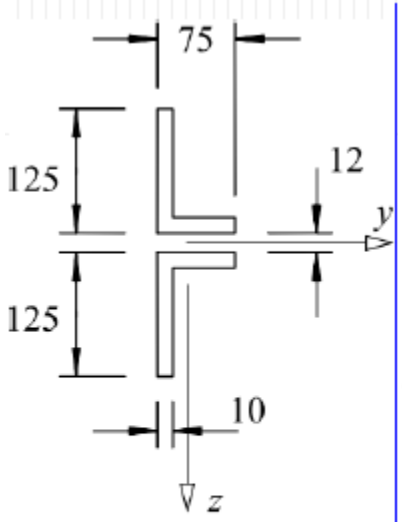



$$N_{b,y,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0.296 \times 60.8 \times 10^2 \times 355}{1.0} = 640\ \text{kN} > 561\ \text{kN} = N_{Ed}$$

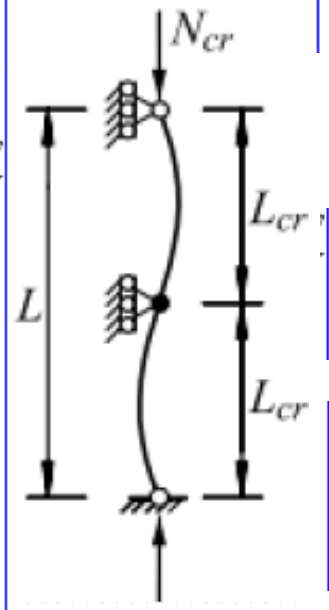
and so the member is satisfactory!

# Example on buckling of double angles

Example 3.6. Two steel 125 × 75 × 10 UA are connected together at 1.5 m intervals to form the long compression member whose properties are given. The minimum second moment of area of each angle is 49.9 $cm^4$. The member is simply supported about its major axis at 4.5 m intervals and about its minor axis at 1.5 m intervals. Determine the elastic buckling load of the member $N_{cr}$.




2 – 125 × 75 × 10 UA
$I_y = 1495\ cm^4$
$I_z = 164.2\ cm^4$




Material Properties:

► E = 210 GPa

## Solution

Step1: Compute the elastic buckling load about the major and minor axis, $N_{cr,y}$ and $N_{cr,Z}$ for the whole section.

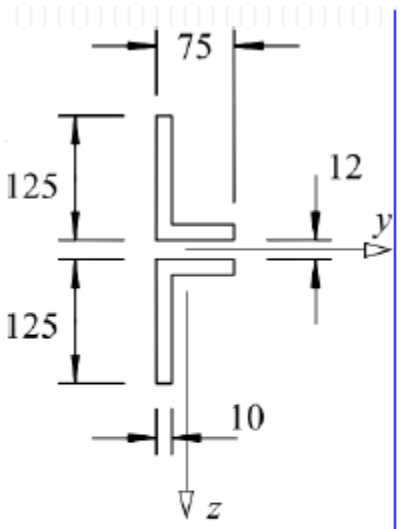
Member buckling about the major axis:

$$N_{cr,y} = \pi^2 \times 210\,000 \times 1495 \times 10^4 / 4500^2\ \text{N} = 1530\ \text{kN}$$

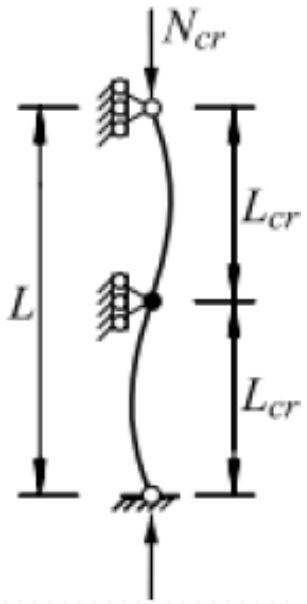
Member buckling about the minor axis:

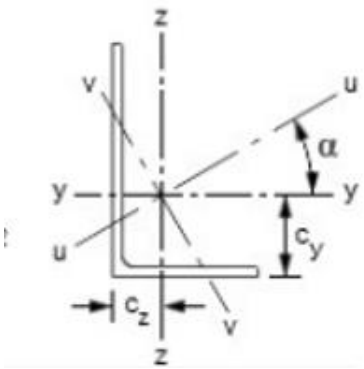
$$N_{cr,z} = \pi^2 \times 210\,000 \times 164.2 \times 10^4 / 1500^2\ \text{N} = 1513\ \text{kN}$$

# Example on buckling of double angles




2 – 125 × 75 × 10 UA
$I_y = 1495\ \text{cm}^4$
$I_z = 164.2\ \text{cm}^4$




$I_y$ = 302 cm4
$C_y$=4.23
S=0.6 cm
A =19.1 cm2
$I_Y$ =302+19.1(4.23+.6)=747.5 cm3
2L =747.5 *2 =1495

To calculate the elastic buckling load following equation is generally applicable for compression members;

$$N_{cr} = \frac{\pi^2 EI}{L_{cr}}$$

Step2: Compute the elastic buckling load, $N_{cr}$ for a single angle about its own minor axis.

$$N_{cr,min} = \pi^2 \times 210\,000 \times 49.9 \times 10^4 / 1500^2$$
$$= 459.7\ \text{kN}$$

and so for both angles
$2N_{cr,min}$=2 × 459.7= 919kN < 1513 kN

The lowest buckling load of 919 kN corresponds to the case where each unequal angle buckles about its own minimum axis.

BS EN 1993-1-1: 2005
BS EN 10056-1: 1999

Table 2.1.6.1

UK EUROCODES

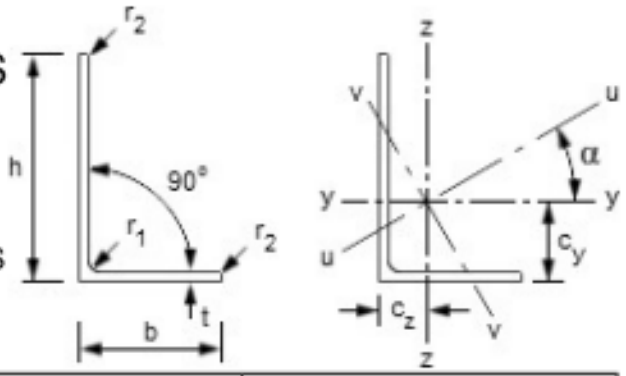
B-40

# SECTION PROPERTIES

## UNEQUAL ANGLES

**Advance® UKA - Unqual**

DIMENSIONS AND PROPERTIES




| Section Designation | | Mass per Metre | Radius | | Dimension | | Second Moment of Area | | | | Radius of Gyration | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Size h x b | Thickness t | | Root $r_1$ | Toe $r_2$ | $c_y$ | $c_z$ | Axis y-y | Axis z-z | Axis u-u | Axis v-v | Axis y-y | Axis z-z | Axis u-u | Axis v-v |
| mm | mm | kg/m | mm | mm | cm | cm | $cm^4$ | $cm^4$ | $cm^4$ | $cm^4$ | cm | cm | cm | cm |
| 200 x 150 | 18 + | 47.1 | 15.0 | 7.50 | 6.33 | 3.85 | 2380 | 1150 | 2920 | 623 | 6.29 | 4.37 | 6.97 | 3.22 |
| | 15 | 39.6 | 15.0 | 7.50 | 6.21 | 3.73 | 2020 | 979 | 2480 | 526 | 6.33 | 4.40 | 7.00 | 3.23 |
| | 12 | 32.0 | 15.0 | 7.50 | 6.08 | 3.61 | 1650 | 803 | 2030 | 430 | 6.36 | 4.44 | 7.04 | 3.25 |
| 200 x 100 | 15 | 33.8 | 15.0 | 7.50 | 7.16 | 2.22 | 1760 | 299 | 1860 | 193 | 6.40 | 2.64 | 6.59 | 2.12 |
| | 12 | 27.3 | 15.0 | 7.50 | 7.03 | 2.10 | 1440 | 247 | 1530 | 159 | 6.43 | 2.67 | 6.63 | 2.14 |
| | 10 | 23.0 | 15.0 | 7.50 | 6.93 | 2.01 | 1220 | 210 | 1290 | 135 | 6.46 | 2.68 | 6.65 | 2.15 |
| 150 x 90 | 15 | 33.9 | 12.0 | 6.00 | 5.21 | 2.23 | 761 | 205 | 841 | 126 | 4.74 | 2.46 | 4.98 | 1.93 |
| | 12 | 21.6 | 12.0 | 6.00 | 5.08 | 2.12 | 627 | 171 | 694 | 104 | 4.77 | 2.49 | 5.02 | 1.94 |
| | 10 | 18.2 | 12.0 | 6.00 | 5.00 | 2.04 | 533 | 146 | 591 | 88.3 | 4.80 | 2.51 | 5.05 | 1.95 |
| 150 x 75 | 15 | 24.8 | 12.0 | 6.00 | 5.52 | 1.81 | 713 | 119 | 753 | 78.6 | 4.75 | 1.94 | 4.88 | 1.58 |
| | 12 | 20.2 | 12.0 | 6.00 | 5.40 | 1.69 | 588 | 99.6 | 623 | 64.7 | 4.78 | 1.97 | 4.92 | 1.59 |
| | 10 | 17.0 | 12.0 | 6.00 | 5.31 | 1.61 | 501 | 85.6 | 531 | 55.1 | 4.81 | 1.99 | 4.95 | 1.60 |
| 125 x 75 | 12 | 17.8 | 11.0 | 5.50 | 4.31 | 1.84 | 354 | 95.5 | 391 | 58.5 | 3.95 | 2.05 | 4.15 | 1.61 |
| | 10 | 15.0 | 11.0 | 5.50 | 4.23 | 1.76 | 302 | 82.1 | 334 | 49.9 | 3.97 | 2.07 | 4.18 | 1.61 |
| | 8 | 12.2 | 11.0 | 5.50 | 4.14 | 1.68 | 247 | 67.6 | 274 | 40.9 | 4.00 | 2.09 | 4.21 | 1.63 |
| 100 x 75 | 12 | 15.4 | 10.0 | 5.00 | 3.27 | 2.03 | 189 | 90.2 | 230 | 49.5 | 3.10 | 2.14 | 3.42 | 1.59 |
| | 10 | 13.0 | 10.0 | 5.00 | 3.19 | 1.95 | 162 | 77.6 | 197 | 42.2 | 3.12 | 2.16 | 3.45 | 1.59 |
| | 8 | 10.6 | 10.0 | 5.00 | 3.10 | 1.87 | 133 | 64.1 | 162 | 34.6 | 3.14 | 2.18 | 3.47 | 1.60 |
| 100 x 65 | 10 + | 12.3 | 10.0 | 5.00 | 3.36 | 1.63 | 154 | 51.0 | 175 | 30.1 | 3.14 | 1.81 | 3.35 | 1.39 |
| | 8 + | 9.94 | 10.0 | 5.00 | 3.27 | 1.55 | 127 | 42.2 | 144 | 24.8 | 3.16 | 1.83 | 3.37 | 1.40 |
| | 7 + | 8.77 | 10.0 | 5.00 | 3.23 | 1.51 | 113 | 37.6 | 128 | 22.0 | 3.17 | 1.83 | 3.39 | 1.40 |

UK EUROCODES

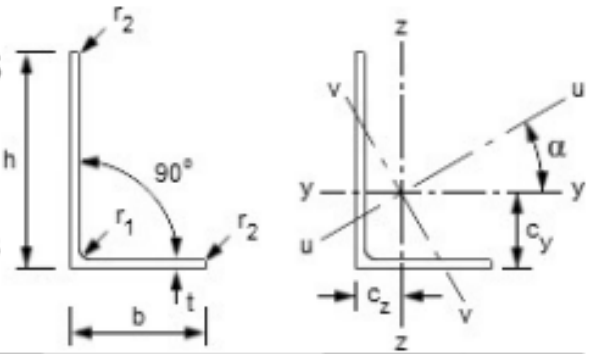
# SECTION PROPERTIES

## UNEQUAL ANGLES

### Advance® UKA - Unqual

DIMENSIONS AND PROPERTIES






| Section Designation | | Elastic Modulus | | Angle Axis y-y to Axis u-u Tan α | Torsional Constant | Equivalent Slenderness Coefficient | | Mono-symmetry Index | Area of Section |
|---|---|---|---|---|---|---|---|---|---|
| Size h x b mm | Thickness t mm | Axis y-y $cm^3$ | Axis z-z $cm^3$ | | $I_T$ $cm^4$ | Min $\varphi_a$ | Max $\varphi_a$ | $\psi_a$ | $cm^2$ |
| 200 x 150 | 18 + | 174 | 103 | 0.549 | 67.9 | 2.93 | 3.72 | 4.60 | 60.0 |
| | 15 | 147 | 86.9 | 0.551 | 39.9 | 3.53 | 4.50 | 5.55 | 50.5 |
| | 12 | 119 | 70.5 | 0.552 | 20.9 | 4.43 | 5.70 | 6.97 | 40.8 |
| 200 x 100 | 15 | 137 | 38.5 | 0.260 | 34.3 | 3.54 | 5.17 | 9.19 | 43.0 |
| | 12 | 111 | 31.3 | 0.262 | 18.0 | 4.42 | 6.57 | 11.5 | 34.8 |
| | 10 | 93.2 | 26.3 | 0.263 | 10.66 | 5.26 | 7.92 | 13.9 | 29.2 |
| 150 x 90 | 15 | 77.7 | 30.4 | 0.354 | 26.8 | 2.58 | 3.59 | 5.96 | 33.9 |
| | 12 | 63.3 | 24.8 | 0.358 | 14.1 | 3.24 | 4.58 | 7.50 | 27.5 |
| | 10 | 53.3 | 21.0 | 0.360 | 8.30 | 3.89 | 5.56 | 9.03 | 23.2 |
| 150 x 75 | 15 | 75.2 | 21.0 | 0.253 | 25.1 | 2.62 | 3.74 | 6.84 | 31.7 |
| | 12 | 61.3 | 17.1 | 0.258 | 13.2 | 3.30 | 4.79 | 8.60 | 25.7 |
| | 10 | 51.6 | 14.5 | 0.261 | 7.80 | 3.95 | 5.83 | 10.4 | 21.7 |
| 125 x 75 | 12 | 43.2 | 16.9 | 0.354 | 11.6 | 2.66 | 3.73 | 6.23 | 22.7 |
| | 10 | 36.5 | 14.3 | 0.357 | 6.87 | 3.21 | 4.55 | 7.50 | 19.1 |
| | 8 | 29.6 | 11.6 | 0.360 | 3.62 | 4.00 | 5.75 | 9.43 | 15.5 |
| 100 x 75 | 12 | 28.0 | 16.5 | 0.540 | 10.05 | 2.10 | 2.64 | 3.46 | 19.7 |
| | 10 | 23.8 | 14.0 | 0.544 | 5.95 | 2.54 | 3.22 | 4.17 | 16.6 |
| | 8 | 19.3 | 11.4 | 0.547 | 3.13 | 3.18 | 4.08 | 5.24 | 13.5 |
| 100 x 65 | 10 + | 23.2 | 10.5 | 0.410 | 5.61 | 2.52 | 3.43 | 5.45 | 15.6 |
| | 8 + | 18.9 | 8.54 | 0.413 | 2.96 | 3.14 | 4.35 | 6.86 | 12.7 |
| | 7 + | 16.6 | 7.53 | 0.415 | 2.02 | 3.58 | 5.00 | 7.85 | 11.2 |

*Table 2.1.6.2. Advance® UKA - Unequal. Dimensions and Properties*

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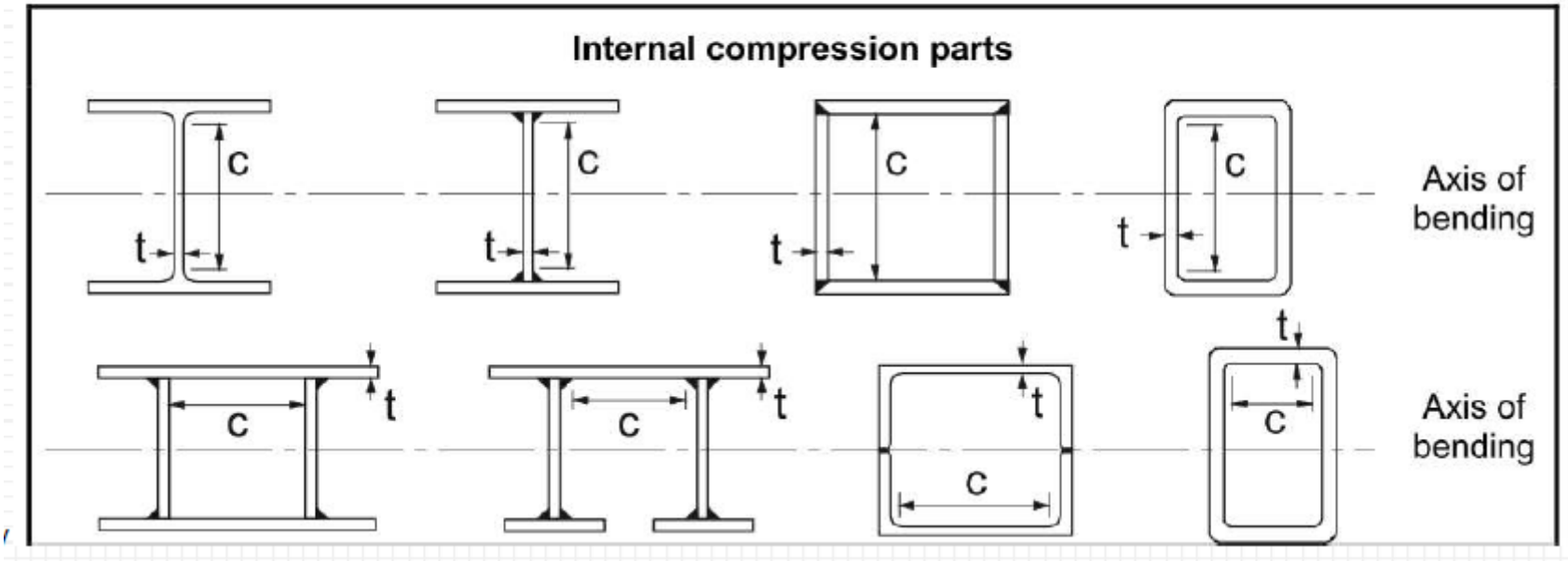
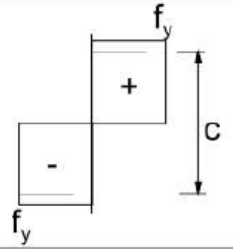
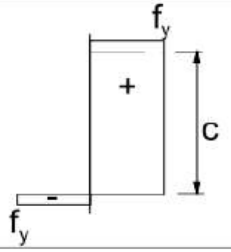
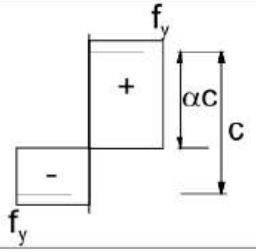
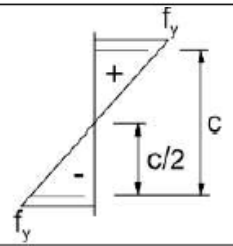
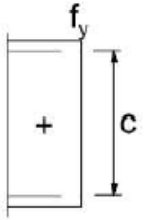
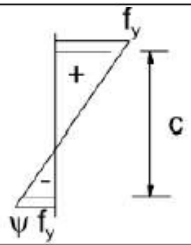
# Classification of Cross-sections تصنيف المقاطع العرضية

**Table 5.2 (sheet 1 of 3): Maximum width-to-thickness ratios for compression parts**



# Classification of Cross-sections تصنيف المقاطع العرضية

| Class | Part subject to bending | Part subject to compression | Part subject to bending and compression |
|---|---|---|---|
| Stress distribution in parts (compression positive) |   |   |   |
| 1 | $c/t \le 72\varepsilon$ | $c/t \le 33\varepsilon$ | when $\alpha > 0{,}5$: $c/t \le \frac{396\varepsilon}{13\alpha - 1}$ <br> when $\alpha \le 0{,}5$: $c/t \le \frac{36\varepsilon}{\alpha}$ |
| 2 | $c/t \le 83\varepsilon$ | $c/t \le 38\varepsilon$ | when $\alpha > 0{,}5$: $c/t \le \frac{456\varepsilon}{13\alpha - 1}$ <br> when $\alpha \le 0{,}5$: $c/t \le \frac{41{,}5\varepsilon}{\alpha}$ |
| Stress distribution in parts (compression positive) |   |   |   |
| 3 | $c/t \le 124\varepsilon$ | $c/t \le 42\varepsilon$ | when $\psi > -1$: $c/t \le \frac{42\varepsilon}{0{,}67 + 0{,}33\psi}$ <br> when $\psi \le -1^{*)}$: $c/t \le 62\varepsilon(1-\psi)\sqrt{(-\psi)}$ |

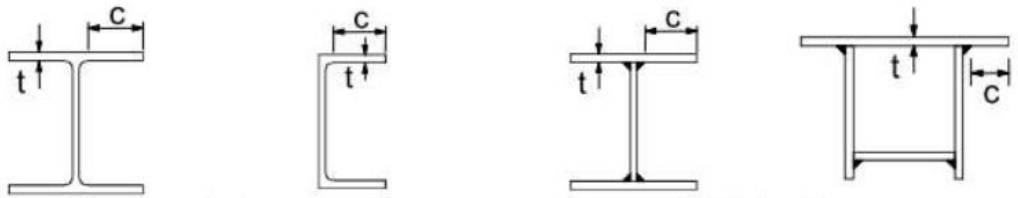
| $\varepsilon = \sqrt{235/f_y}$ | $f_y$ | 235 | 275 | 355 | 420 | 460 |
|---|---|---|---|---|---|---|
| | $\varepsilon$ | 1,00 | 0,92 | 0,81 | 0,75 | 0,71 |

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

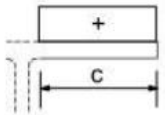
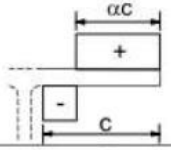
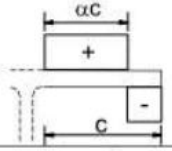
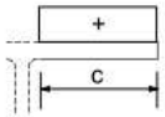
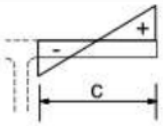
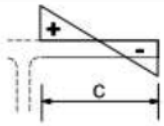
# Classification of Cross-sections تصنيف المقاطع العرضية

**Table 5.2 (sheet 2 of 3): Maximum width-to-thickness ratios for compression parts**

**Outstand flanges**




Rolled sections | Welded sections

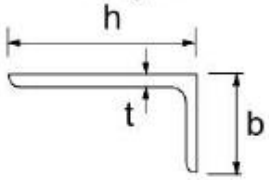
| Class | Part subject to compression | Part subject to bending and compression | |
|---|---|---|---|
| | | Tip in compression | Tip in tension |
| Stress distribution in parts (compression positive) |  |  |  |
| 1 | $c/t \le 9\varepsilon$ | $c/t \le \frac{9\varepsilon}{\alpha}$ | $c/t \le \frac{9\varepsilon}{\alpha\sqrt{\alpha}}$ |
| 2 | $c/t \le 10\varepsilon$ | $c/t \le \frac{10\varepsilon}{\alpha}$ | $c/t \le \frac{10\varepsilon}{\alpha\sqrt{\alpha}}$ |
| Stress distribution in parts (compression positive) |  |  |  |
| 3 | $c/t \le 14\varepsilon$ | $c/t \le 21\varepsilon\sqrt{k_\sigma}$ For $k_\sigma$ see EN 1993-1-5 | |

| $\varepsilon = \sqrt{235/f_y}$ | $f_y$ | 235 | 275 | 355 | 420 | 460 |
|---|---|---|---|---|---|---|
| | $\varepsilon$ | 1,00 | 0,92 | 0,81 | 0,75 | 0,71 |

# Classification of Cross-sections تصنيف المقاطع العرضية

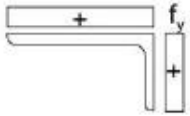
**Table 5.2 (sheet 3 of 3): Maximum width-to-thickness ratios for compression parts**

**Angles**

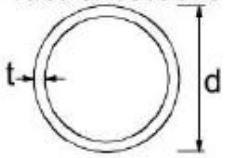



Refer also to "Outstand flanges" (see sheet 2 of 3)

Does not apply to angles in continuous contact with other components

| Class | Section in compression |
|---|---|
| Stress distribution across section (compression positive) |   |
| 3 | $h/t \le 15\varepsilon : \dfrac{b+h}{2t} \le 11{,}5\varepsilon$ |

**Tubular sections**

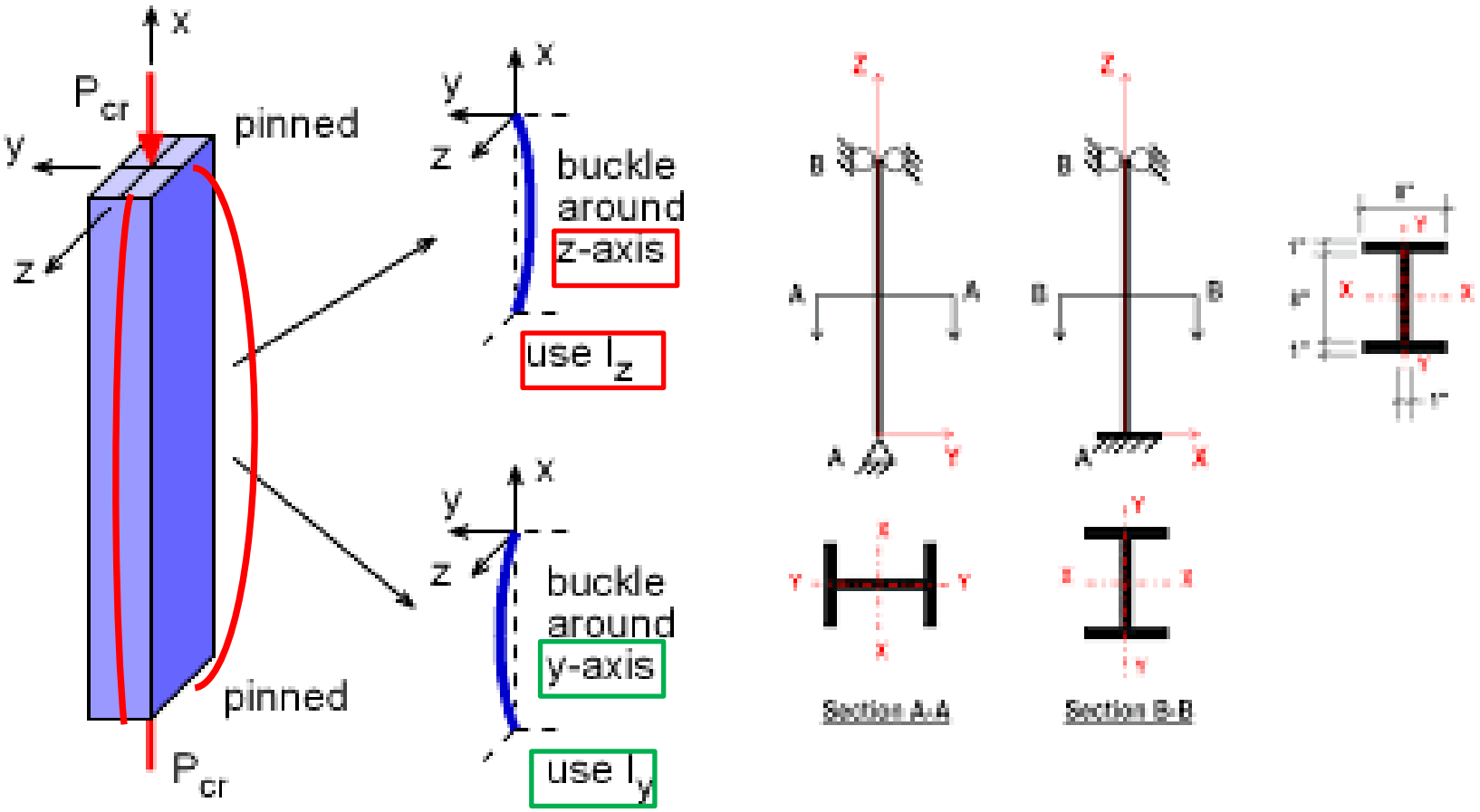



| Class | Section in bending and/or compression |
|---|---|
| 1 | $d/t \le 50\varepsilon^2$ |
| 2 | $d/t \le 70\varepsilon^2$ |
| 3 | $d/t \le 90\varepsilon^2$ <br> **NOTE** For $d/t > 90\varepsilon^2$ see EN 1993-1-6. |

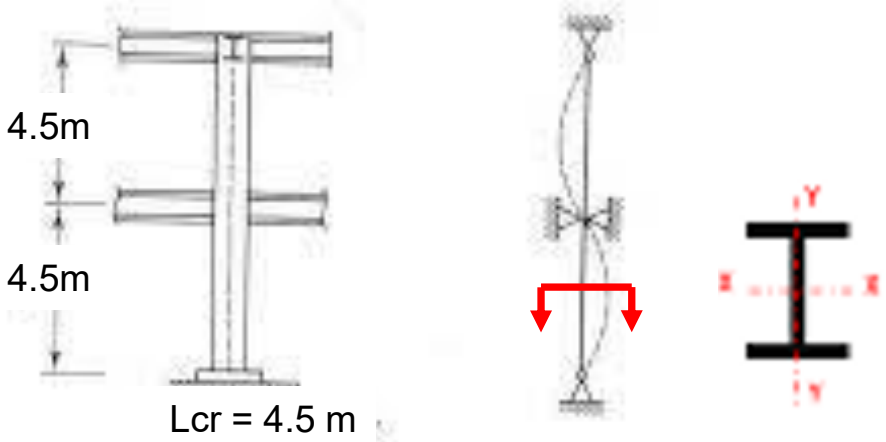
$\varepsilon = \sqrt{235/f_y}$

| $f_y$ | 235 | 275 | 355 | 420 | 460 |
|---|---|---|---|---|---|
| $\varepsilon$ | 1,00 | 0,92 | 0,81 | 0,75 | 0,71 |
| $\varepsilon^2$ | 1,00 | 0,85 | 0,66 | 0,56 | 0,51 |

# Plane Of buckling مستويات التحنيب

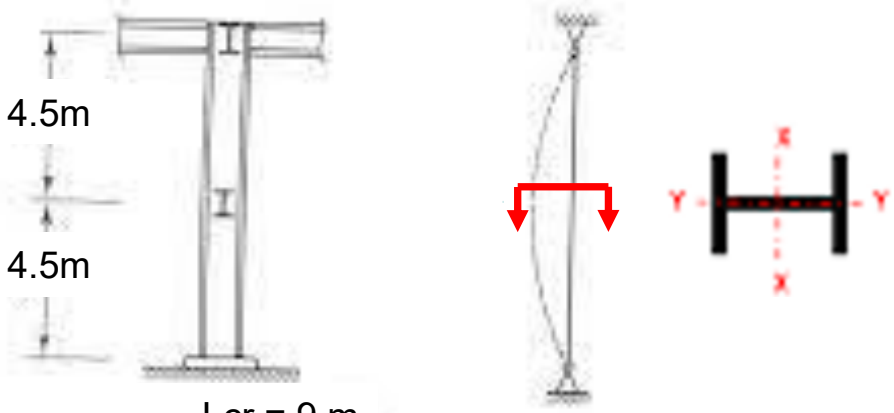


# Plane Of buckling مستويات التحنيب




Lcr = 4.5 m

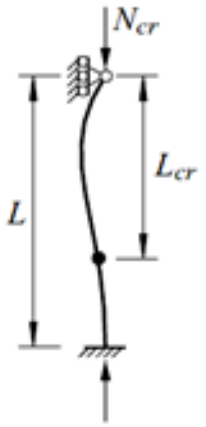
a) Minor Axis Buckling




Lcr = 9 m

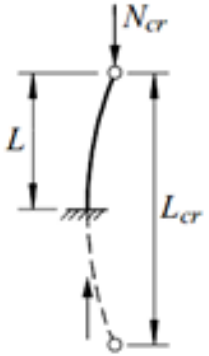
b) Major Axis Buckling

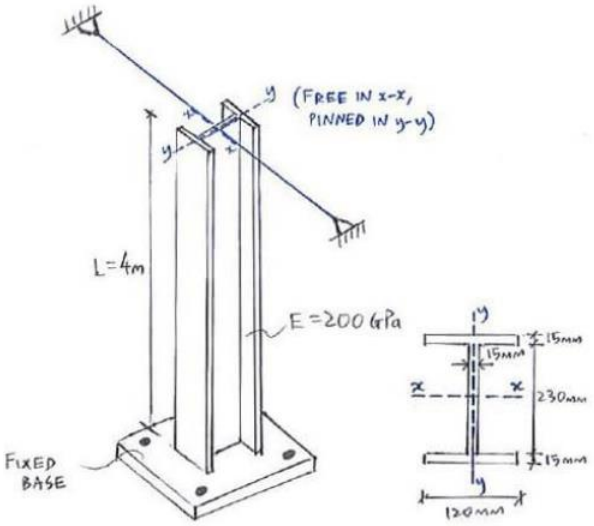
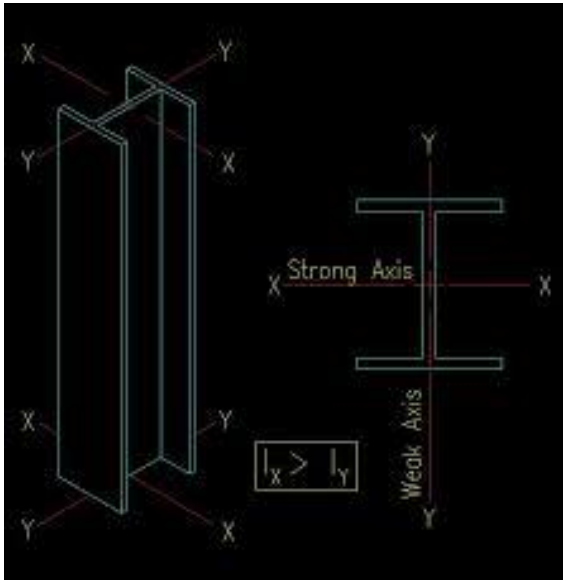
# Plane Of buckling مستويات التحنيب




$$N_{cr} = 2\pi^2 EI/L^2$$
$$L_{cr} = 0.7L$$

a) Buckling plane xz
Bending about yy
Bending about
Minor (weak ) axis




$$N_{cr} = \pi^2 EI/4L^2$$
$$L_{cr} = 2L$$

b) Buckling plane yz
Bending about xx
Bending about
Major (strong ) axis