جَـامعة
المَـنارة
MANARA UNIVERSITY

Steel Structures 1
Sem. 2
2023-2024

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)

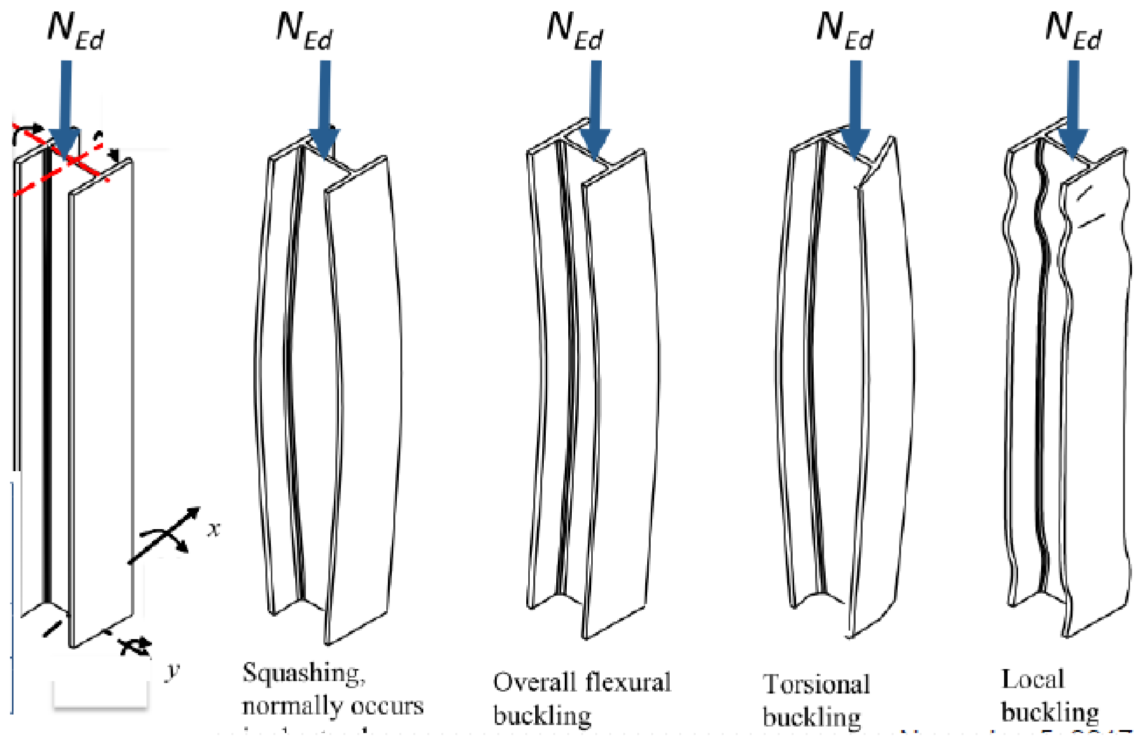
تصميم عناصر الضغط على الاستقرار تبعا للكود الأوربي EC3 (المنهجية)

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, $N_{b,Rd}$	✓	

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

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

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

$$N_{b,Rd} = \chi \frac{A \cdot f_y}{\gamma_{M1}}$$ cross-sections of class 1, 2 or 3:,

$$N_{b,Rd} = \chi \frac{A_{eff} \cdot f_y}{\gamma_{M1}}$$ cross-sections of class 4

- X هي عامل تخفيض تبعا لنمط التحنيب الموافق. نحصل عليها من العلاقات:

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

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

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

$$\bar{\lambda} = \sqrt{A f_y / N_{cr}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1}$$ → cross-sections of class 1, 2 or 3:,

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

Design of compression members

- α 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

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

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

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

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

$$\bar{\lambda} = \sqrt{A f_y / N_{cr}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1}$$ → cross-sections of class 1, 2 or 3:,

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

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

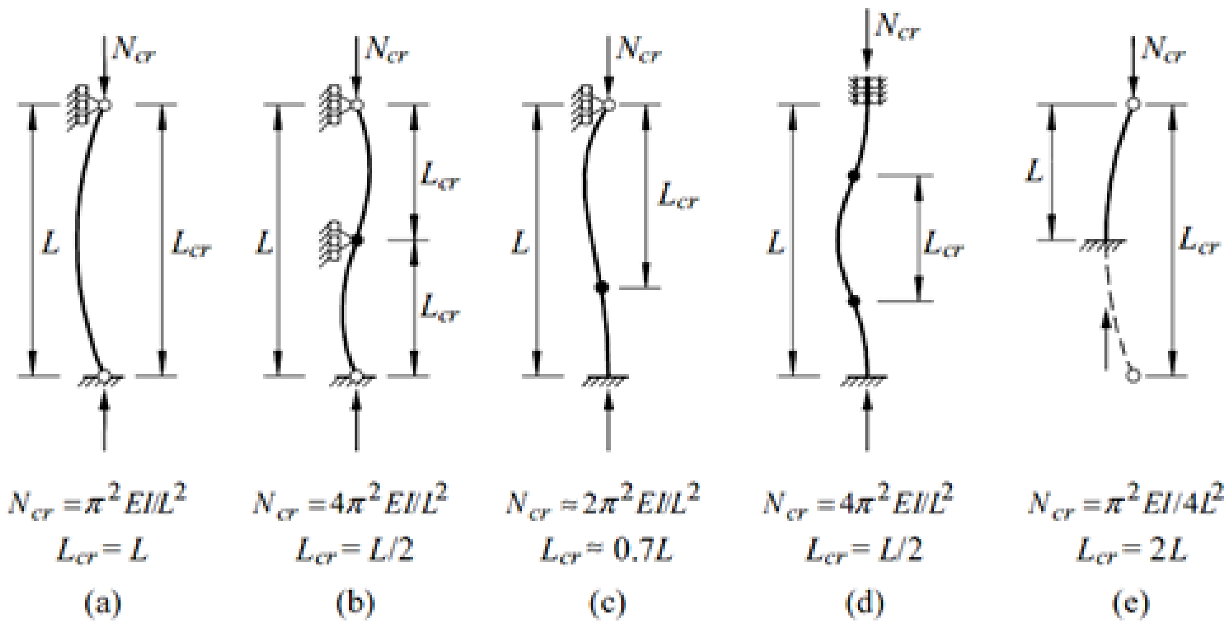
تتغير حمولة التحنيب N_{cr} حسب

- **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.

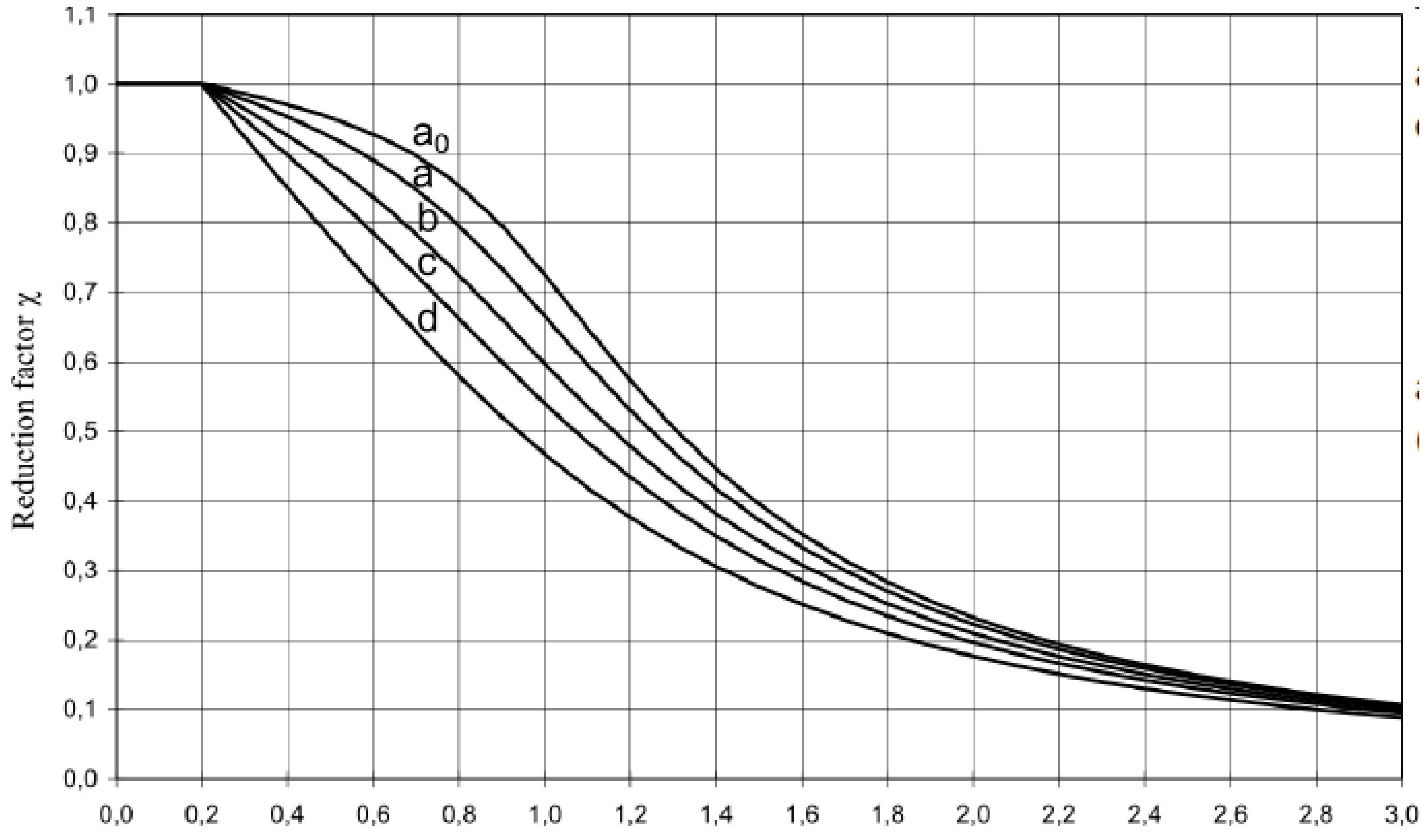
- تملك العناصر ذات العيوب الأولية العالية مقاومات أخفض نتيجة الخضوع المبكر، وتكون هذه موافقة لقيم α عالية.
- من ناحية أخرى لاتتأثر عناصر الضغط ذات التشوه الأولي القليل بالخضوع الأولي، وتكون قيم α المحددة لها اصغر.

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

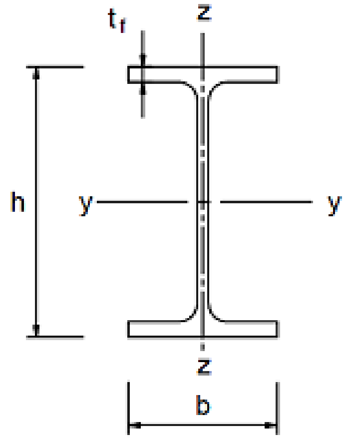
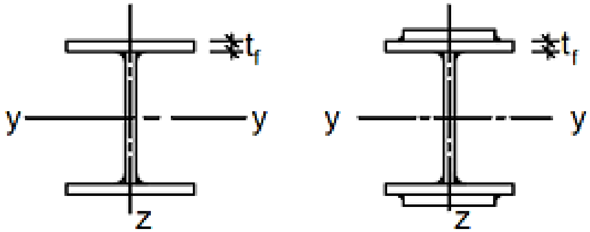
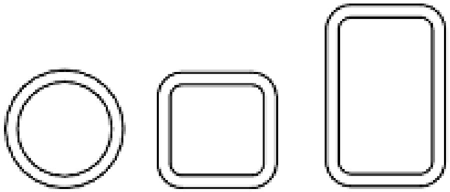
توضح الجداول اللاحقة ذلك



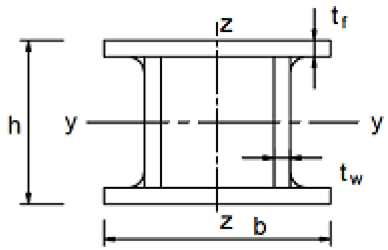
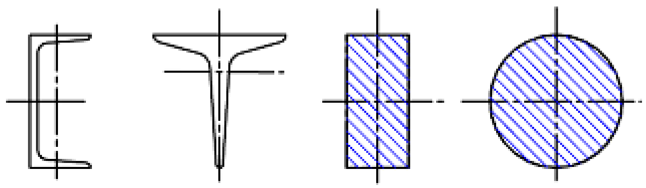
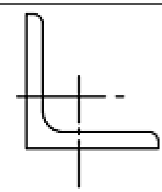
Buckling curve	a_0	a	b	c	d
Imperfection factor α	0,13	0,21	0,34	0,49	0,76

منحنيات التحنيب وعوامل العيوب a

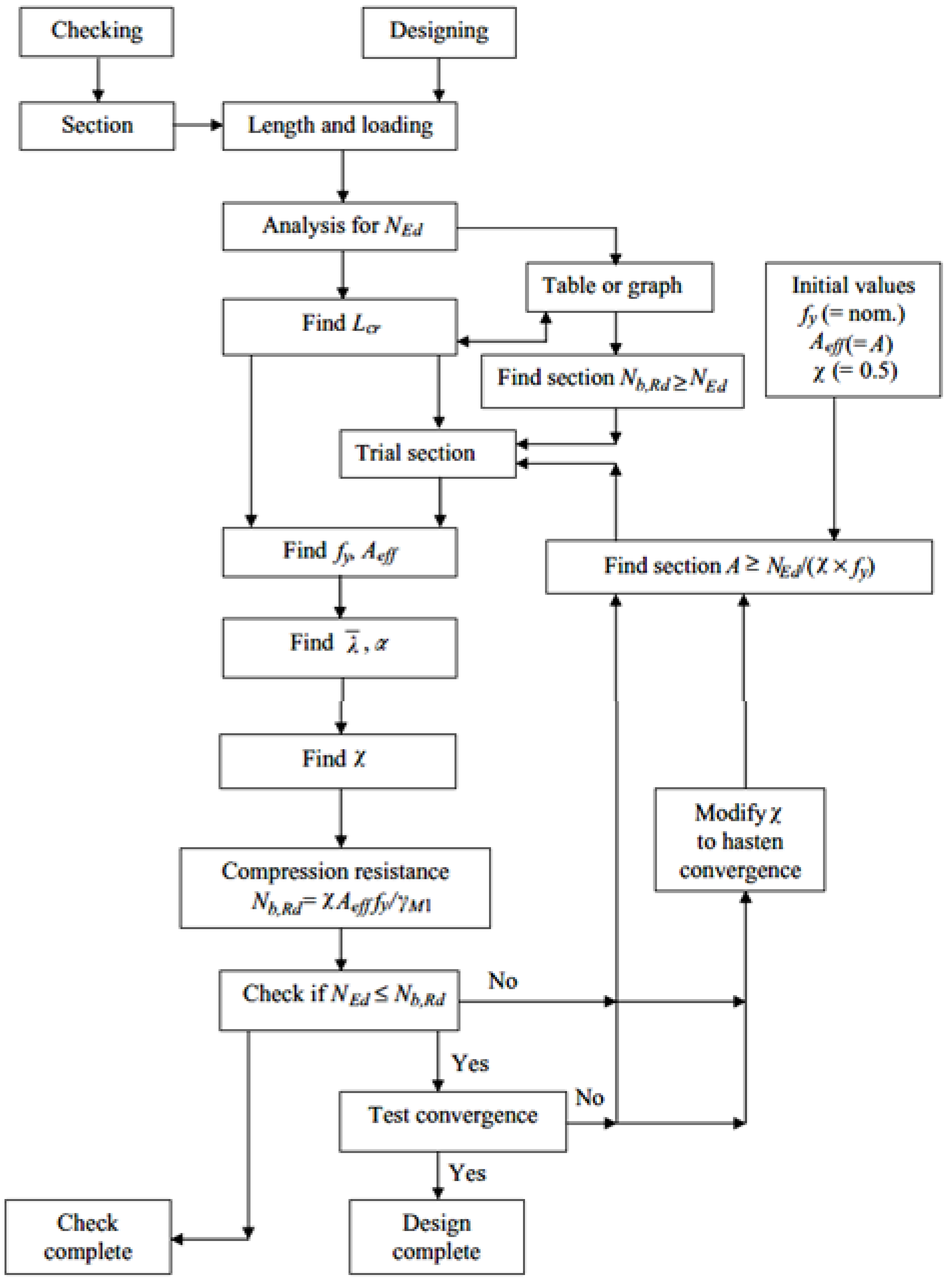
اختيار منحني التحنيب حسب نوع المقطع

Cross section		Limits		Buckling about axis	Buckling curve S 235 S 275 S 355 S 420	Buckling curve S 460
Rolled sections		$h/b > 1{,}2$	$t_f \leq 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm < $t_f \leq 100$	y – y z – z	b c	a a
		$h/b \leq 1{,}2$	$t_f \leq 100$ mm	y – y z – z	b c	a a
			$t_f > 100$ mm	y – y z – z	d d	c c
Welded I-sections		$t_f \leq 40$ mm		y – y z – z	b c	b c
		$t_f > 40$ mm		y – y z – z	c d	c 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 S 275 S 355 S 420	S 460
Welded box sections		generally (except as below)	any	b	b
		thick welds: $a > 0{,}5t_f$ $b/t_f < 30$ $h/t_w < 30$	any	c	c
U-, T- and solid sections			any	c	c
L-sections			any	b	b

ملخص التصميم والتحقيق للعناصر المضغوطة



Example on resistance in compression against buckling

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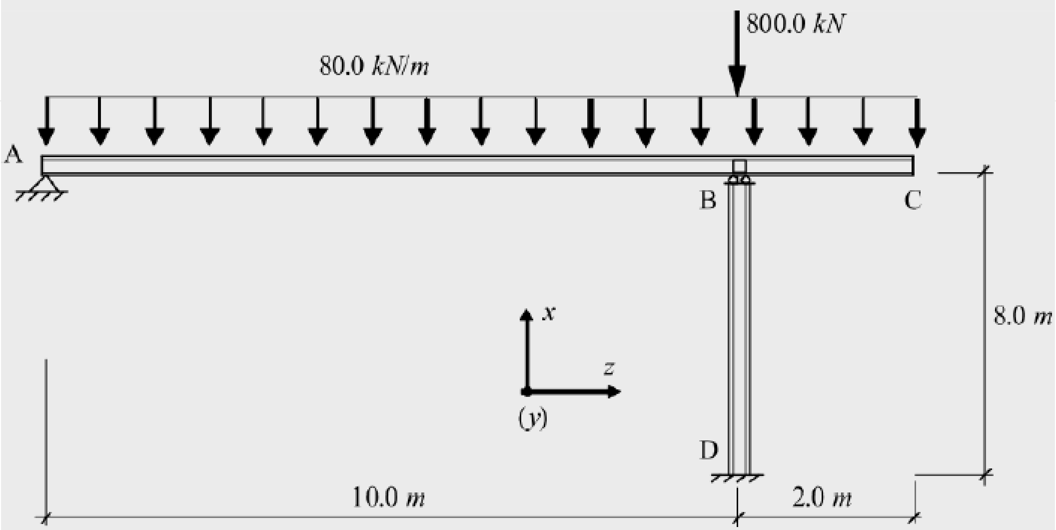
Example 3.2. Design the column BD of the steel structure represented in the figure below, using a HEB cross section in S 355 steel, according to EC1993-1-1. The column is fixed at the base and hinged at section B (with respect to the two principal axis of the cross section). Cross section B is fixed 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.

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

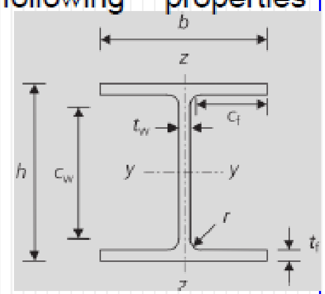
$$A \geq 38.76 \times 10^{-4}\,m^2 = 38.76\,cm^2$$

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

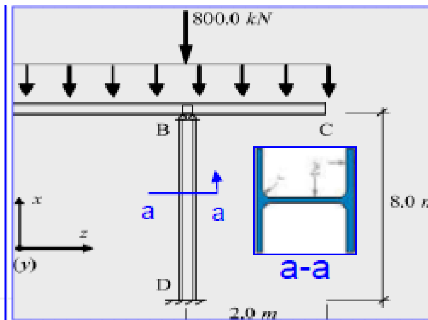
- A = 106cm²
- I_y = 11260cm⁴
- I_z = 3923cm⁴
- i_y = 10.31cm
- i_z = 6.08cm

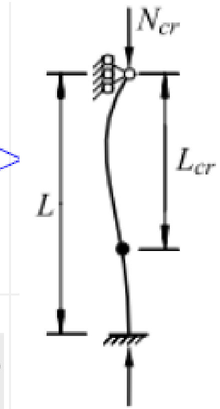


Step3: Check for instability.

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

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

$L_{cr} \approx 0.7L$

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

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

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

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

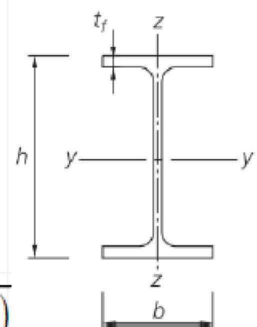
$$\lambda_1 = \pi\sqrt{\left(210\times10^6 / 355\times10^3\right)}$$

$$\lambda_1 = 76.4$$

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	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

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

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

$$\chi_z = 0.43$$

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

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

$$\phi_z = 1.48$$

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

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

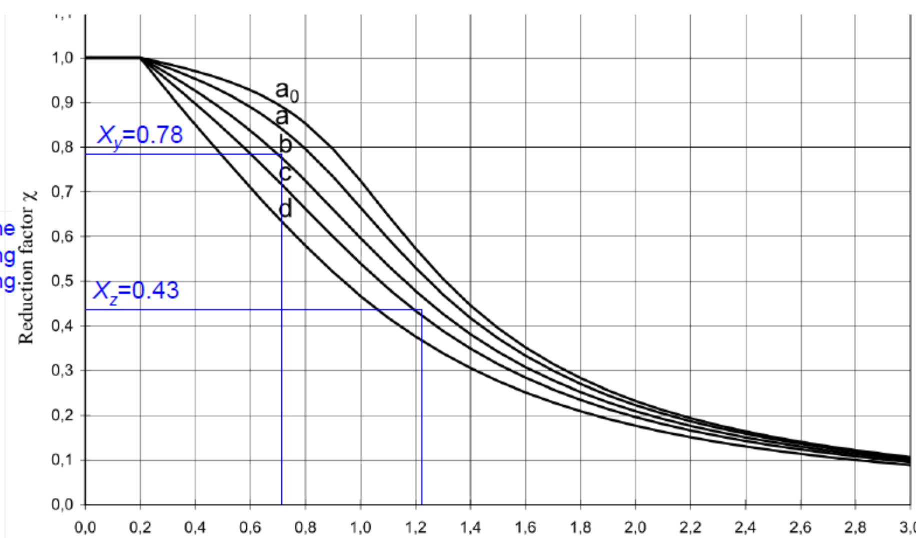
$$\text{As } \overline{\lambda}_z > \overline{\lambda}_y \text{ and } \alpha_{\,curve\ c} > \alpha_{\,curve\ b} \Rightarrow \chi_{min} \Rightarrow \chi_z.$$

Step4: Section Verification.

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

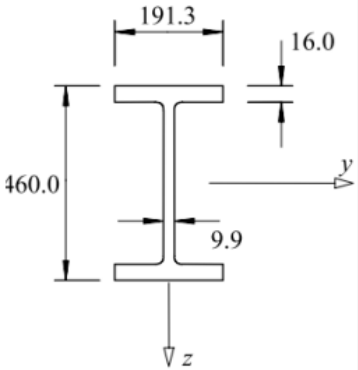
$$N_{Ed} = 1376.0\,kN < N_{b,Rd} = 1618.1\,kN$$

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.

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

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

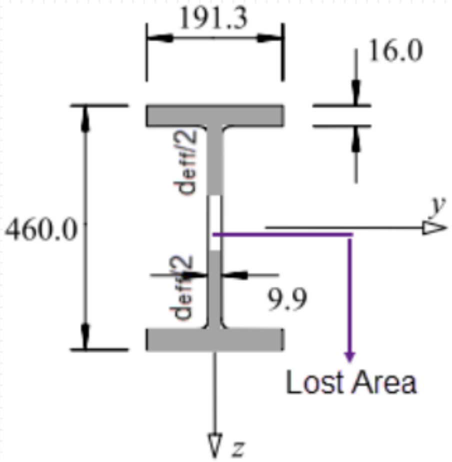
Web = internal or stiffened element.

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

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

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 $N_{b,Rd}$.

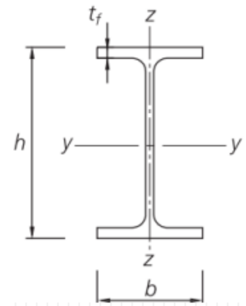
Since the selected section is section of class 4: Slenderness coefficient

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

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

$$= 1.608 > 0.724$$

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

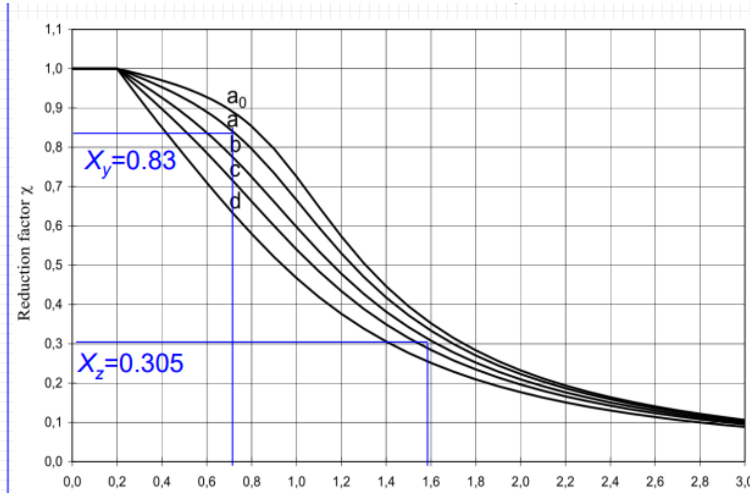
Buckling will occur about the minor (z) axis. For a rolled UB section (with $h/b > 1.2$ and $t_f \le 40$mm), buckling about the z-axis, use buckling curve (b) with $\alpha = 0.34$.

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

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

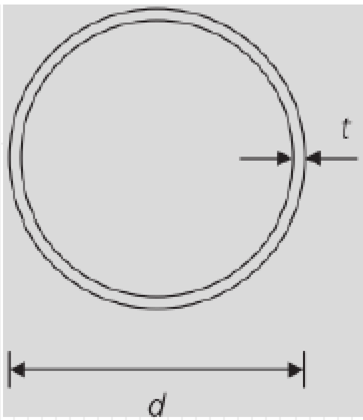
$$N_{b,z,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}} = \frac{0.305 \times 10\,067 \times 275}{1.0} = 844 \text{ kN} > 561 \text{ kN} = N_{Ed}$$

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

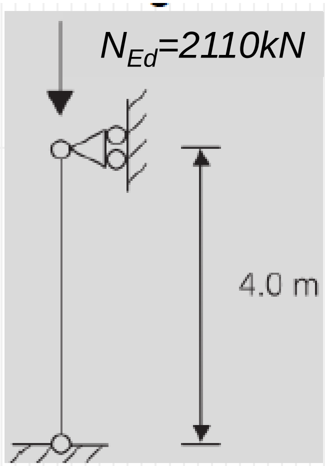
$t = 10.0$ mm

$A = 7370$ 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):

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

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

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

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

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

$$2616 > 2110 \text{ kN} \qquad \therefore \text{ cross-section resistance is acceptable}$$

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

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

Example on buckling resistance of CHS compression member

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

where

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

and

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

Buckling curve	a_0	a	b	c	d
Imperfection factor α	0.13	0.21	0.34	0.49	0.76

Elastic critical force and nondimensional slenderness or flexural buckling

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

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

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

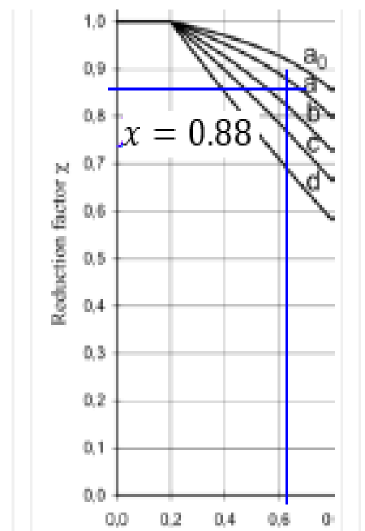
$$\chi = \frac{1}{0.74 + \sqrt{0.74^2 - 0.63^2}} = 0.88$$

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

$2297 > 2110$ kN $\quad \therefore$ buckling resistance is acceptable.

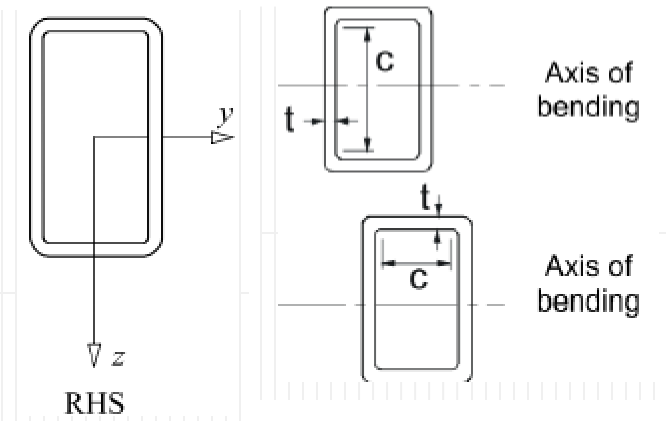
For a hot-rolled CHS, use buckling curve a (table (6-5) (table 6-2 of EN 1993-1-1)) for buckling curve a , α=0.21

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

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

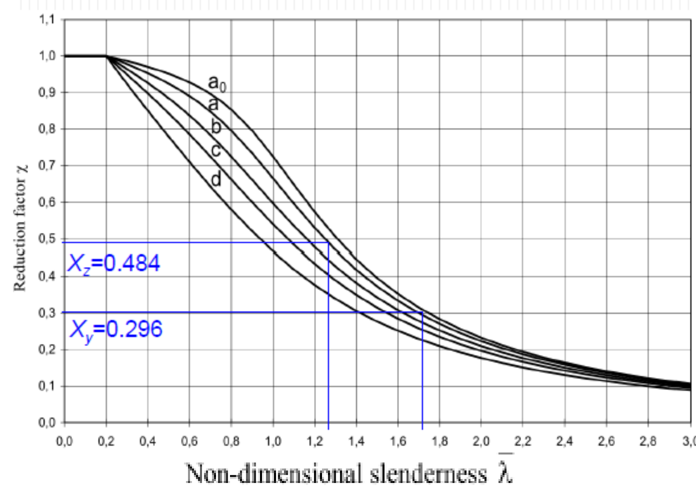
Since the selected section is section of class 2: Slenderness coefficient

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

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

Select the buckling curve and corresponding "α" value

Hollow sections		hot finished	any	a	a_0
		cold formed	any	c	c



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

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

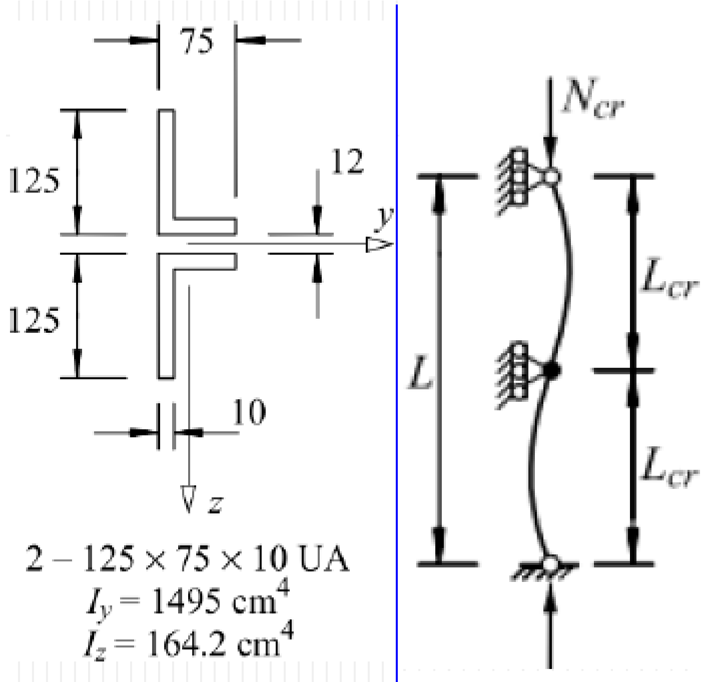
$$\chi_y = \frac{1}{2.121 + \sqrt{2.121^2 - 1.710^2}} = 0.296$$

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

<u>and so the member is satisfactory!</u>

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}.



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.

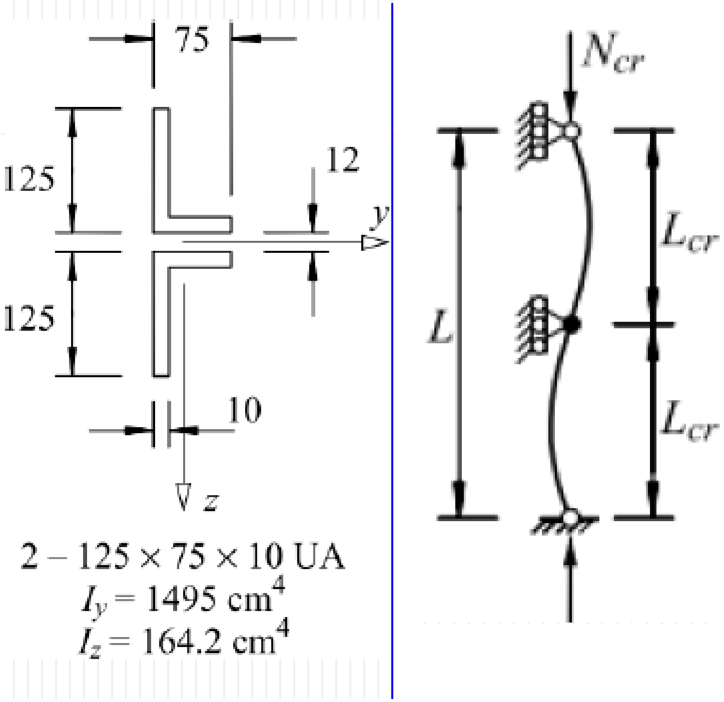
Member buckling about the major axis:

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

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



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.

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

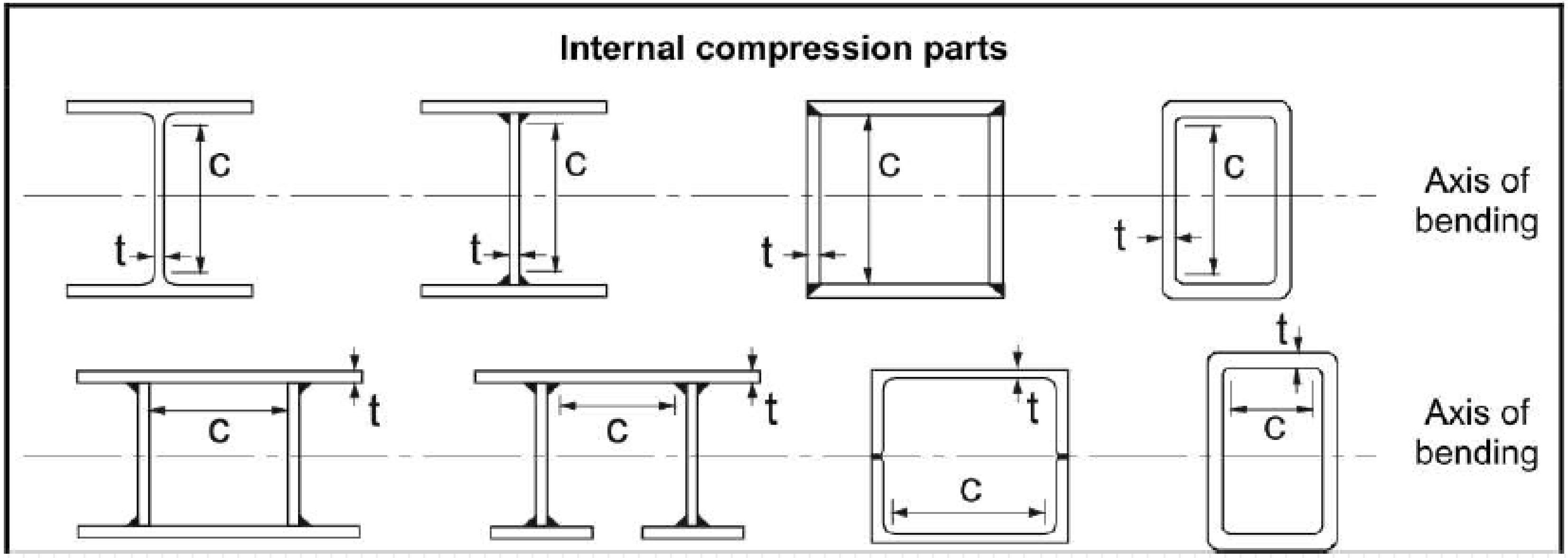
$$= 459.7 \text{ kN}$$

and so for both angles
$2N_{cr,min} = 2 \times 459.7 = 919\text{kN} < 1520\text{kN}$.

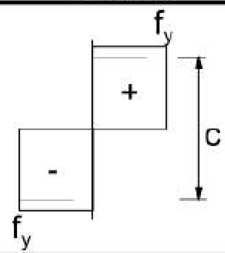
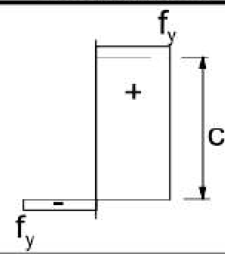
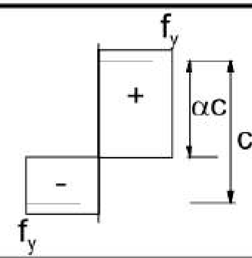
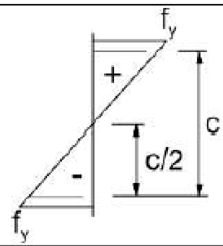
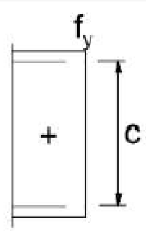
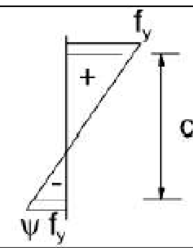
The lowest buckling load of 919 kN corresponds to the case where each unequal angle buckles about its own minimum axis.

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 $\alpha > 0{,}5: \; c/t \le \frac{396\varepsilon}{13\alpha - 1}$ when $\alpha \le 0{,}5: \; c/t \le \frac{36\varepsilon}{\alpha}$
2	$c/t \le 83\varepsilon$	$c/t \le 38\varepsilon$	when $\alpha > 0{,}5: \; c/t \le \frac{456\varepsilon}{13\alpha - 1}$ 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 $\psi > -1: \; c/t \le \frac{42\varepsilon}{0{,}67 + 0{,}33\psi}$ when $\psi \le -1^{*)}: \; c/t \le 62\varepsilon(1-\psi)\sqrt{(-\psi)}$

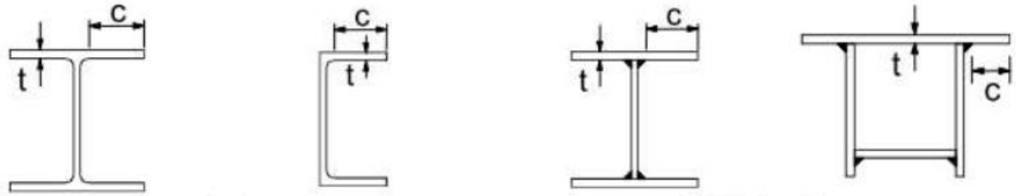
$\varepsilon = \sqrt{235/f_y}$	f_y	235	275	355	420	460
	ε	1,00	0,92	0,81	0,75	0,71

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

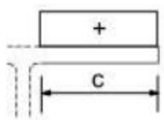
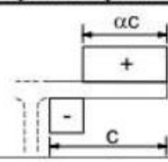
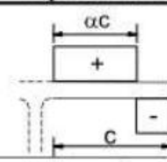
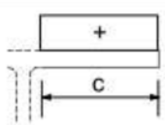
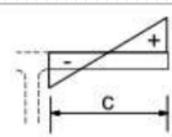
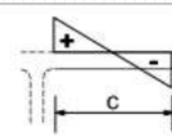
Classification of Cross-sections تصنيف المقاطع العرضية

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

Outstand flanges



Rolled sections — Welded sections

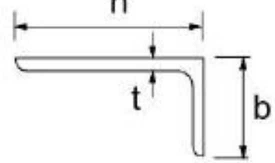
Class	Part subject to compression	Part subject to bending and compression: Tip in compression	Part subject to bending and compression: Tip in tension
Stress distribution in parts (compression positive)			
1	$c/t \le 9\varepsilon$	$c/t \le \dfrac{9\varepsilon}{\alpha}$	$c/t \le \dfrac{9\varepsilon}{\alpha\sqrt{\alpha}}$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

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

Classification of Cross-sections تصنيف المقاطع العرضية

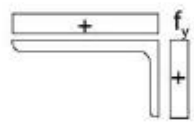
Table 5.2 (sheet 3 of 3): Maximum width-to-thickness ratios for compression parts

Angles

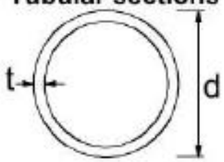


Refer also to "Outstand flanges" (see sheet 2 of 3)

Does not apply to angles in continuous contact with other components

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

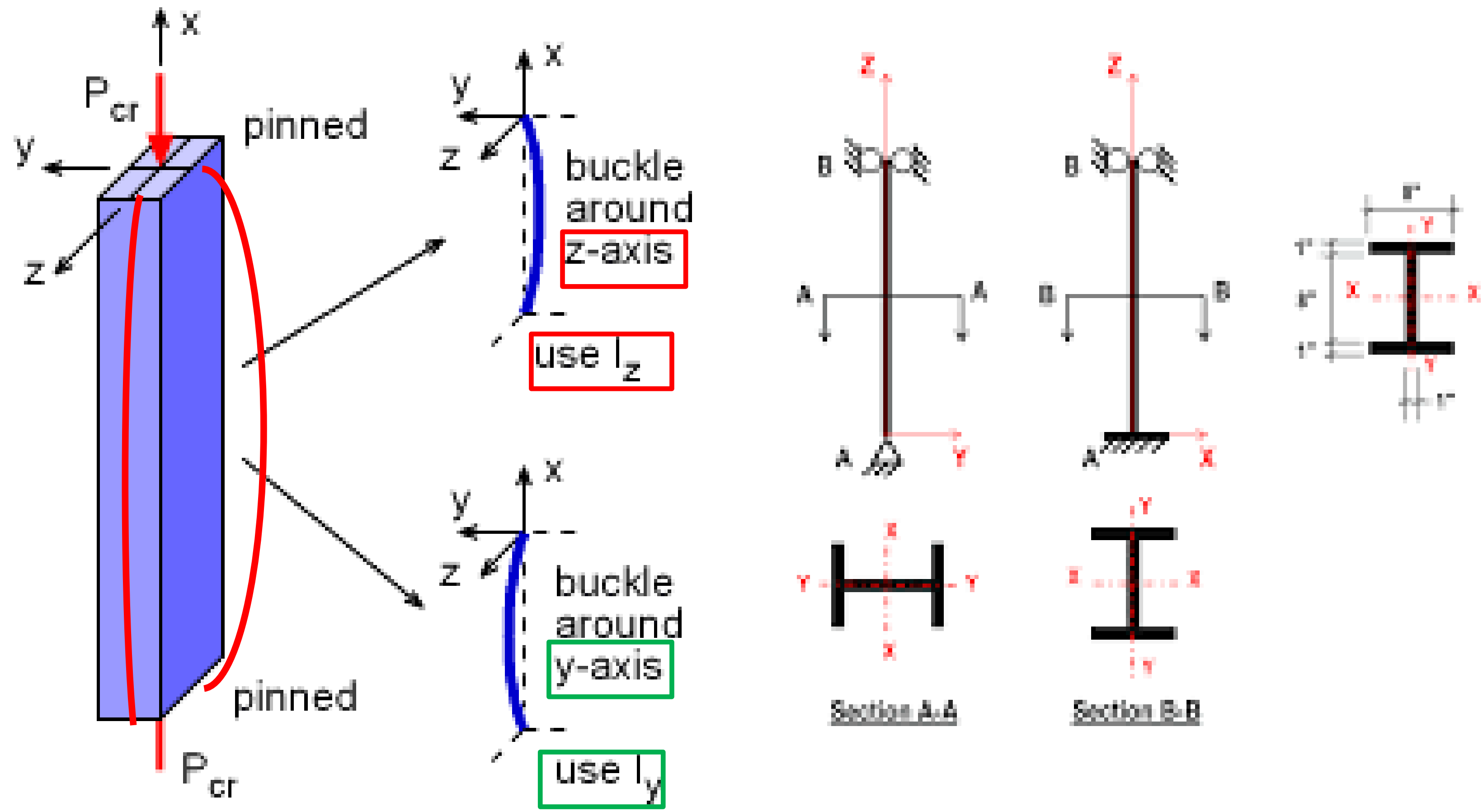
Tubular sections



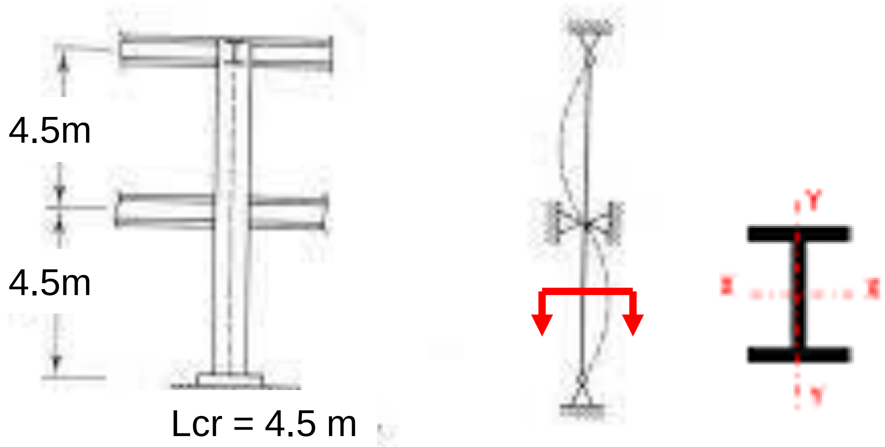
Class	Section in bending and/or compression
1	$d/t \le 50\varepsilon^2$
2	$d/t \le 70\varepsilon^2$
3	$d/t \le 90\varepsilon^2$ NOTE For $d/t > 90\varepsilon^2$ see EN 1993-1-6.

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

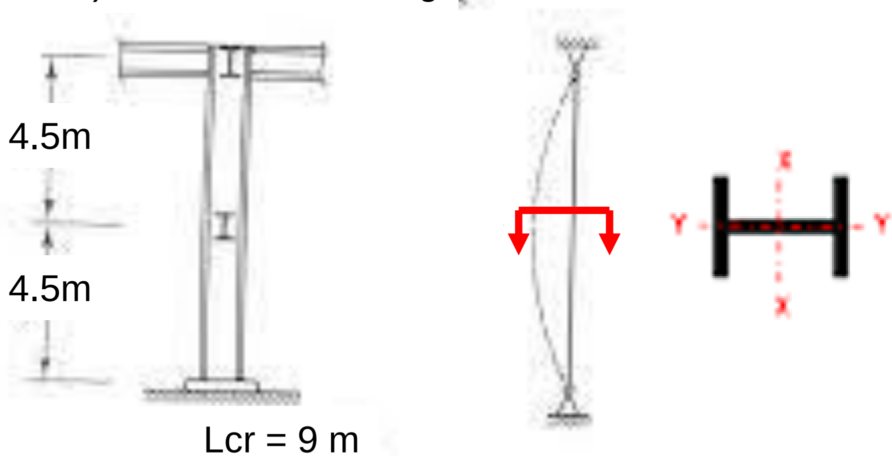
Plane Of buckling مستويات التحنيب



Plane Of buckling مستويات التحنيب

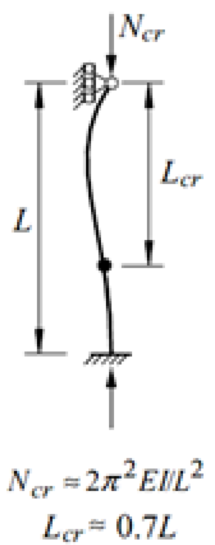


a) Minor Axis Buckling

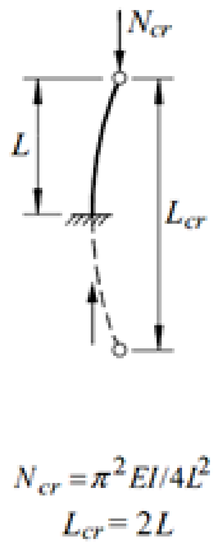


b) Major Axis Buckling

Plane Of buckling مستويات التحنيب



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



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