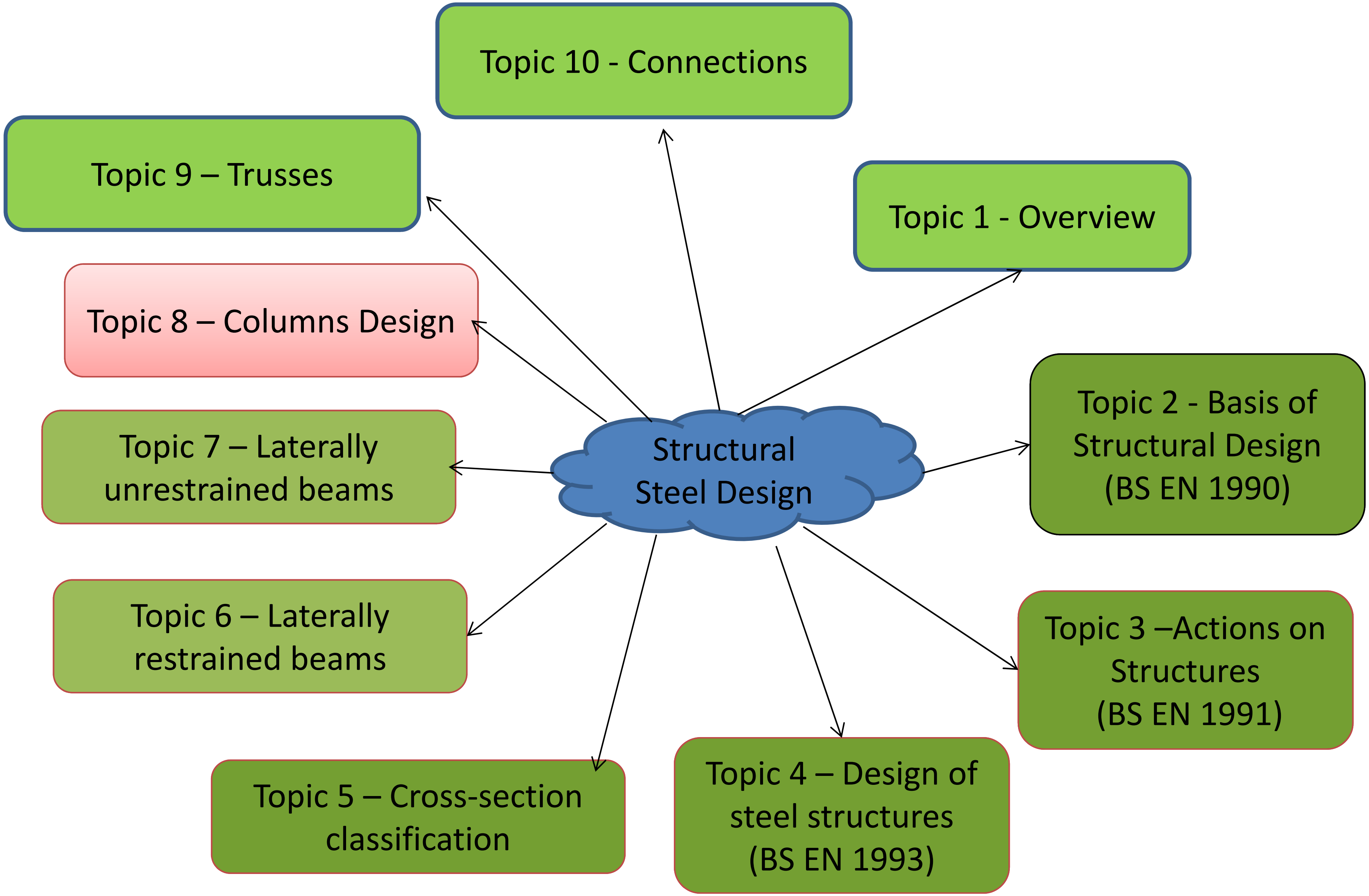
Structural Steel and Timber Design SAB3233

Topic 8
Columns Design

Prof Dr Shahrin Mohammad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Structural Steel Design
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Columns subjected to axial load

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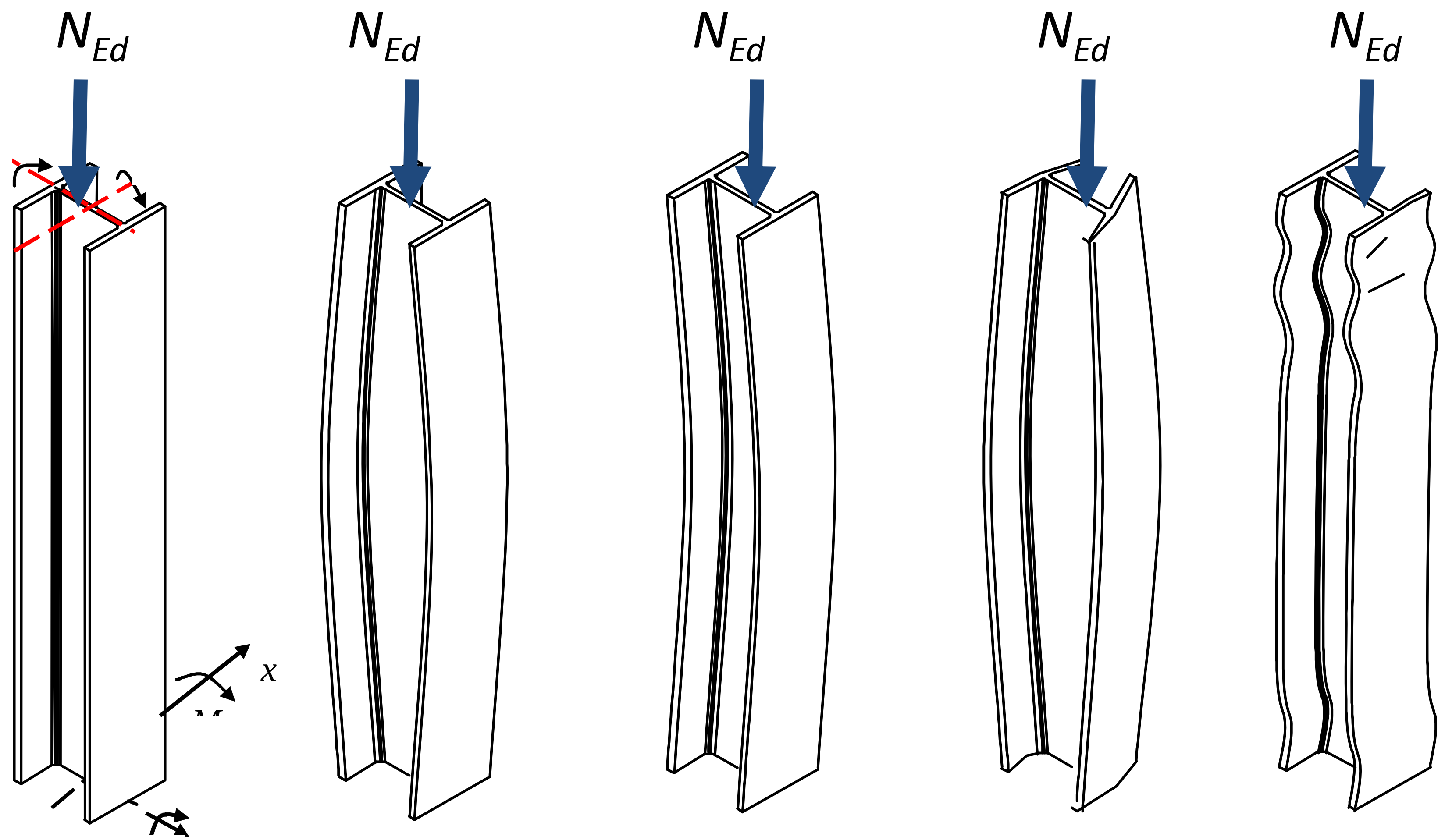


Squashing, normally occurs in short column

Overall flexural buckling

Torsional buckling

Local buckling

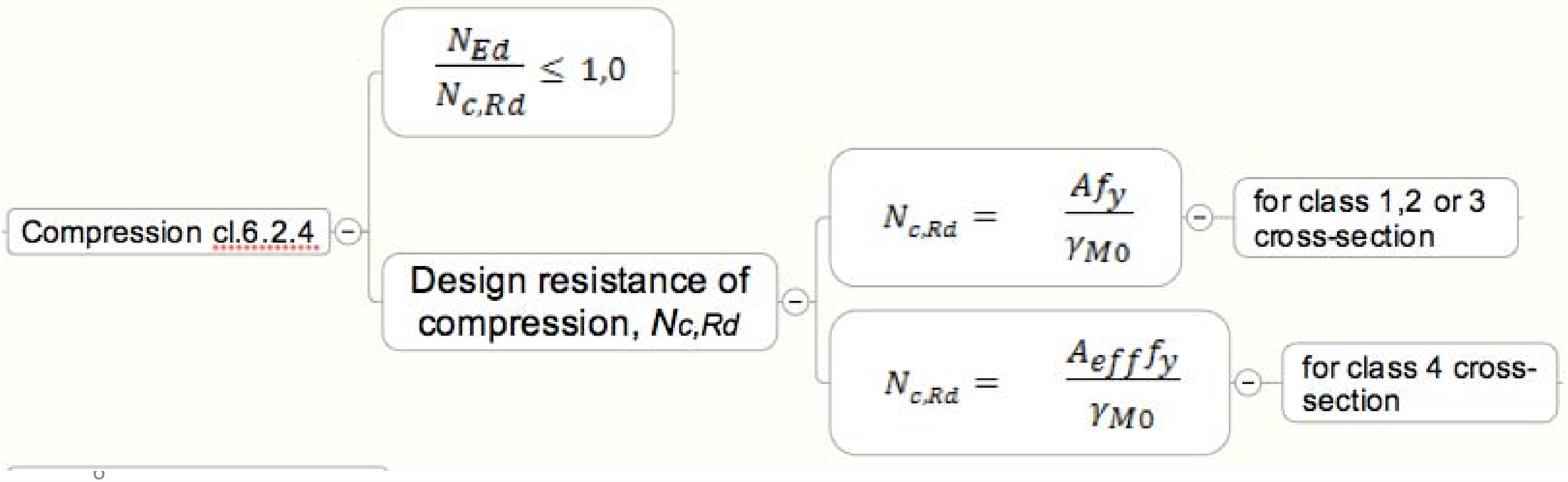
N_{Ed} = *Design value of compression force*

- compression members subject to
  - axial compression only
  - no bending
- however in practically real columns are subject to
  - eccentricities of axial loads
  - transverse forces
- the treatment distinguishes between
  - stocky columns, and
  - slender columns

Stocky columns

- The characteristics of stocky columns are
  - very low slenderness
  - unaffected by overall buckling

- The compressive strength of stocky columns is
  - dictated by the cross-section
  - a function of the section classification

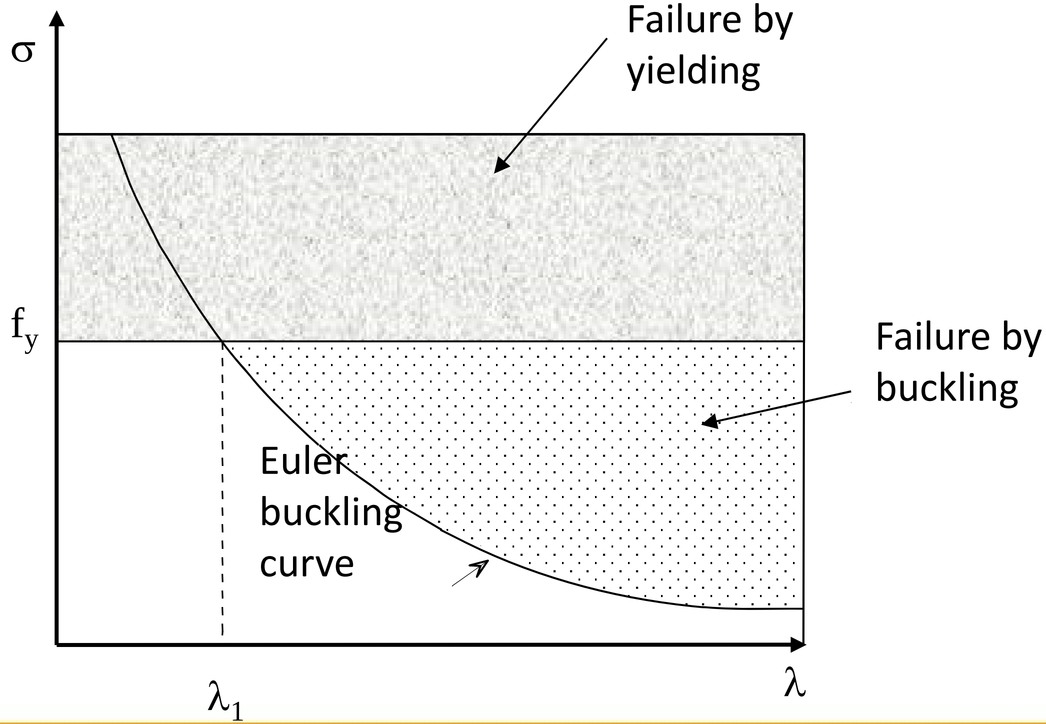


Slender Steel Columns

- Slender columns present a quasi elastic buckling behaviour
- Euler critical stress $\sigma_{cr} = \dfrac{\pi^2 E}{\lambda^2}$

$\lambda = L_{cr} / r$, where r is radius of gyration
L_{cr} is the buckling length

Euler buckling curve and modes of failure



Behaviour of real steel columns

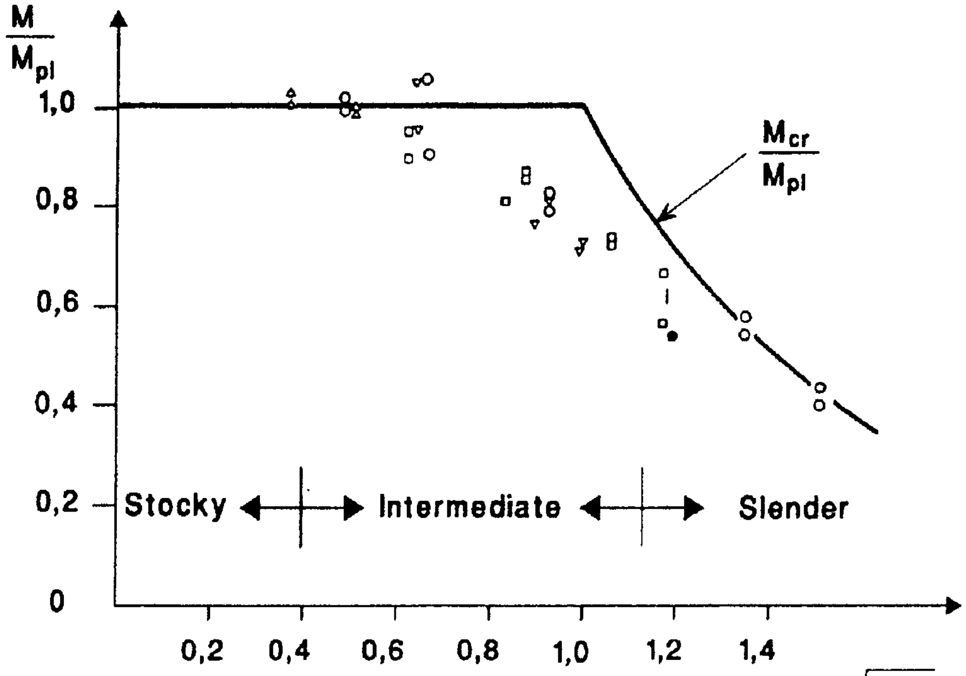
- columns of medium slenderness are very sensitive to the effects of imperfections
- inelastic buckling occurs before the Euler buckling load due to various imperfections
  - initial out-of-straightness
  - residual stresses
  - eccentricity of axial applied loads
  - strain-hardening

Effects of imperfections

- structural imperfections most important for intermediated columns

- this represents most practical columns

- lower bound curve is obtained from a statistical analysis of test results

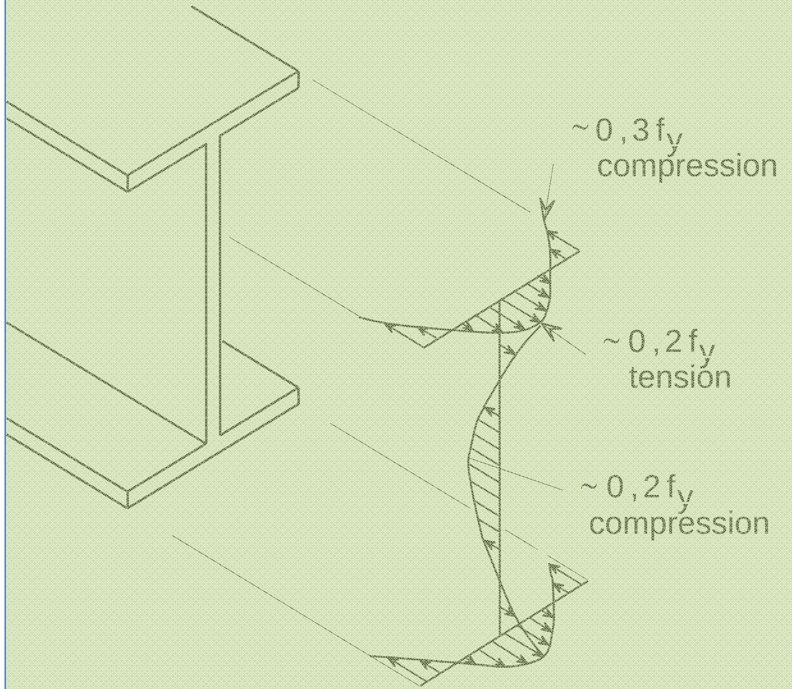


(b) Comparison of test data with M_{cr} using a non-dimensional form of plot $\bar{\lambda}_{LT} = \sqrt{\frac{M_{pl}}{M_{cr}}}$

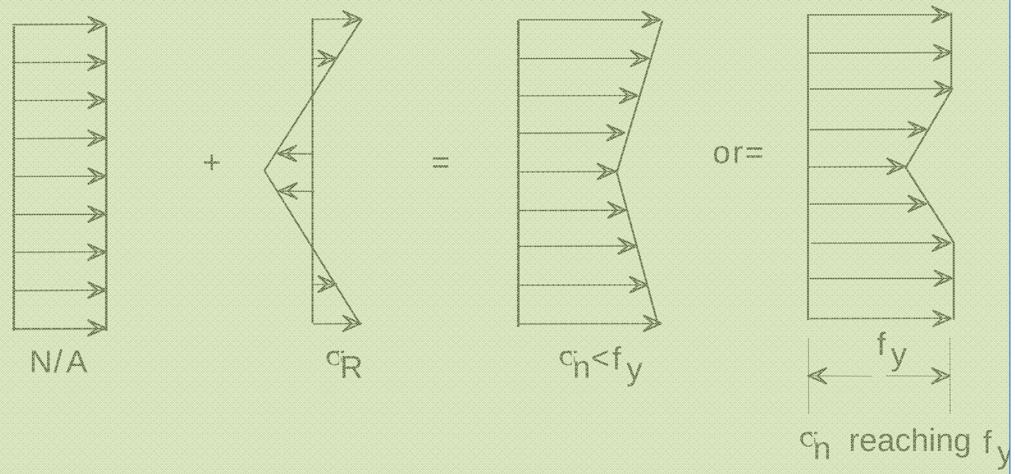
Effect of imperfections in relation to slenderness

- Slender column
  - largely unaffected by imperfections
  - ultimate failure load ≈ Euler load (N_{cr})
  - independent of the yield stress
- Intermmediate column
  - imperfections important
  - failure load less than Euler load
  - out-of-straightness and residual stresses are the most significant imperfections

Residual stresses patterns



Typical residual stress pattern

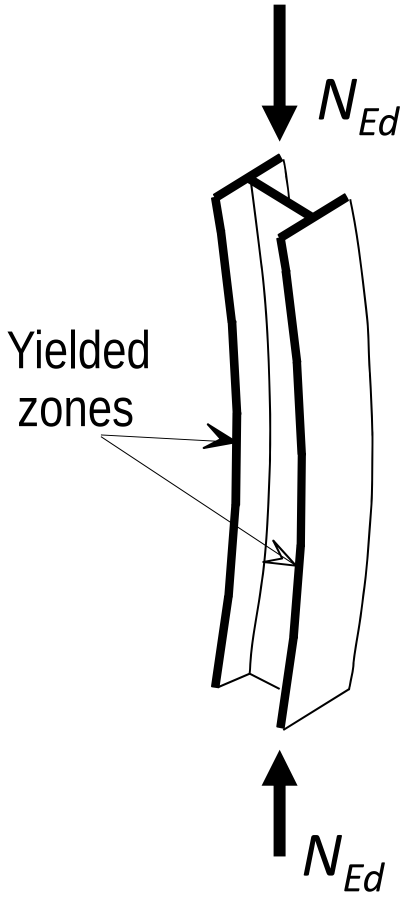


Combination with axial stresses

- combined with axial stresses cause yielding
- effective area reduced

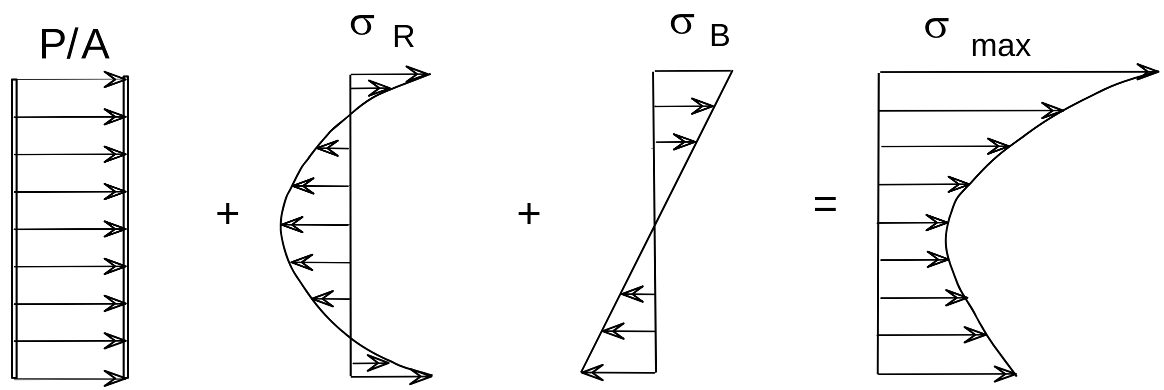
Initial out-of-straightness

- induces bending moments



Combined effect of imperfections and axial load

- bending stress σ_B
- residual stress, σ_R
- applied axial stress, N_{Ed}/A



Buckling resistance in axial compression

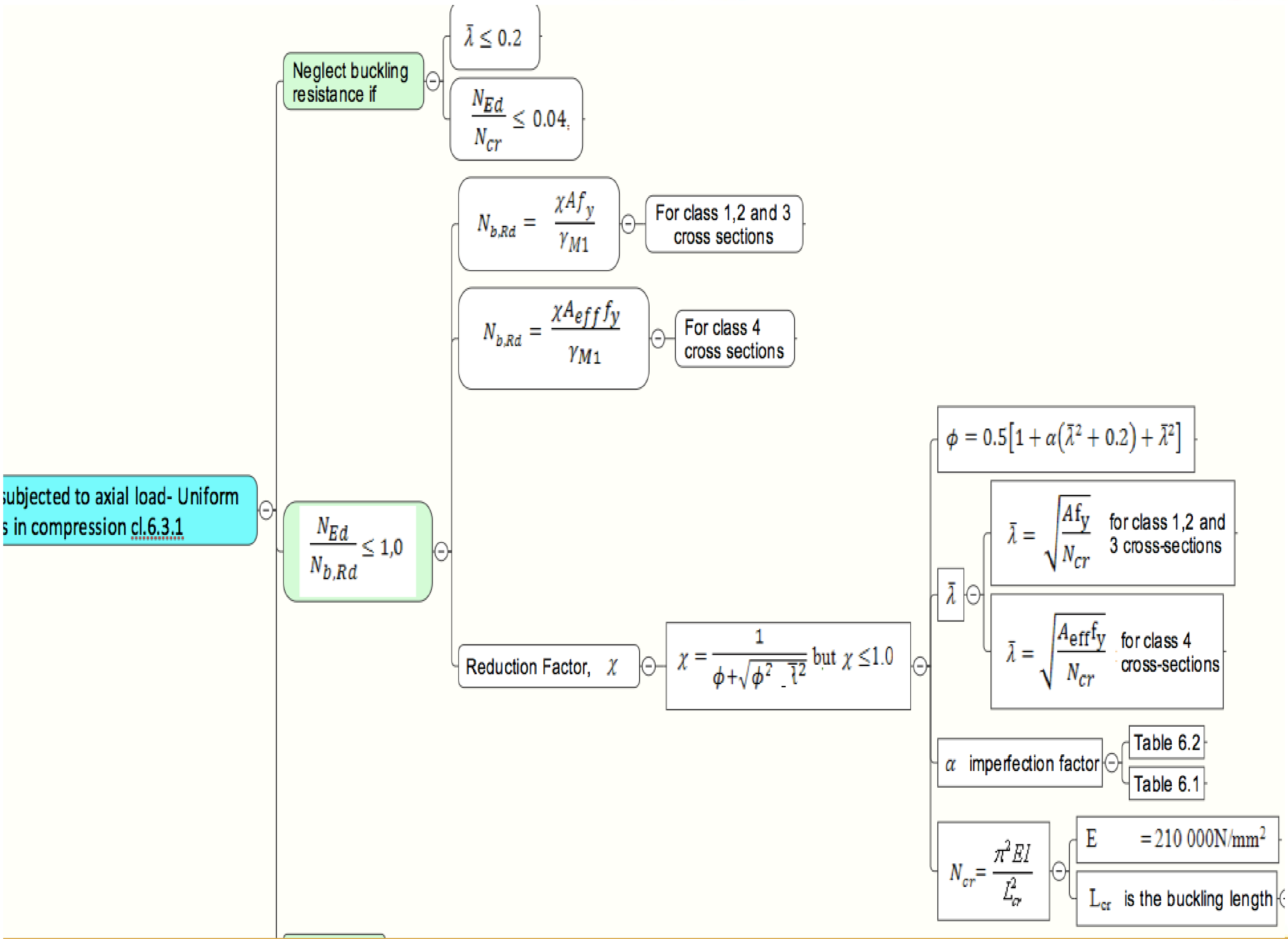
The design buckling resistance of a compression member

for Class 1, 2 and 3 cross section $$N_{b.Rd} = \chi \frac{Af_y}{\gamma_{M1}}$$

for Class 4 cross section $$N_{b.Rd} = \chi \frac{A_{eff} f_y}{\gamma_{M1}}$$

where χ a reduction factor and is related to the reference slenderness

Buckling curves plotted as χ versus reference slenderness ratio


subjected to axial load- Uniform
s in compression cl.6.3.1
Neglect buckling resistance if
$\bar{\lambda} \leq 0.2$
$\frac{N_{Ed}}{N_{cr}} \leq 0.04$
$\frac{N_{Ed}}{N_{b,Rd}} \leq 1,0$
$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}$
For class 1,2 and 3 cross sections
$N_{b,Rd} = \frac{\chi A_{eff} f_y}{\gamma_{M1}}$
For class 4 cross sections
Reduction Factor, χ
$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}}$ but $\chi \leq 1.0$
$\phi = 0.5[1 + \alpha(\bar{\lambda}^2 + 0.2) + \bar{\lambda}^2]$
$\bar{\lambda}$
$\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}}$ for class 1,2 and 3 cross-sections
$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}}$ for class 4 cross-sections
α imperfection factor
Table 6.2
Table 6.1
$N_{cr} = \frac{\pi^2 EI}{L_{cr}^2}$
E = 210 000N/mm^2
L_{cr} is the buckling length

European buckling curves (Cl 6.3.1.2)

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \quad \text{but } \chi \leq 1{,}0$$

where $\Phi = 0{,}5\left[1 + \alpha\left(\bar{\lambda} - 0{,}2\right) + \bar{\lambda}^2\right]$

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

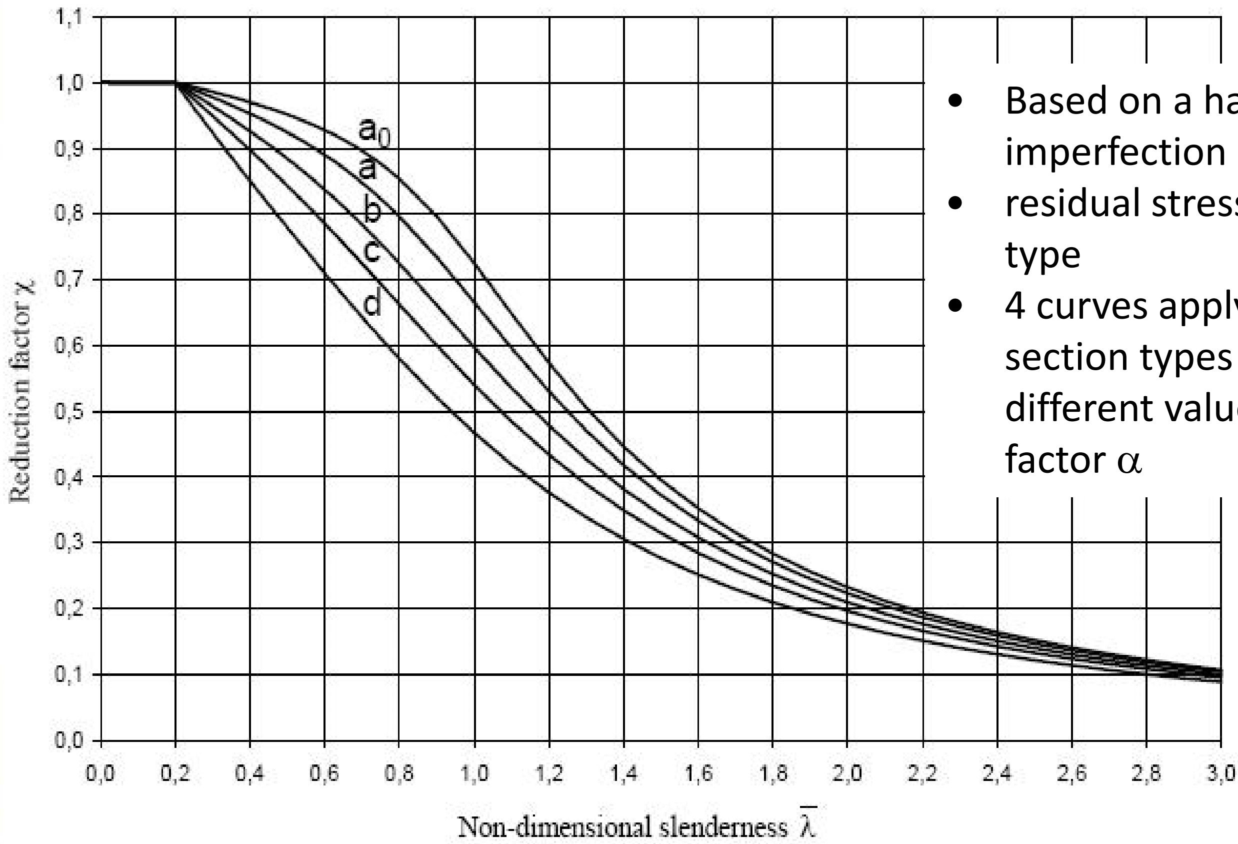
$$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} \quad \text{for Class 4 cross-sections}$$

α is an imperfection factor

N_{cr} is the elastic critical force for the relevant buckling mode based on the gross cross sectional properties.

European buckling curves

Based on experiment more than 1000 tests section
Range of slenderness ratios between 55 and 160



- Based on a half sine-wave geometric imperfection = L/1000
- residual stresses related to section type
- 4 curves apply to different cross-section types corresponding to different values of the imperfection factor α

Imperfection factor α

- α depends on
  - the shape of the column cross-section
  - the direction of buckling (y or z axis)
  - the fabrication process (hot-rolled, welded or cold-formed
- imperfection factors given in *Table 6.1*

Table 6.1: Imperfection factors for buckling curves

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

Non dimensional slenderness, $\bar{\lambda}$

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1} \quad \text{for Class 1, 2 and 3 cross-sections}$$

$$\bar{\lambda} = \sqrt{\frac{A_{eff} f_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{\sqrt{\frac{A_{eff}}{A}}}{\lambda_1} \quad \text{for Class 4 cross-sections}$$

where L_{cr} is the buckling length in the buckling plane considered

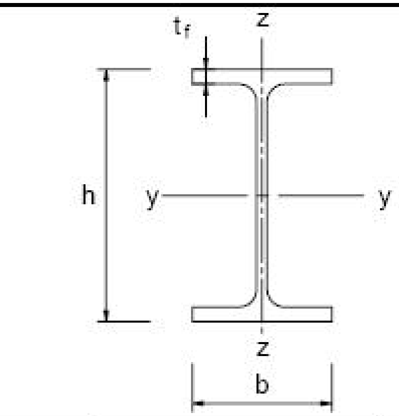
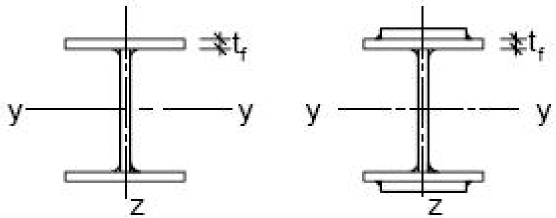
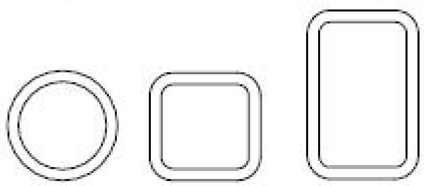
i is the radius of gyration about the relevant axis, determined using the properties of the gross cross-section

$$\lambda_1 = \pi\sqrt{\frac{E}{f_y}} = 93{,}9\varepsilon$$

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

Selection of appropriate buckling curve

Table 6.2 helps with the selection of the appropriate buckling curve

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	$t_f \le 40$ mm	y – y z – z	a b	a_0 a_0
			40 mm < $t_f \le 100$	y – y z – z	b c	a a
		h/b ≤ 1,2	$t_f \le 100$ mm	y – y z – z	b c	a a
			$t_f > 100$ mm	y – y z – z	d d	c c
Welded I-sections		$t_f \le 40$ 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

Example 1 : Design of an axially loaded column