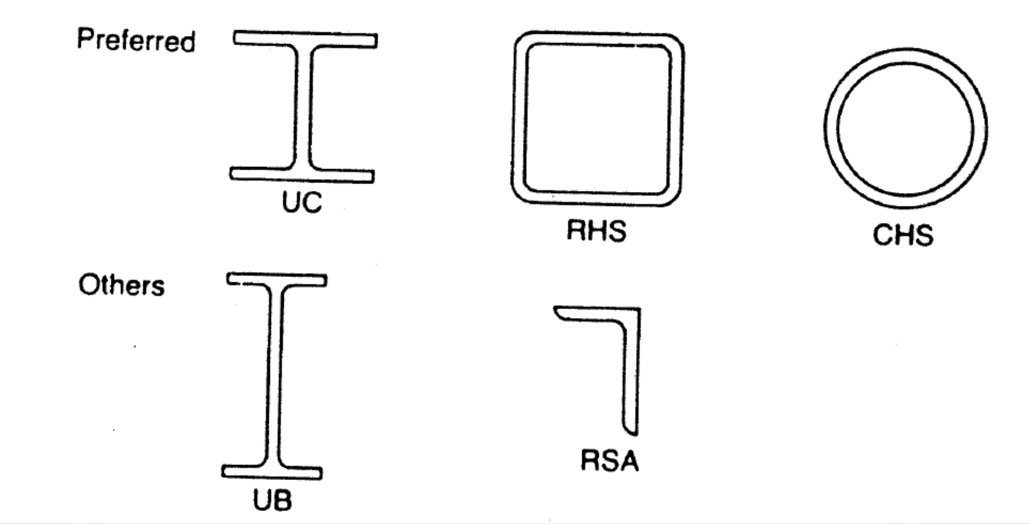
COLUMN DESIGN

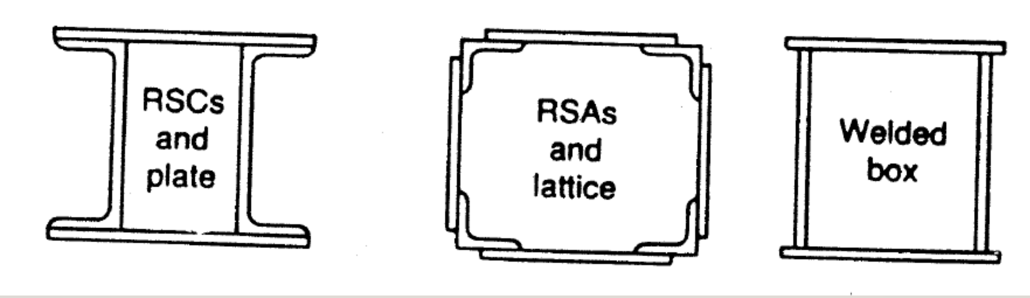
AXIALLY LOADED COLUMNS

TYPICAL COMPRESSION MEMBER SECTION

COLUMN CROSS-SECTIONS



COMPOUND SECTIONS



LIMITING WIDTH TO THICKNESS RATIOS (BASED ON TABLE 5.2. EC3)

TYPE OF ELEMENT (ALL ROLLED SECTIONS)	CLASS OF SECTION		
	(1)	(2)	(3)
OUTSTAND ELEMENT OF COMPRESSION FLANGE	$c/t \leq 9\varepsilon$	$c/t \leq 10\varepsilon$	$c/t \leq 14\varepsilon$
WEB WITH NEUTRAL AXIS AT MID-DEPTH	$c/t \leq 72\varepsilon$	$c/t \leq 83\varepsilon$	$c/t \leq 124\varepsilon$
WEB WHERE THE WHOLE CROSS-SECTION IS SUBJECT TO AXIAL COMPRESSION ONLY	$c/t \leq 33\varepsilon$	$c/t \leq 38\varepsilon$	$c/t \leq 42\varepsilon$
NOTE, $\varepsilon = (235/f_y)^{1/2}$			

CLASSIFICATION

COLUMN CROSS-SECTIONS CAN BE CLASSIFIED AS

- **CLASS 1**
- **CLASS 2**
- **CLASS 3**
- **CLASS 4**

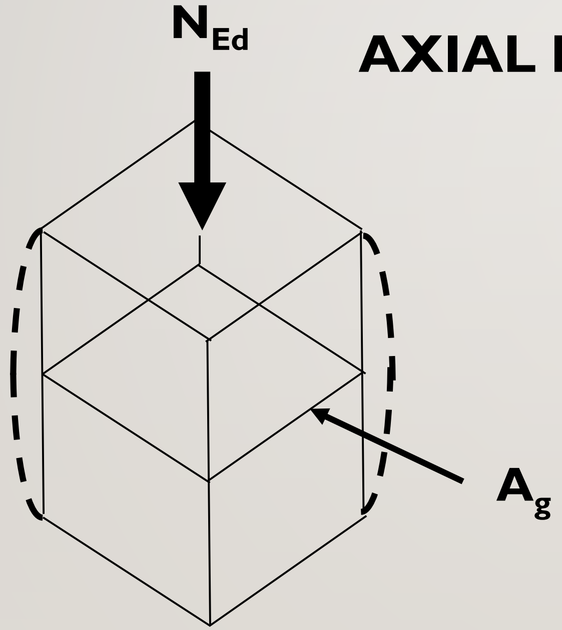
SUITABLE

FAILURE MECHANISMS

THERE ARE TWO PRINCIPAL MODES OF COLUMN FAILURE:

- CRUSHING – SHORT
- BUCKLING - SLENDER

SHORT COLUMNS

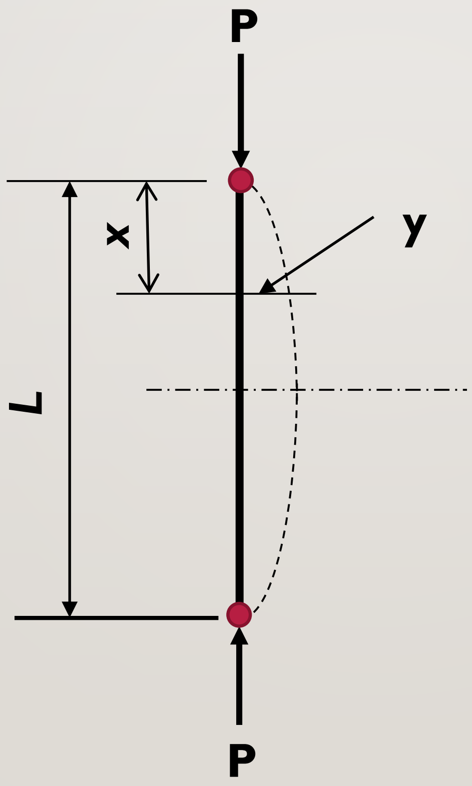


AXIAL RESISTANCE, $N_{Rd} = f_y A_g$

YIELD STRENGTH

SLENDER COLUMN

CONSIDER A PIN-ENDED, STRAIGHT COLUMN SUPPORTING AN AXIAL COMPRESSIVE LOAD P



SLENDER COLUMN (CONT'D)

IF THE COLUMN IS GIVEN A SMALL DEFLECTION *y*, THE BENDING MOMENT, *M*, AT A DISTANCE, *x*, FROM THE TOP OF THE COLUMN IS

$$M = EI\frac{d^2y}{dx^2} = -Py$$

HENCE

$$\frac{d^2y}{dx^2} + \frac{Py}{EI} = 0$$

THE SOLUTION OF THIS DIFFERENTIAL EQUATION IS:

$$y = A\,sin\left(\frac{P}{EI}\right)^{½} x + B\,cos\left(\frac{P}{EI}\right)^{½} x$$

WHERE A AND B ARE INTEGRATION CONSTANTS. THE BOUNDARY CONDITIONS ARE:

(a) y = 0 at *x* = 0

(b) y = 0 at *x* = L

SLENDER COLUMN (CONT'D)

FROM (a), $B = 0$ AND $y = A \sin\left(\frac{P}{EI}\right)^{½} x$

AND FROM (b), $0 = A \sin\left(\frac{P}{EI}\right)^{½} L$

THEN EITHER $A = 0$ or $\left(\frac{P}{EI}\right)^{½} L = n\pi$ (where $n = 0, 1, 2$ etc)

If A = 0 OR THE INTEGER *n* = 0 THEN THE COLUMN REMAINS STRAIGHT. IF *n* IS TAKEN AS 1, THEN:

$$P = \frac{\pi^2 EI}{L^2} \quad ------(2)$$

AND THE COLUMN DEFLECTION FORM IS A HALF SINE CURVE. THE VALUE OF *P* GIVEN BY EQUATION (2) IS THE LOWEST CRITICAL LOAD FOR BUCKLING FAILURE FOR A PIN-ENDED STRAIGHT COLUMN AND IS COMMONLY REFERRED TO AS THE EULER BUCKLING LOAD, P_E, WHERE

$$P_E = \frac{\pi^2 EI}{L^2} \quad ------(3)$$

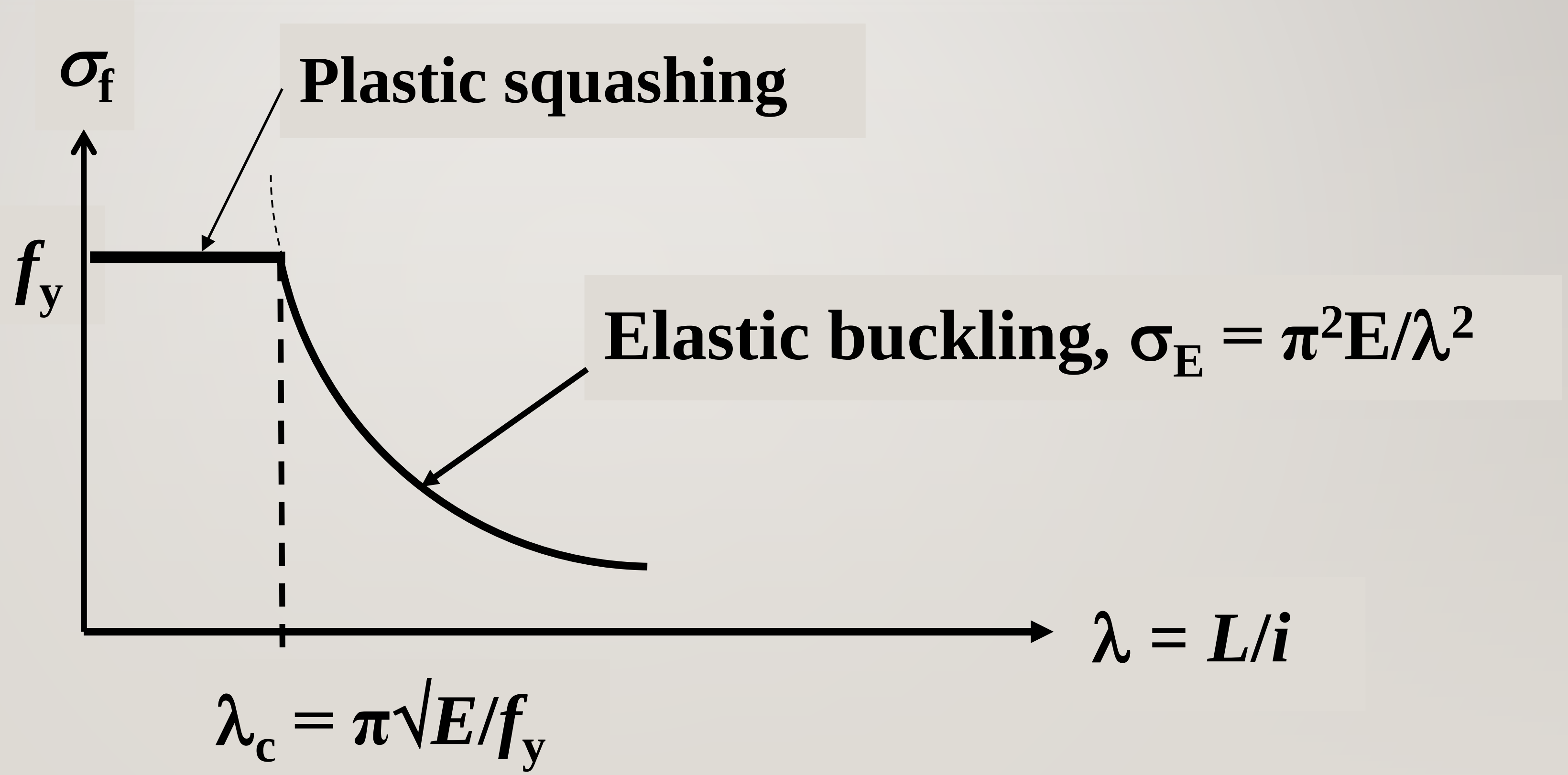
LOAD CAPACITY OF SLENDER COLUMNS

$$P_E = \frac{\pi^2 EI}{L^2} = \frac{\pi^2 E A_g i^2}{L^2} = \frac{\pi^2 E A_g}{\lambda^2}$$

$$\text{SINCE } \mathrm{i} = \sqrt{\frac{I}{A}} \quad \text{AND } \lambda = \frac{L}{i}$$

A USEFUL PLOT, BOTH FOR UNDERSTANDING THE RELATIONSHIP BETWEEN THESE TWO FAILURE MECHANISMS I.E. PLASTIC SQUASH AND ELASTIC BUCKLING AS WELL AS FOR DESIGN CALCULTIONS IS ONE OF MEAN COMPRESSIVE STRESS AT FAILURE AGAINST SLENDERNESS RATIO AS SHOWN BELOW.

PERFECT COLUMN BEHAVIOUR



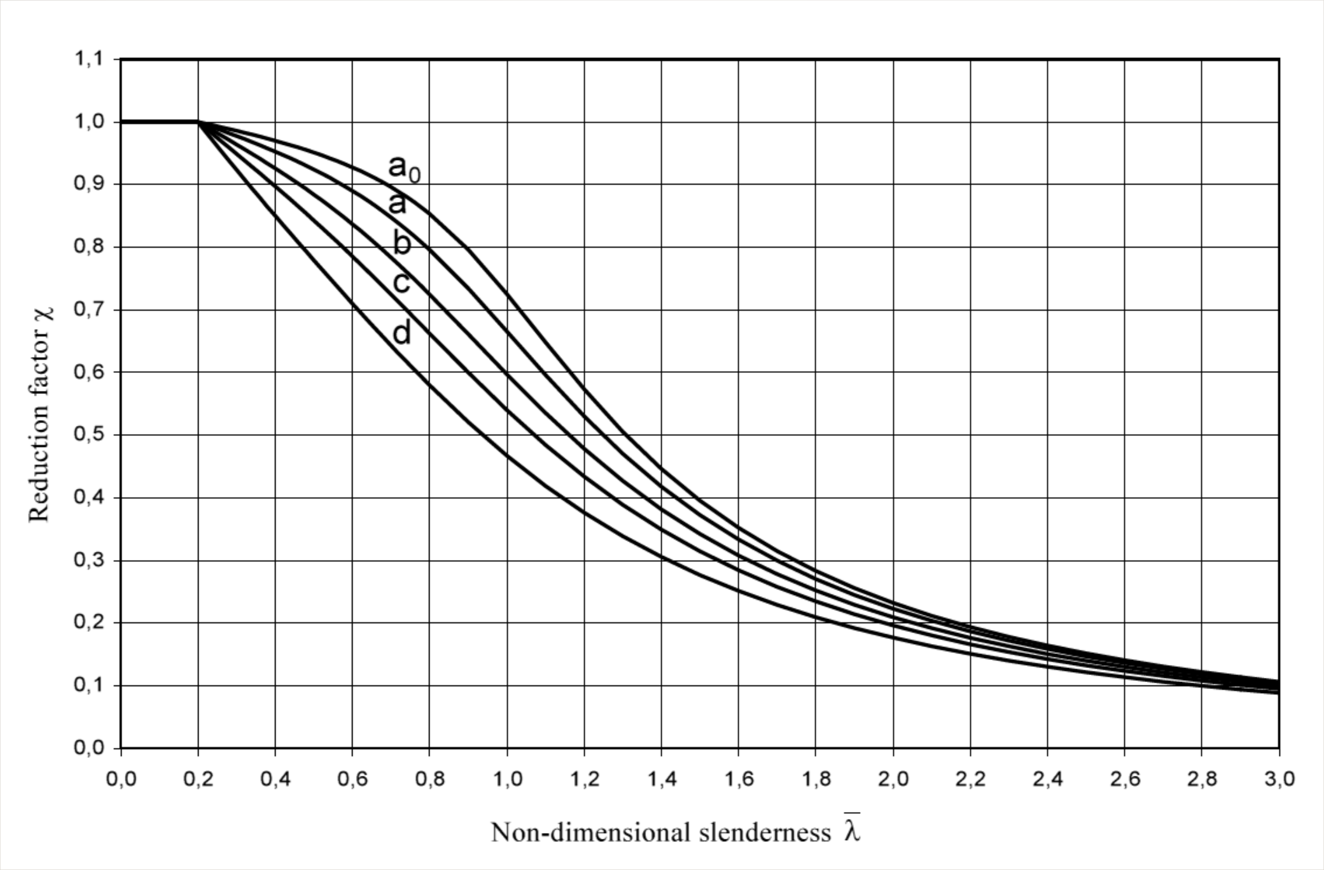
ACTUAL COLUMN BEHAVIOUR

THE ABOVE PLOT CANNOT BE USED FOR DESIGN SINCE, IN PRACTICE

- **COLUMNS ARE NOT PERFECTLY STRAIGHT**
- **LOADS ARE NOT APPLIED CONCENTRICALLY**
- **RESIDUAL STRESS OCCUR IN COLUMN SECTIONS.**

THE EFFECT OF EACH OF THESE FACTORS (IMPERFECTIONS) IS TO REDUCE THE CAPACITY OF THE SECTION. THE ACTUAL BUCKLING BEHAVIOUR OF AXIALLY LOADED COLUMNS IS SHOWN IN FIG. 6.4 OF EC3.

DESIGN BUCKLING CURVES: FIG 6.4, EC3



EC3 USES THE NON-DIMENSIONAL SLENDERNESS RATIO TO DETERMINE THE FAILURE STRESS OF STRUTS WHEREAS BS5950 USES THE SLENDERNESS RATIO, λ, DEFINED AS

$$\lambda = \frac{L_E}{r}$$

S/S

λ	Steel grade and design strength p_y (N/mm²)									
	S275					S355				
	235	245	255	265	275	315	325	335	345	355
15	235	245	255	265	275	315	325	335	345	355
20	234	243	253	263	272	310	320	330	339	349
25	229	239	248	258	267	304	314	323	332	342
30	225	234	243	253	262	298	307	316	325	335
35	220	229	238	247	256	291	300	309	318	327
40	216	224	233	241	250	284	293	301	310	318

NON-DIMENSIONAL SLENDERNESS RATIO

NON-DIMENSIONAL SLENDERNESS RATIO, $\bar{\lambda}$, IS GIVEN BY

$$\bar{\lambda} = \sqrt{\frac{Af_y}{N_{cr}}} = \frac{L_{cr}}{i}\frac{1}{\lambda_1} \text{ FOR CLASSES } 1, 2 \; and \; 3 \text{ CROSS} - \text{SECTIONS}$$

WHERE

***L*$_{cr}$** **IS THE BUCKLING LENGTH**

i **IS THE RADIUS OF GYRATION**

$$\lambda_1 = \pi\sqrt{\frac{E}{f_y}} = 93\epsilon$$

$$\epsilon = \sqrt{\frac{235}{f_y}}$$

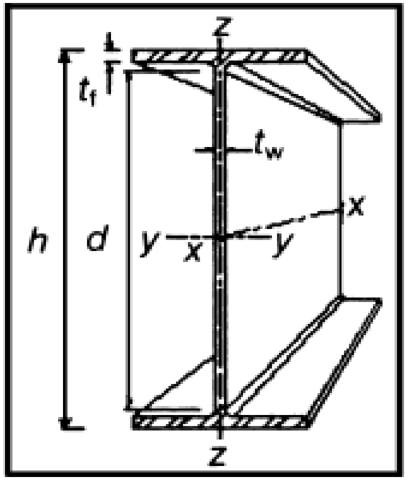
EFFECTIVE LENGTH (TABLE 22, BS5950)

a) non-sway mode

Restraint (in the plane under consideration) by other parts of the structure		L_E
Effectively held in position at both ends	Effectively restrained in direction at both ends (1)	$0.7L$
	Partially restrained in direction at both ends (2)	$0.85L$
	Restrained in direction at one end (3)	$0.85L$
	Not restrained in direction at either end (4)	$1.0L$

SELECTION OF BUCKLING CURVE (TABLE 6.2, EC3)

Cross-section	*Limits*	*Buckling about axis*	*Buckling curve*
Rolled sections	$h/b > 1.2$		
	$t_f \leq 40$ mm	y–y	*a*
		z–z	*b*
	$40 \text{ mm} < t_f \leq 100$ mm	y–y	*b*
		z–z	*c*
	$h/b \leq 1.2$		
	$t_f \leq 100$ mm	y–y	*b*
		z–z	*c*
	$t_f > 100$ mm	y–y	*d*
		z–z	*d*



BUCKLING RESISTANCE OF COLUMNS

THE DESIGN BUCKLING RESISTANCE OF CLASSES 1, 2 AND 3 CROSS-SECTIONS IS GIVEN BY

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}}$$

WHERE

$$\chi = \frac{1}{\phi + \left(\phi^2 - \bar{\lambda}^2\right)^{0.5}} \leq 1$$

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

IMPERFECTION FACTOR, α, FOR BUCKLING CURVES

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

DESIGN PROCEDURE

1. **SELECT STEEL GRADE AND SECTION**
2. **DETERMINE DESIGN STRENGTH OF SECTION, f_y, VIA TABLE 7 OF EN 10025-2**
3. **DETERMINE EFFECTIVE LENGTH OF COLUMN, L_{cr} , VIA TABLE 22 OF BS5950**
4. **CALCULATE NON-DIMENSIONAL SLENDERNESS RATIO, $\bar{\lambda}$, FOR APPROPRIATE AXIS**
5. **SELECT APPROPRIATE BUCKLING CURVE (a_o, a, b, c, d) VIA TABLE 6.2 OF EC3**
6. **DETERMINE REDUCTION FACTOR, χ**
7. **CALCULATE DESIGN BUCKLING RESISTANCE OF COLUMN, $N_{b,Rd}$, USING**

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

8. **CHECK $N_{b,Rd} > N_{Ed}$. IF NOT RETURN TO (1)**