



# Eurocodes

Background and Applications

## Design of **Steel Buildings** with worked examples



16-17 October 2014  
Brussels, Belgium

### Organised and supported by

European Commission

DG Enterprise and Industry  
Joint Research Centre

European Convention for Constructional Steelwork

European Committee for Standardization

CEN/TC250/SC3

## Basis of Design, a case study building

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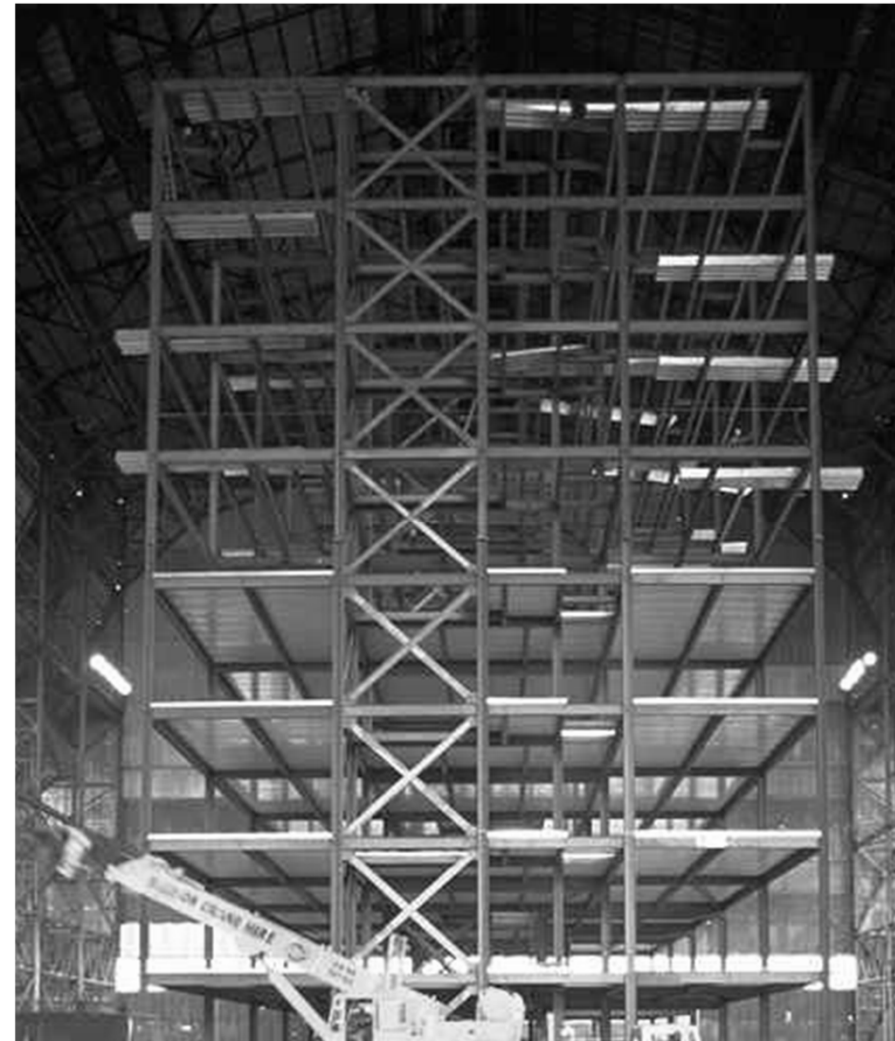
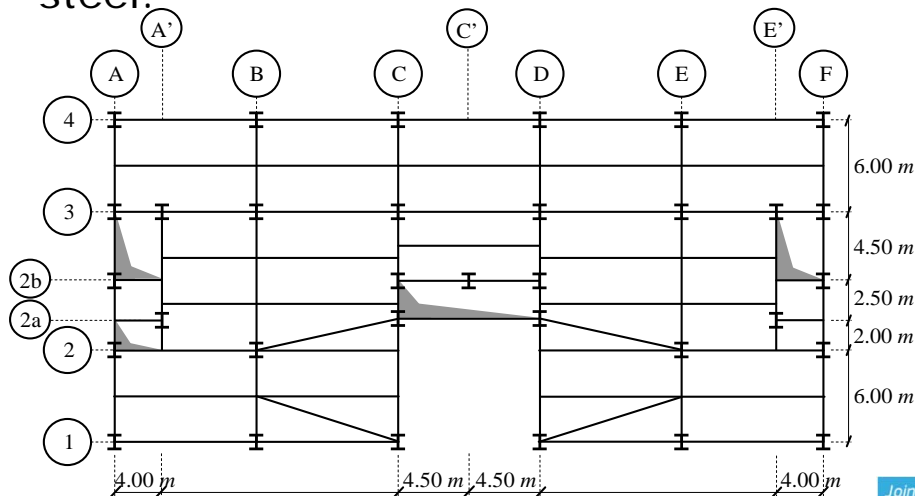
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- ✓ Definitions and basis of design
- ✓ Global analysis
  - Structural modeling
  - Structural analysis
  - Case study: building
- ✓ Classification of cross-sections

# Case-study building

## Cardington Building, UK

Total area of 21 m by 45 m and total height of 33 m (8 storeys). 5 bays, each 9 m long by 3 bays of 6 m, 9 m and 6 m. The height of the first storey is 4.335 m from the ground floor to the top-of-steel height. All the other storeys have a height of 4.135 m from top-of-steel to top-of-steel.



Building – master example (Cardington - UK)

# Global Analysis: case-study building

## Geometric Characteristics of Steel Members

Beams	Cross-section	Steel grade
A1 – F1, A4 – F4	IPE 400	S 355
A1 – A4, B1 – B2, B3 – B4, C2a – C4, D2a – D4, E1 – E2, E3 – E4, F1 – F4	IPE 400	S 355
C1 – C2a, D1 – D2a	IPE 600	S 355
B2 – B3, E2 – E3	IPE 600	S 355
A2 – B2, A2a – A'2a, A2b – A'2b, A3 – A'3, A'2 – A'3	IPE 400	S 355
E'2a – E'3, E'2b – F2b, E'3 – F3	IPE 400	S 355
C2a – D2a, C2b – D2b, C3 – D3	IPE 400	S 355
All others secondary beams	IPE 360	S 355

**Geometric characteristics of the beams  
(1<sup>st</sup> floor)**

Beams	Cross-section	Steel grade
A1 – F1, A4 – F4	IPE 400	S 355
A1 – A4, B1 – B2, B3 – B4, C1 – C4, D1 – D4, E1 – E2, E3 – E4, F1 – F4	IPE 400	S 355
B2 – B3, E2 – E3	IPE 600	S 355
A2 – B2, A2a – A'2a, A2b – A'2b, A3 – A'3, A'2 – A'3	IPE 400	S 355
E'2a – E'3, E'2b – F2b, E'3 – F3	IPE 400	S 355
C2a – D2a, C2b – D2b, C3 – D3	IPE 400	S 355
All others secondary beams	IPE 360	S 355

**Geometric characteristics of the beams  
(3<sup>rd</sup> to 8<sup>th</sup> floors)**

Beams	Cross-section	Steel grade
A1 – F1, A4 – F4	IPE 400	S 355
A1 – A4, B1 – B2, B3 – B4, C2a – C4, D2a – D4, E1 – E2, E3 – E4, F1 – F4	IPE 400	S 355
C1 – C2a, D1 – D2a	2 x HEA 700	S 355
B2 – B3, E2 – E3	IPE 600	S 355
A2 – B2, A2a – A'2a, A2b – A'2b, A3 – A'3, A'2 – A'3	IPE 400	S 355
E'2a – E'3, E'2b – F2b, E'3 – F3	IPE 400	S 355
C2a – D2a, C2b – D2b, C3 – D3	IPE 400	S 355
All others secondary beams	IPE 360	S 355

**Geometric characteristics of the beams (2<sup>nd</sup> floor)**

Columns	Ground floor – 2 <sup>nd</sup> floor	2 <sup>nd</sup> floor – 5 <sup>th</sup> floor	5 <sup>th</sup> floor – 8 <sup>th</sup> floor
B2, C2, D2, E2, C2b, C'2b, D2b, B3, C3, D3, E3	HEB 340	HEB 320	HEB 260
	Ground floor – 4 <sup>th</sup> floor	4 <sup>th</sup> floor – 8 <sup>th</sup> floor	
B1, C1, D1, E1, A2, F2, A3, F3, B4, C4, D4, E4, A'2a, A2b, A'3, E'2a, F2b, E'3	HEB 320	HEB 260	
	Ground floor – 8 <sup>th</sup> floor		
A1, A4, F1, F4	HEB 260		

**Geometric characteristics of the columns**

# Global Analysis: case-study building

## General safety criteria, actions and combinations of actions

Action no.	Description	Type	Value
LC1	Self-weight of structural elements	Permanent action	varies
LC2	Imposed load on office buildings (Cat. B)	Variable action	$q_k^1 = 3.0 \text{ kN/m}^2$
LC3	Movable partitions	Variable action	$q_k^2 = 0.5 \text{ kN/m}^2$
LC4	Wind direction $\theta = 0^\circ$	Variable action	varies (see Figure 4.40)
LC5	Wind direction $\theta = 90^\circ$	Variable action	varies (see Figure 4.41)

### SLS

$$E_d7 = 1.00 \times \text{LC1} + 0.5 \times (\text{LC2} + \text{LC3}).$$

$$E_d8 = 1.00 \times \text{LC1} + 0.2 \times \text{LC4}.$$

$$E_d9 = 1.00 \times \text{LC1} + 0.2 \times \text{LC5}.$$

$$E_d10 = 1.00 \times \text{LC1} + 0.2 \times \text{LC4} + 0.3 \times (\text{LC2} + \text{LC3}).$$

$$E_d11 = 1.00 \times \text{LC1} + 0.2 \times \text{LC5} + 0.3 \times (\text{LC2} + \text{LC3}).$$

$$E_d12 = \text{LC1} + 0.5 \times (\text{LC2} + \text{LC3}).$$

$$E_d13 = \text{LC1} + 0.2 \times \text{LC4} + 0.3 \times (\text{LC2} + \text{LC3}).$$

$$E_d14 = \text{LC1} + 0.2 \times \text{LC5} + 0.3 \times (\text{LC2} + \text{LC3}).$$

### ULS

#### i) Combination 1

$$E_d1 = 1.35 \times \text{LC1} + 1.5 [(\text{LC2} + \text{LC3}) + 0.6 \times \text{LC4}]$$

#### ii) Combination 2

$$E_d2 = 1.35 \times \text{LC1} + 1.5 [(\text{LC2} + \text{LC3}) + 0.6 \times \text{LC5}]$$

#### iii) Combination 3

$$E_d3 = 1.00 \times \text{LC1} + 1.5 \times \text{LC4}$$

#### iv) Combination 4

$$E_d4 = 1.00 \times \text{LC1} + 1.5 \times \text{LC5}$$

#### v) Combination 5

$$E_d5 = 1.35 \times \text{LC1} + 1.5 [\text{LC4} + 0.7 \times (\text{LC2} + \text{LC3})]$$

#### vi) Combination 6

$$E_d6 = 1.35 \times \text{LC1} + 1.5 [\text{LC5} + 0.7 \times (\text{LC2} + \text{LC3})]$$



# Global Analysis: case-study building

## Structural analysis

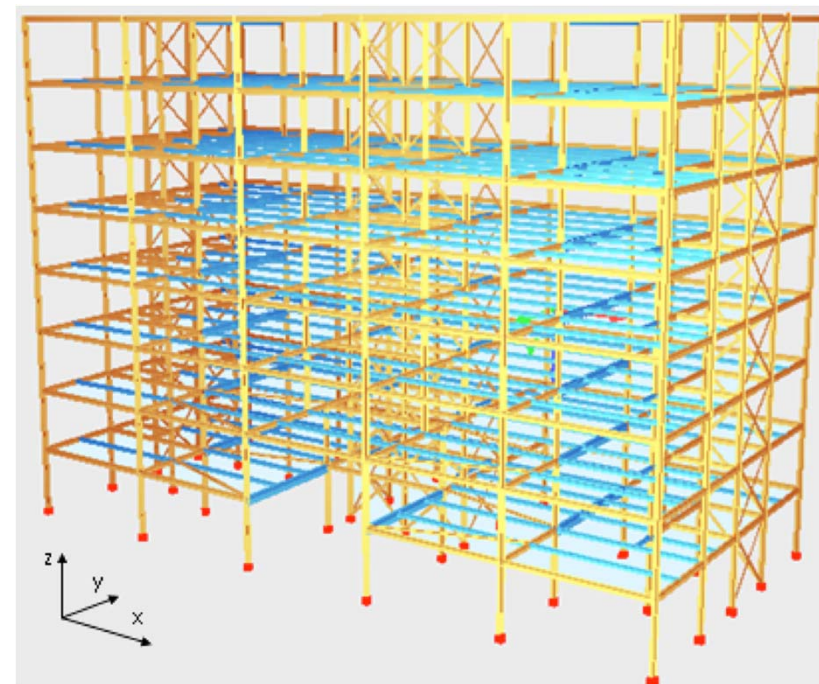
### Linear elastic analysis

Susceptibility to 2<sup>nd</sup> order effects: elastic critical loads

	$\alpha_{cr}^1$	$\alpha_{cr}^2$	$\alpha_{cr}^3$	$\alpha_{cr}^4$	$\alpha_{cr}^5$
Combination 1	7.96	8.22	8.28	8.40	8.67
Combination 2	8.01	8.08	8.48	8.57	8.66
Combination 3	21.11	25.15	28.28	28.62	29.38
Combination 4	13.14	14.21	18.56	18.84	19.98
Combination 5	9.87	10.16	10.23	10.39	10.62
Combination 6	8.58	9.37	10.07	10.14	10.17

### 2<sup>nd</sup> order elastic analysis

For combinations 1, 2, 5 and 6 the values of  $\alpha_{cr}$  are smaller than 10. According to clause 5.2.1, the frame requires a second-order analysis for load combinations 1, 2, 5 and 6.

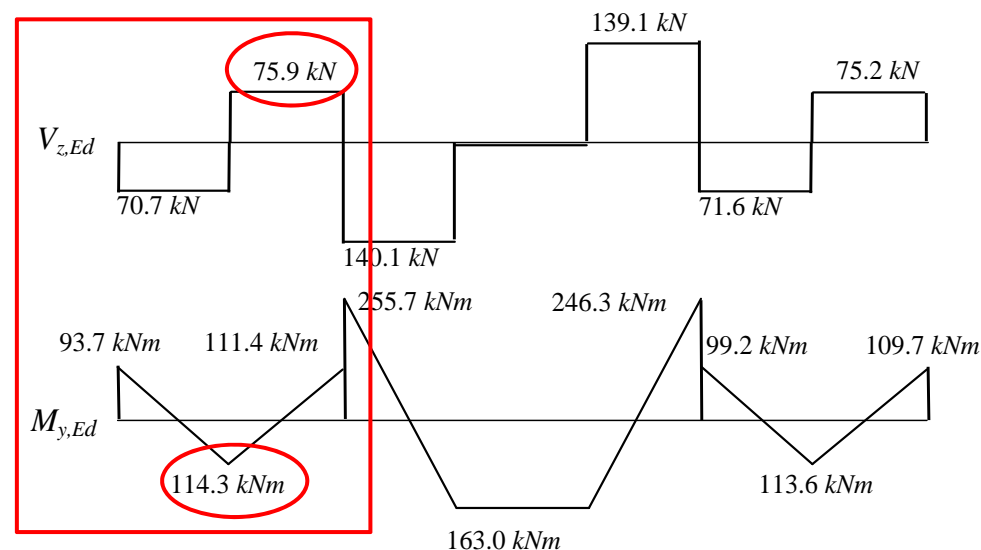




## Global Analysis: case-study building

### Results for Beam E1 to E4 (4th floor, combination 1)

The internal forces (neglecting the axial force) are represented in the figure. The design values are  $M_{Ed} = 114.3 \text{ kNm}$  and  $V_{Ed} = 75.9 \text{ kN}$ .



	1 <sup>st</sup> Order		2 <sup>nd</sup> Order			
	$M_{Ed} (kNm)$	$N_{Ed} (kN)$	$M_{Ed} (kNm)$	$\Delta (\%)$	$N_{Ed} (kN)$	$\Delta (\%)$
E1-E2	+114/-106	61	+114/-111	0/4.7	39	-36.1
E2-E3	+168/-269	155	+163/-256	-3.0/-4.8	139	-10.3
E3-E4	+113/-105	61	+114/-110	0.9/4.8	50	-18.0

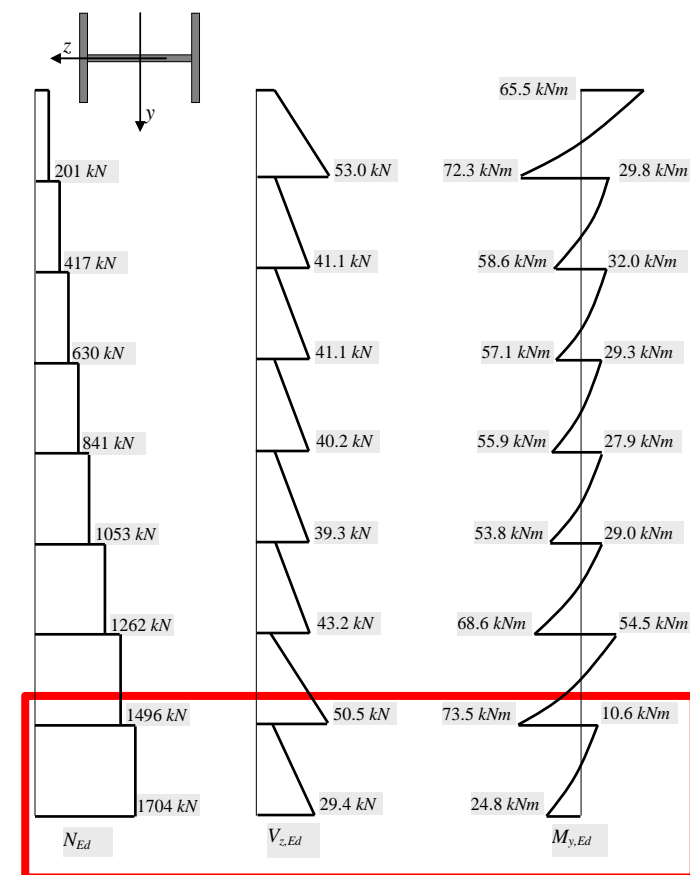


# Global Analysis: case-study building

## Results for column E1 (combination 1)

	1 <sup>st</sup> Order		2 <sup>nd</sup> Order			
	$M_{Ed} (kNm)$	$N_{Ed} (kN)$	$M_{Ed} (kNm)$	$\Delta (%)$	$N_{Ed} (kN)$	$\Delta (%)$
1 <sup>st</sup> floor	25/14	1699	25/11	0/-21.4	1704	+0.3
2 <sup>nd</sup> floor	62/47	1492	74/55	19.4/17.0	1496	+0.3
3 <sup>rd</sup> floor	69/28	1261	69/29	0/3.6	1262	+0.1
4 <sup>th</sup> floor	51/25	1052	54/28	5.9/12.0	1053	+0.1
5 <sup>th</sup> floor	53/27	841	56/29	5.7/7.4	841	0
6 <sup>th</sup> floor	54/29	630	57/32	5.6/10.3	630	0
7 <sup>th</sup> floor	55/26	417	59/30	7.3/15.4	417	0
8 <sup>th</sup> floor	69/63	201	72/66	4.3/4.8	201	0

**Design values** are:  $N_{Ed} = 1704 \text{ kN}$ ;  $M_{y,Ed} = 24.8 \text{ kNm}$   
at the base cross section.





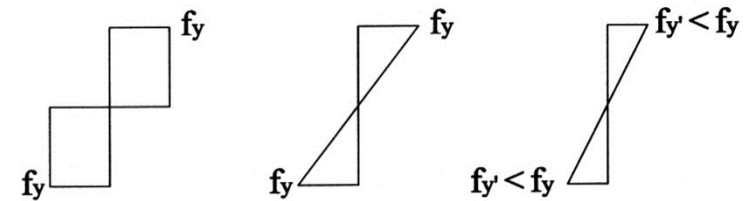
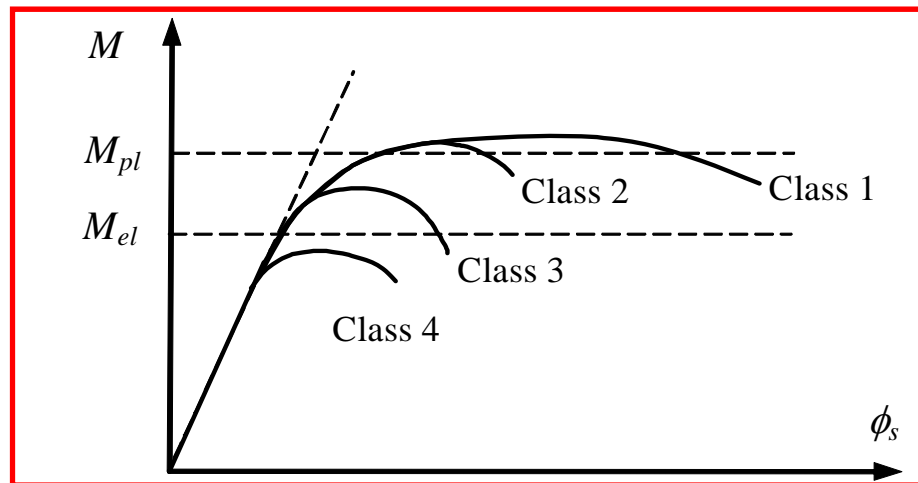
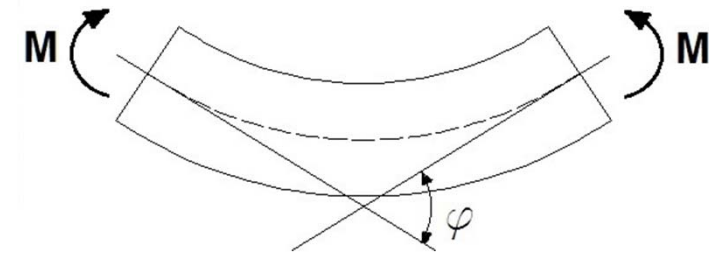
## Classification of cross-sections

Class 1: plastic cross-sections

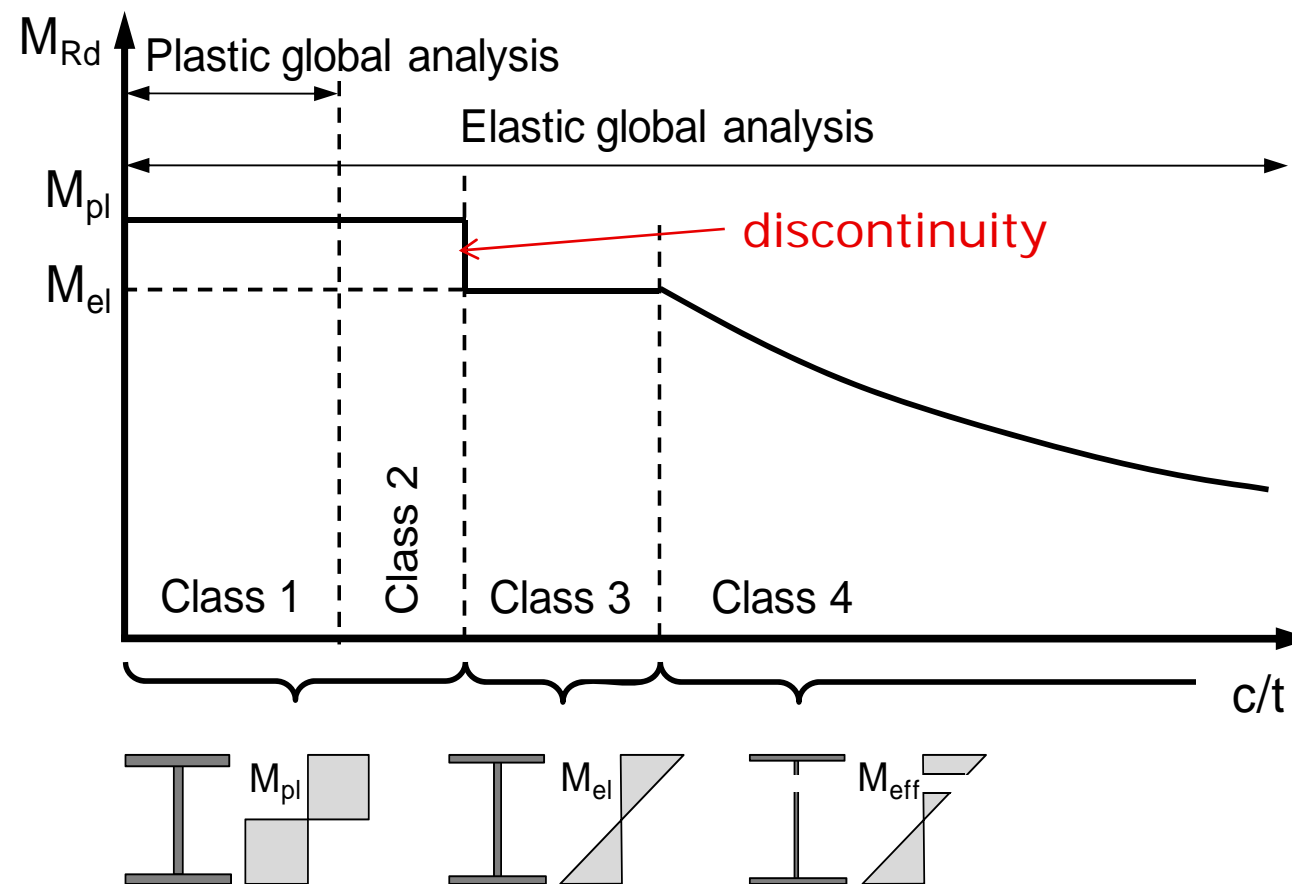
Class 2: compact cross-sections

Class 3: semi-compact cross-sections

Class 4: slender cross-sections



# Classification of cross-sections



# Classification of cross-sections

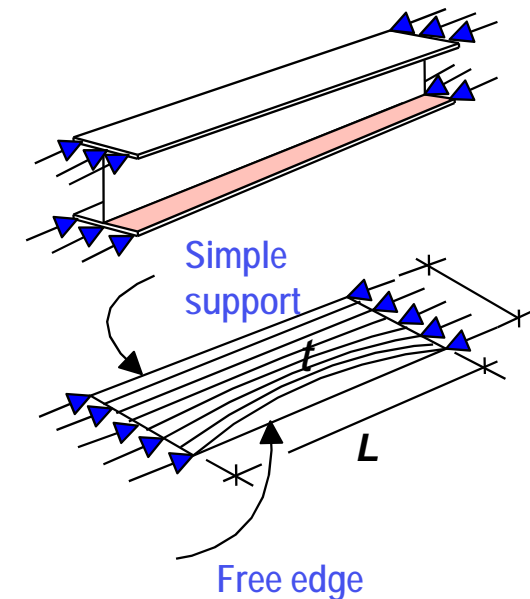
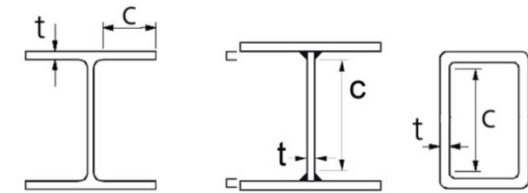
## Cross section classification is required for:

- Selection of the global frame analysis:
  - Elastic frame analysis
  - Plastic frame analysis
- Decision about the type of cross-section verification:
  - Elastic verification
  - Plastic verification
  - Effective cross-section properties
- Decision on the member buckling formulae with respect to the degree of local plastic capacity:
  - Plastic interaction: class 1, 2
  - Elastic interaction

# Classification of cross-sections

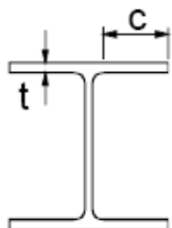
## How to classify a cross-section?

- **Classification** of each plate elements (in full or partial compression) composing the section.
- Compare the **slenderness  $c/t$**  with specific limits, established to prevent local plate buckling (Table 5.2 of EC3-1-1).
- **Cross section class** = most unfavourable class of all plate elements (flange or web).
- **Cross section class depend** of the:
  - slenderness  $c/t$ ;
  - support conditions (internal or external part);
  - distribution of direct stresses (acting forces);
  - class of steel (higher steel grades sections tend to fall into higher classes).

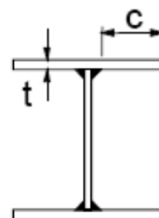




### Outstand flanges



Rolled sections



Welded sections

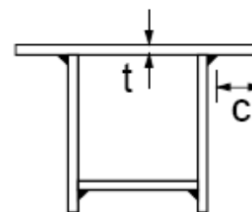


Plate element classification acc. to Table 5.2

Class	Part subject to compression	Part subject to bending and compression	
		Tip in compression	Tip in tension
Stress distribution in parts (compression positive)			
1	$c/t \leq 9\epsilon$	$c/t \leq \frac{9\epsilon}{\alpha}$	$c/t \leq \frac{9\epsilon}{\alpha\sqrt{\alpha}}$
2		$10\epsilon$	$10\epsilon$

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

Class	Part subject to compression	Part subject to bending and compression	
		Tip in compression	Tip in tension
Stress distribution in parts (compression positive)			
3			
$\epsilon = \sqrt{235/f_y}$			
1	$c/t \leq 9\epsilon$	$c/t \leq \frac{9\epsilon}{\alpha}$	$c/t \leq \frac{9\epsilon}{\alpha\sqrt{\alpha}}$



Internal compression parts			
Class	Part subject to bending	Part subject to compression	Part subject to bending and compression
Stress distribution in parts (compression positive)			
1	$c/t \leq 72\epsilon$		$396\epsilon$
2	$c/t \leq 83\epsilon$		
Stress distribution in parts (compression positive)			
3	$c/t \leq 124\epsilon$		
$\epsilon = \sqrt{235/f_y}$	$f_y$		
	$\epsilon$		

Plate element  
classification  
acc. to Table 5.2

Class	Part subject to bending	Part subject to compression	Part subject to bending and compression
Stress distribution in parts (compression positive)			
1	$c/t \leq 72\epsilon$	$c/t \leq 33\epsilon$	when $\alpha > 0,5$ : $c/t \leq \frac{396\epsilon}{13\alpha - 1}$ when $\alpha \leq 0,5$ : $c/t \leq \frac{36\epsilon}{\alpha}$

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



## Acknowledgments

- *Use of material (powerpoint presentations from SEMI-COMP+ Seminar in Guimarães, Portugal, 23.NOV.2011) is gratefully acknowledged.*

Thank you for your attention

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