Fire Engineering Research - Key Issues for the Future II

Naples, Italy, 6 – 9 June 2013

decivil universidade de aveiro departamento de engenharia civil

PhD: BEHAVIOUR OF COLD-FORMED STEEL BEAM-COLUMNS IN CASE OF FIRE

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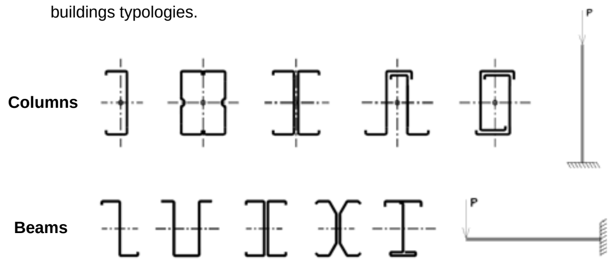
Contents

Introduction

- The cold-formed steel profiles can be applied to almost all existing buildings typologies.



Introduction

- The cold-formed profiles are common in buildings due to their lightness and ability to support large spans, being quite common as roof or wall support elements.

- Cold-formed profiles can have failure modes occurrence:
  - local buckling;
  - distortional buckling;
  - and global buckling (in beams lateral-torsional buckling).

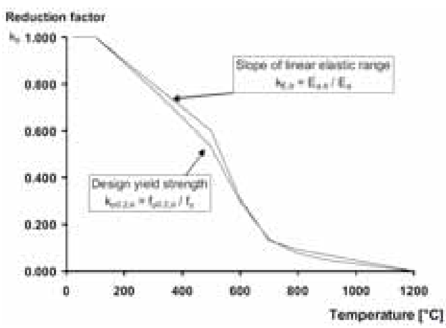
Introduction

- The thin walls of these profiles, together with the high thermal steel conductivity, provide a great loss of strength and stiffness on these structural elements when subjected to fire.

- To consider this mechanical resistance and stiffness loss, it is necessary to apply:
  - the reduction factor of Young's modulus at high temperature; $E_{a,\theta} = k_{E,\theta} E_a$
  - and the reduction factor of the proportional limit strength at 0.2%. $f_{0,2,p,\theta} = k_{0,2,p,\theta} f_y$

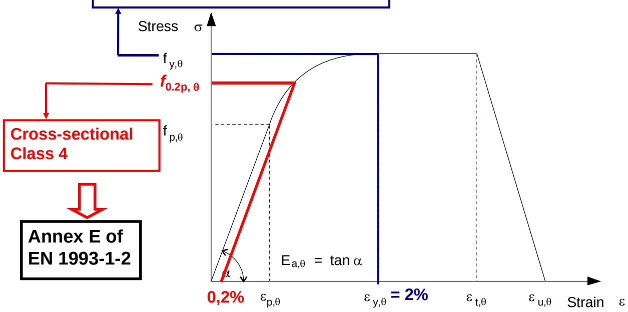
Introduction

- Mechanical properties reduction at high temperatures for Class 4 cross-sections



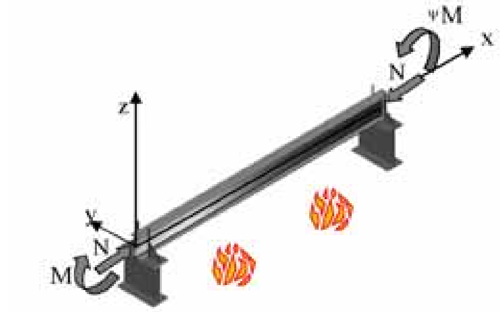
Introduction

- Design yield strength to be used with simple calculation models



Introduction

Beam-Columns



PhD Planning

PhD Planning

Motivation

- Cold-formed steel profiles have been widely used in construction

- Fire design rules from the Eurocode for these elements have demonstrated to be very conservative
- Unclear concepts on research domain of cold-formed steel elements

Objectives

- Understand the cold-formed steel elements **fire behaviour** by means of numerical and experimental analysis
- Study and develop (if necessary) **simple design rules for fire design** of cold-formed steel elements (beams, columns and beam-columns) and **validation of formulae** prescribed in Eurocode 3 for fire resistance.

Working Program

2013 2014 2015 2016 2017

i. Curricular Units
ii. Bibliographic research;
iii. Numerical sensitivity analysis;
iv. Experimental evaluation of cold-formed fire behaviour under different loading types;
v. Parametric study with numerical modulation;
vi. Validation of the design formulae, in Part 1-3 of EC3, for stability check of cold-formed steel members at normal temperature and the adaptation for fire situation;
vii. Development of new fire design methodologies if necessary
viii. Final writings of the PhD Thesis

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Current Situation

2013 2014 2015 2016 2017

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Numerical Sensitivity Analysis

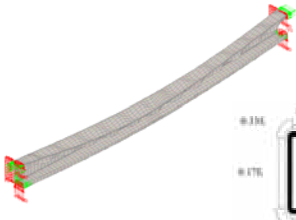
Numerical Sensitivity Analysis

Work Performed

- The fire resistance of buildings made with these profiles has been calculated using advanced methods with finite element programs that consider the local buckling
- In the numerical study, the following programs were used:
  - CUFSM (Johns Hopkins University, USA)
  - CAST3M (Commissariat à l'Énergie Atomique, France); RUBY interface (University of Aveiro, Portugal)
  - SAFIR (University of Liege, Belgium)

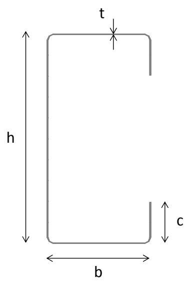
Work Performed

- The influence of **geometrical imperfections** and **residual stresses** on the ultimate load bearing capacity of these profiles is evaluated, by means of numerical analysis



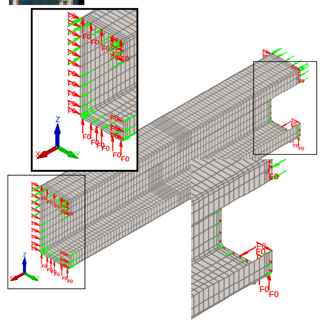
Work Performed

Case Study

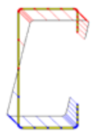


- Simply supported beams
- Class 4 cross-section
- Study case dimensions:
  - Flange 77mm
  - Web 155mm
  - Lips 31mm
  - Thickness 2mm
- Temperature considered uniform throughout the cross-section

Work Performed

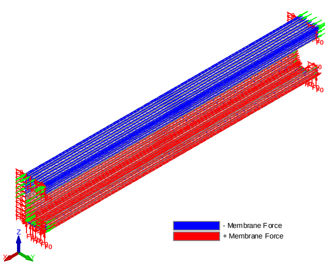


- Concentrated loads applied, in the parallel directions to the beam axis, according to the linear stresses distribution resulting from simple bending around the strong axis;



- Restrictions imposed in order to reproduce one end pinned support and one roller support;

Work Performed

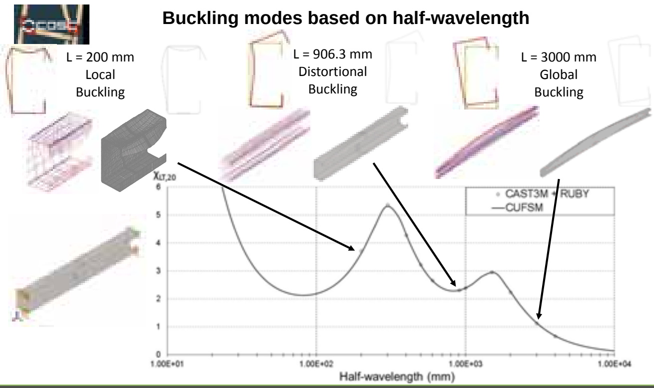


- Concentrated loads applied, in the parallel directions to the beam axis, according to the linear stresses distribution resulting from simple bending around the strong axis;

- Restrictions imposed in order to reproduce one end pinned support and one roller support;

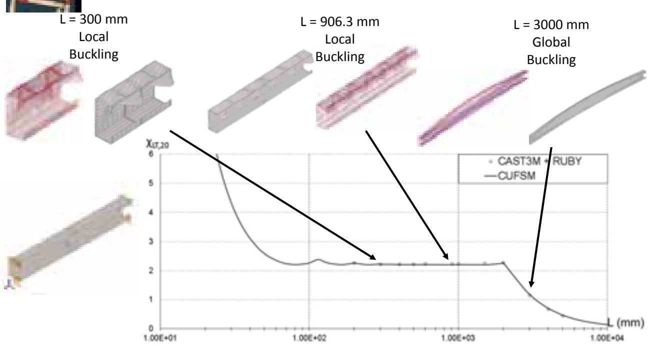
Work Performed

Buckling modes based on half-wavelength



Work Performed

First buckling modes



Work Performed

EC3 (EN 1993-1-2)

$$M_{b,fi,t,Rd} = \chi_{LT,fi} W_{eff,y} k_{p0.2,\theta} \, f_y / \gamma_{M,fi}$$

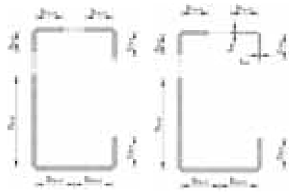
$$\chi_{LT,fi} = \frac{1}{\phi_{LT,\theta,com} + \sqrt{\phi_{LT,\theta,com}^2 - \bar{\lambda}_{LT,\theta,com}^2}} \quad \text{with} \quad \chi_{LT,fi} \le 1$$

$$\phi_{LT,\theta,com} = \frac{1}{2}\left(1 + \alpha \bar{\lambda}_{LT,\theta,com} + \bar{\lambda}_{LT,\theta,com}^2\right)$$

$$\alpha = 0.65\sqrt{235 / f_y}$$

EC3 (EN 1993-1-3)

Effective cross-section



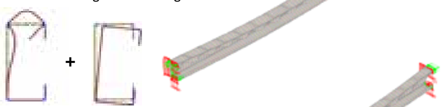
Local instability

Distortional instability

Work Performed

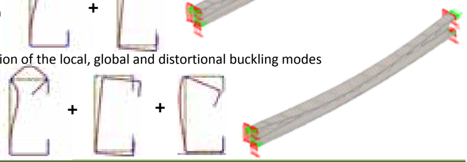
- Without geometrical imperfections
- With geometrical imperfections corresponding to:
  - the local buckling mode (0.8 x b/100)
  - the distortional buckling mode (0.8 x b/100)
  - the global buckling mode (0.8 x L/750)
  - combination of the local and global buckling modes

- Local + 70% Global until 2m
- Global + 70% Local from 2m



- combination of the local, global and distortional buckling modes

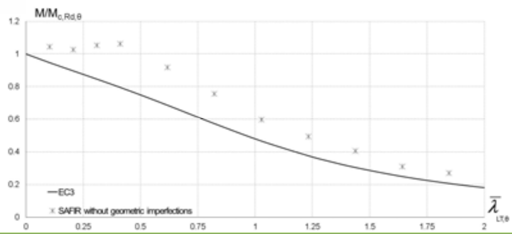
- L + 70% G + 70% D until 2m
- G + 70% L + 70% D from 2m



Work Performed

Influence of initial imperfections on the fire resistance (500 °C)

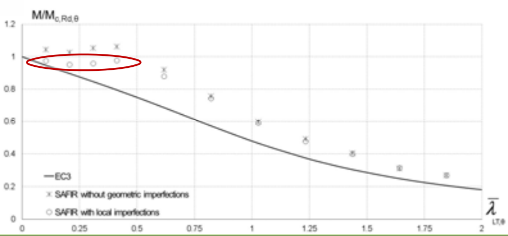
- Without geometric imperfections



Work Performed

Influence of initial imperfections on the fire resistance (500 °C)

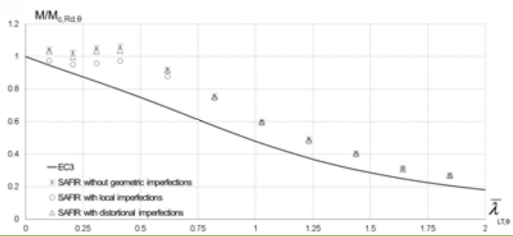
- Without geometric imperfections
- With Local imperfections



Work Performed

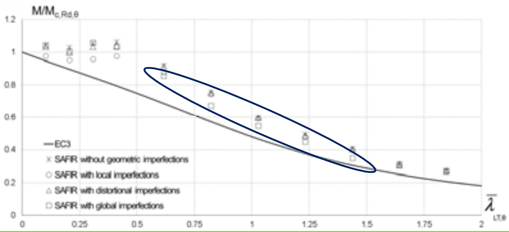
Influence of initial imperfections on the fire resistance (500 °C)

- Without geometric imperfections
- With Local imperfections
- With Distortional imperfections



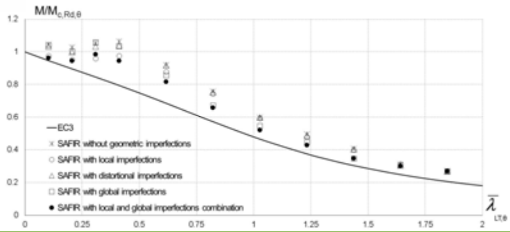
Influence of initial imperfections on the fire resistance (500 °C)

- Without geometric imperfections
- With Local imperfections
- With Distortional imperfections
- With Global imperfections



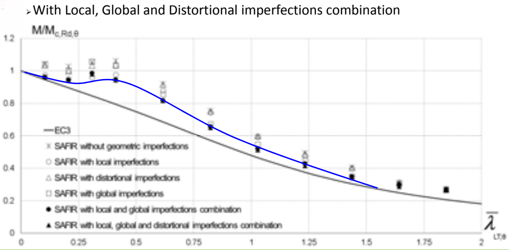
Influence of initial imperfections on the fire resistance (500 °C)

- Without geometric imperfections
- With Local imperfections
- With Distortional imperfections
- With Global imperfections
- With Local and Global imperfections combination



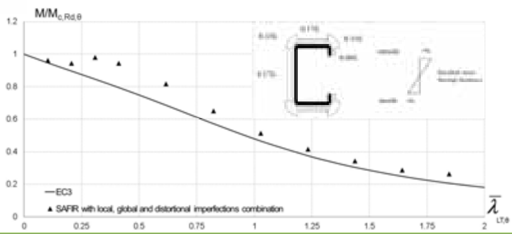
Influence of initial imperfections on the fire resistance (500 °C)

- Without geometric imperfections
- With Local imperfections
- With Distortional imperfections
- With Global imperfections
- With Local and Global imperfections combination
- With Local, Global and Distortional imperfections combination



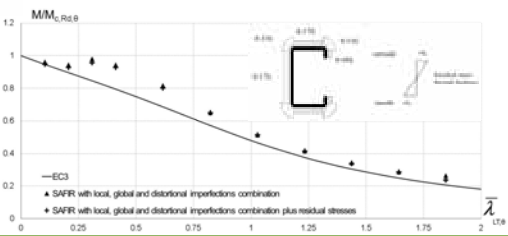
Influence of residual stresses on the fire resistance (500 °C)

- With Local, Global and Distortional imperfections combination



Influence of residual stresses on the fire resistance (500 °C)

- With Local, Global and Distortional imperfections combination
- With Local, Global and Distortional imperfections combination plus residual stresses



Conclusions

The influence of initial geometrical imperfections (local, distortional, global, and combinations of them) on the determination of the ultimate loads of these elements at high temperatures was analysed and it was concluded that these imperfections are relevant to the determination of those ultimate loads.

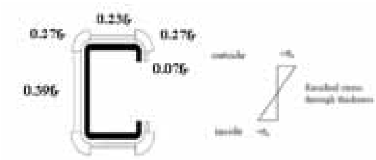
The influence of residual stresses was also analyzed and it was concluded that it did not have impact on the resistance values.

Finally, a comparison between the ultimate loads and the formulae prescribed in EC3 was also performed, concluding that the latter simple calculation rules are on the safe side and sometimes too conservative.

Future Work

Other considerations to be accounted for

- Comparisons with other types of residual stresses (cold-rolling)



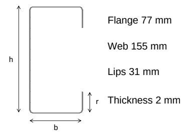
- Consider the increase of yield stress of corners resulting from the cold forming process.

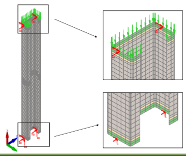
Future Work

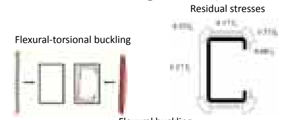
Sensitivity analysis for columns (presented at ASFE, Prague 2013)

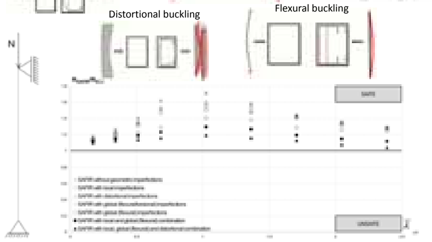
Already done

- Same case study for columns





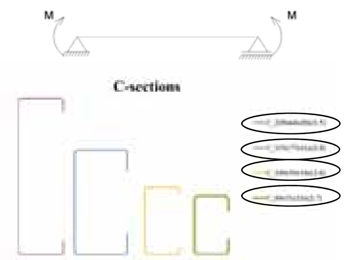


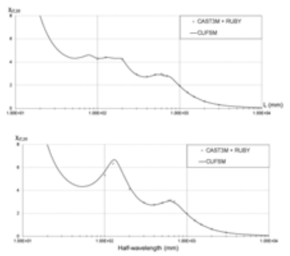


Future Work

Already done

- Same case study for columns
- Preparation of 3 more different cross-sections for beams





Future Work

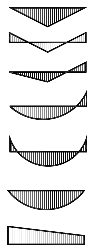
Already done

- Same case study for columns
- Preparation of 3 more different cross-sections for beams

Moving next

- Full study for the 3 different cross-sections for beams (different loading types)
- Same study case for the new sections with columns
- Beam-columns study for different load conditions
- Experimental work
- ...

Moment distribution



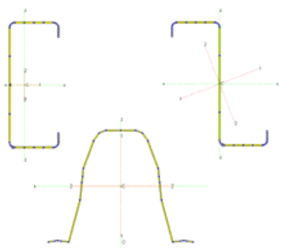
Future Work

Already done

- Same case study for columns
- Preparation of 3 more different cross-sections for beams

Moving next

- Parametric study:
  - sections type C, Z, Ω...
  - sections slenderness
  - steel grade
  - loading type



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Thank you

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