Fire Engineering Research - Key Issues for the Future II  
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PhD: BEHAVIOUR OF COLD-FORMED STEEL BEAM-COLUMNS IN CASE OF FIRE

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Introduction

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

Columns

Beams

- 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; \( E_{t,4} = E_{y,4} f_{y} \)
  - and the reduction factor of the proportional limit strength at 0.2%; \( f_{y,0.2} = f_{y,4} f_{y} \)

- 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

- Design yield strength to be used with simple calculation models

Cross-sectional Class 1, 2 and 3

Cross-sectional Class 4

Annex E of EN 1993-1-2

Stress \( \sigma \)

Strain \( \varepsilon \)

\[ E_{\alpha} = \tan \alpha, \]

\[ \varepsilon_y, \theta, \varepsilon_p, \theta, \varepsilon_u, \theta, \]

\[ f_y, \theta, f_p, \theta, \]

\[ \varepsilon_{0.2}, \theta, \]

\[ f_{0.2}, \theta, \]

Behaviour of cold-formed steel columns in case of fire

PhD Planning

- 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

- Curricular Units
- Bibliographic research;
- Numerical sensitivity analysis;
- Experimental evaluation of cold-formed fire behaviour under different loading types;
- Parametric study with numerical modulation;
- 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;
- Development of new fire design methodologies if necessary
- Final writings of the PhD Thesis
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

Current Situation

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
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Numerical Sensitivity Analysis

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
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**

**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**

Buckling modes based on half-wavelength

Restrictions imposed in order to reproduce one end pinned support and one roller support;
Fire resistance of cold-formed C steel columns

Behaviour of cold-formed steel beam-columns in case of fire

Work Performed

First buckling modes

EC3 (EN 1993-1-2)

EC3 (EN 1993-1-3)

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

Influence of initial imperfections on the fire resistance (500 °C)
Fire resistance of cold-formed C steel columns

Behaviour of cold-formed steel beam-columns in case of fire

Work Performed

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

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

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

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.

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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