WP4 –BENCHMARK STUDY : NUMERICAL BEHAVIOUR OF STEEL COLUMNS UNDER LOCALIZED FIRE LOADING

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INTRODUCTION

BENCHMARK STUDY: Numerical model of a steel column under a natural fire

OBJECTIVE:

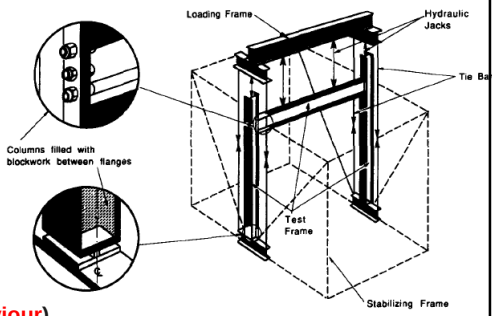
Validation of the utilization of ABAQUS and SAFIR for steel structures under fire: thermal and mechanical analyses	**against**	**Experimental results and the numerical results obtained by the software CEFICOSS**

FIVE STUDY CASES:

- the reference case
- the model definition
- axial restraint to beam
- frame continuity
- non-uniform temperature

BENCHMARK STUDY

- PAPER PUBLISHED BY **Franssen, Cooke and Latham** (1995): Fully loaded, **2D** unprotected steel frame under a natural fire loading
- **COLUMN: 3530mm long, Grade 43A (≈S355), pin jointed at the base**
- **BEAM: 4550mm long, Grade 43A**
- **BOLTED BEAM-TO-COLUMN JOINTS**
- **LATERAL AND SWAY INSTABILITIES PREVENTED**
- **CONCRETE BLOCKS between the column flanges (non-composite behaviour)**
- **CONCRETE SLAB (non-composite behaviour)**



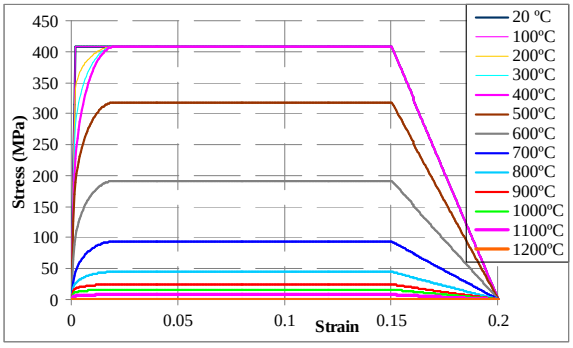
MATERIAL PROPERTIES

- **STEEL PROPERTIES**

Eurocode 3, part 1.2 (**EN 1993-1-2:2005**)

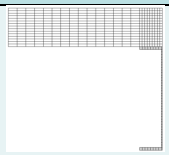
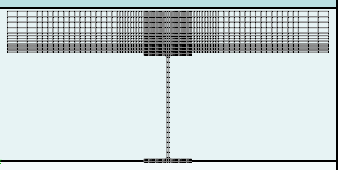
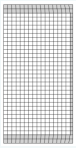
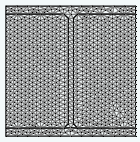
At ambient temperature: **f_y = 408 MPa; E = 210 GPa**

- **CONCRETE PROPERTIES** (Slab + Blocks between column flanges): **Only plays an insulating role**

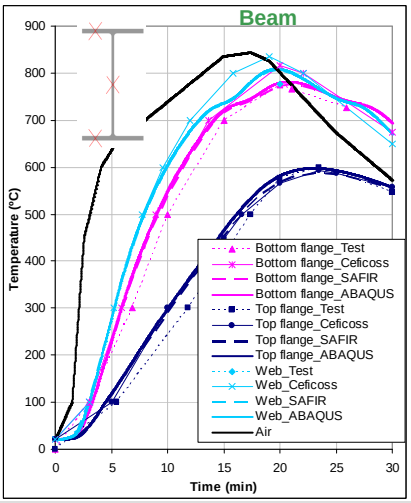


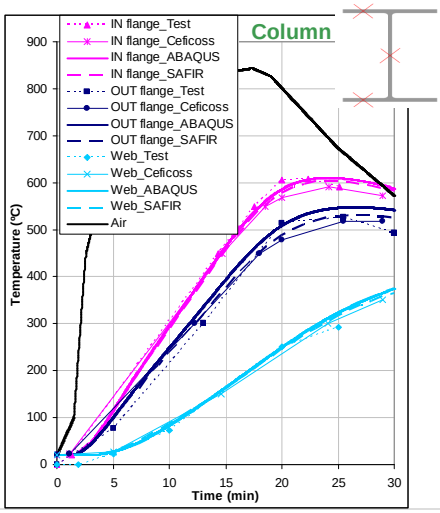
THERMAL ANALYSIS

- **ANALYSIS** to determine the **distribution of temperatures** in each element
  - Involves **conduction and boundary radiation**
  - The **concrete** slab and the concrete blocks are modelled (thermal boundary conditions)
  - **2-D SOLID FE elements**

Mesh:	ABAQUS	SAFIR
Beam		
Column		

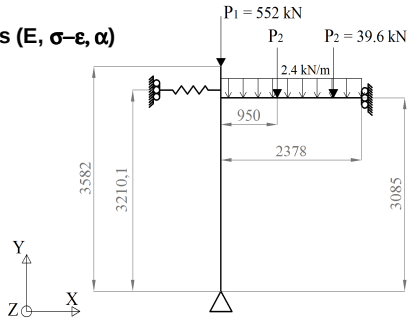
THERMAL RESULTS: Good correlation between CEFICOSS, SAFIR, ABAQUS and experimental results





MECHANICAL ANALYSIS

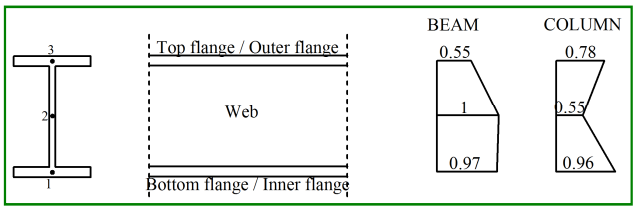
- **GENERAL MODELLING ASSUMPTIONS**
  - **Static analysis**
  - **2D Beam elements**
  - **Large-displacement effects and material nonlinearities**
  - **Temperature dependent material properties (E, σ–ε, α)**
  - **Nonlinear temperature gradient**
  - **Concrete (slab + blocks) not modelled**
  - **Rigid beam-to-column connection**
  - **Bi-linear spring (restraint – 2nd steelwork)**



MECHANICAL ANALYSIS

- **MECHANICAL LOADING**: (i) applied at room temp, (ii) maintained constant (fire)

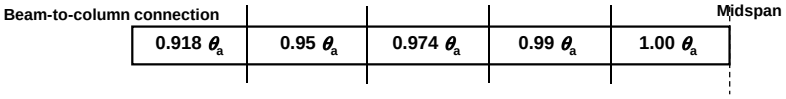
- **THERMAL GRADIENT THROUGH THE SECTION**
  - ***CEFICOSS, SAFIR:*** **calculated temp. (thermal analysis) used by the structural part**
  - ***ABAQUS:*** **3 Dependent temperatures at three points**



MECHANICAL ANALYSIS

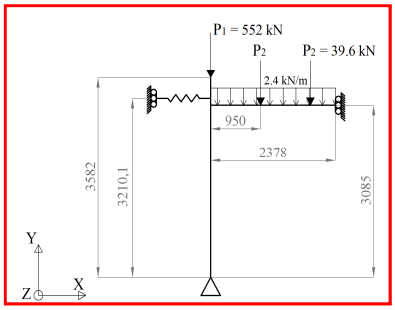
- **THERMAL GRADIENT ALONG THE BEAM SPAN** (lower temp. at joint)
  - ***CEFICOSS, SAFIR:*** sinusoidal function

  - ***ABAQUS:*** temperature along each length part is constant



MECHANICAL RESULTS

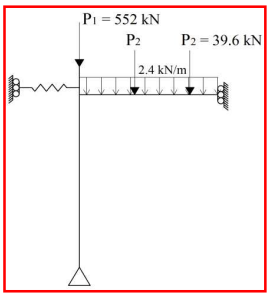
- **STUDY CASES**
  1. Reference case
  2. Model definition
  3. Axial restraint to beam
  4. Frame continuity
  5. Non-uniform distribution of temperature

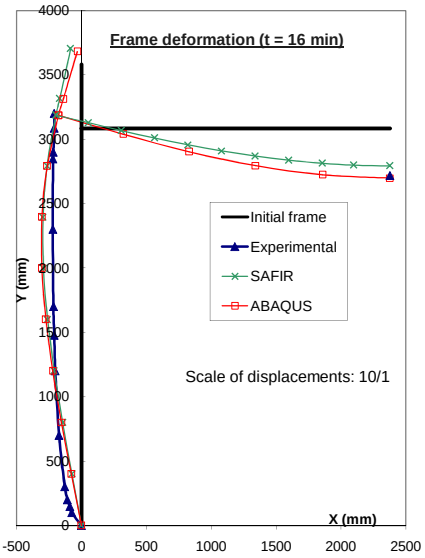


MECHANICAL RESULTS

- **1. REFERENCE CASE**

Lateral deformation influenced by the **concrete blocks** inserted between column flanges



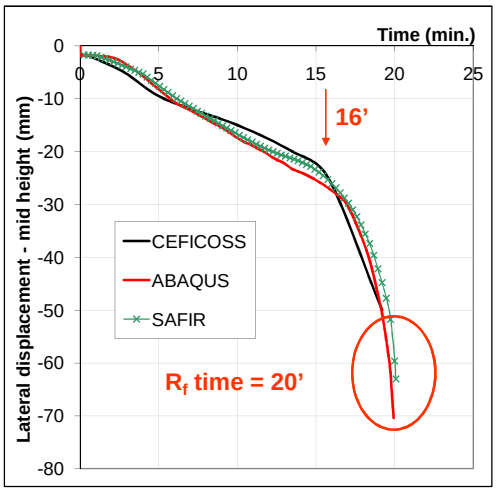


MECHANICAL RESULTS

- **1. REFERENCE CASE**

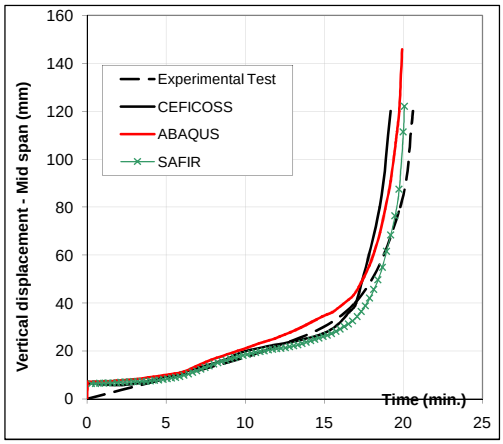
Due to the elongation of the beam → the **column bows laterally** up to the buckling around 19-20 min

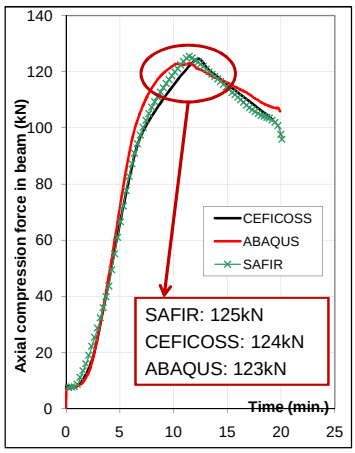
Differences between programs: **Slight ≠ temperature gradients** in cross-sections



MECHANICAL RESULTS

❑ **1. REFERENCE CASE - Beam mid-span vertical displacement**

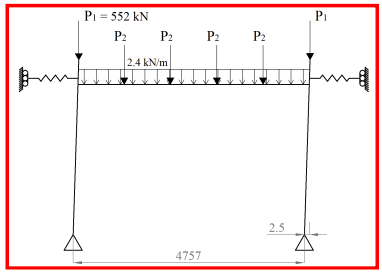




MECHANICAL RESULTS

❑ **2. INFLUENCE OF THE MODEL DEFINITION**

- Initial lateral **imperfection**: $0.8H_c/1000$
- Fire resistance time:
  - Good agreement between CEFICOSS and ABAQUS
  - **≠ SAFIR** → difficulty in modelling the two springs working together

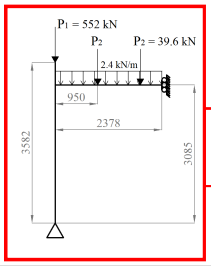


	R_f CEFICOSS	R_f SAFIR	R_f ABAQUS
1 - half of the frame	19'12"	20'04"	19'55"
2 - complete frame	***19'22"***	***17'55"***	***19'51"***

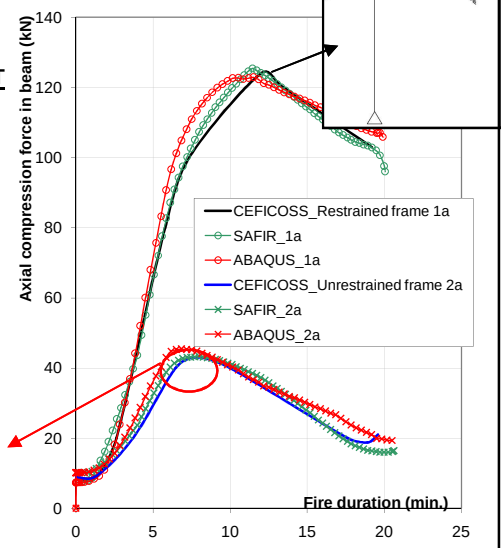
MECHANICAL RESULTS

❑ **3. INFLUENCE OF THE AXIAL RESTRAINT**

- **GOOD CORRELATION**
- **Axial compression force** ↘
- **Fire resistance and Stability few affected**



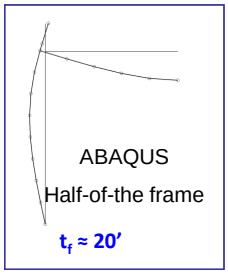
ABAQUS: 45kN
SAFIR: 43kN
CEFICOSS: 43kN



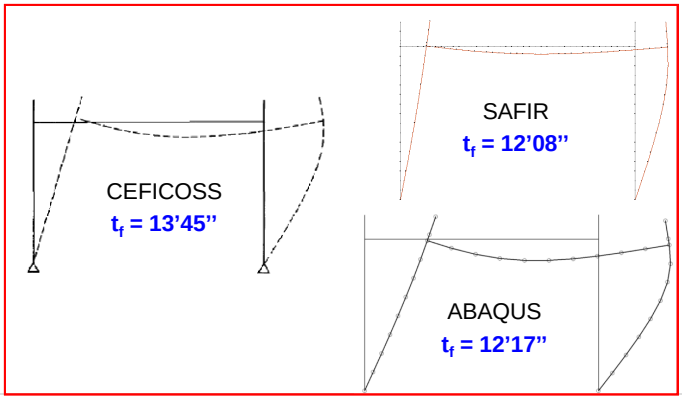
MECHANICAL RESULTS

❑ **3. INFLUENCE OF THE AXIAL RESTRAINT TO BEAM – Complete frame**

- ≠ failure mode (**sway**) → Fire resistance reduced from 20 min. to 12-13 min.
- Good correlations between numerical programs

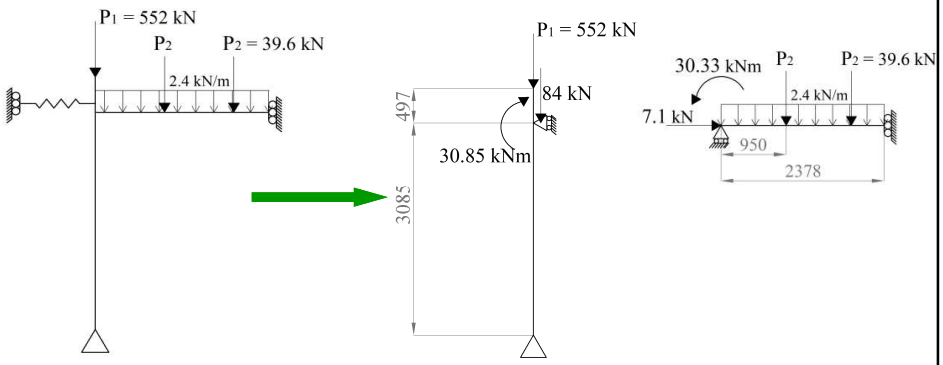


ABAQUS
Half-of-the frame
$t_f \approx 20'$



MECHANICAL RESULTS

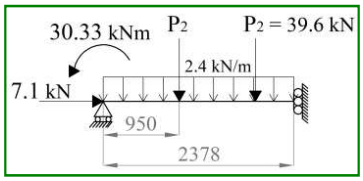
❑ **4. INFLUENCE OF THE FRAME CONTINUITY**

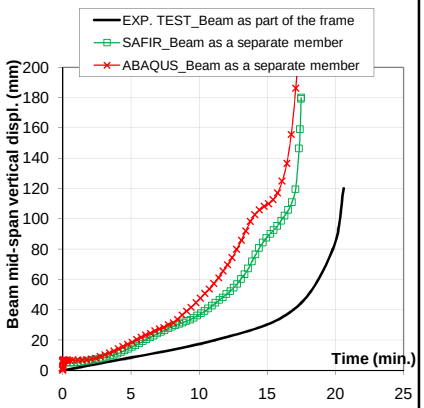


MECHANICAL RESULTS

❑ **4. INFLUENCE OF THE FRAME CONTINUITY – Beam on its own**

- **Vertical displacement ↑ (no beneficial restraints from the column**
- **Reduction of the R_f time (17'-18' for SAFIR and ABAQUS)**
- **Small Discrepancies between FE programs SAFIR and ABAQUS**





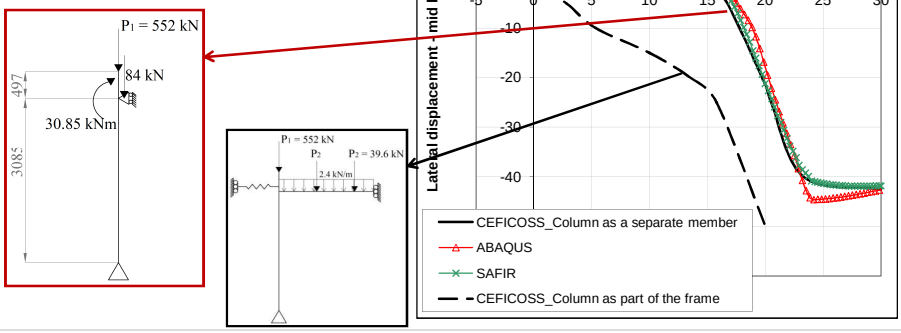
Vertical displacement of the beam

MECHANICAL RESULTS

❑ **4. INFLUENCE OF THE FRAME CONTINUITY – Column on its own**

- **All the programs: R_f time > 30' (≠ 20min.)**
- **Column on its own: behaviour ≠**
- **Column remains stable - no collapse**

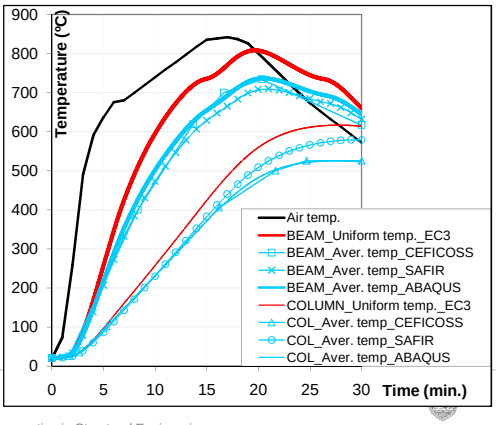
Horizontal displacement of the column



MECHANICAL RESULTS

❑ **5. INFLUENCE OF THE NON-UNIFORM TEMPERATURE**

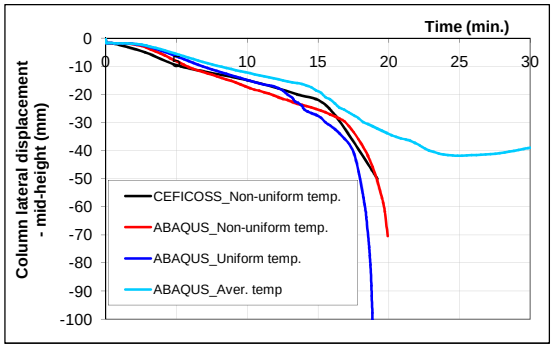
- **Gradient temp. (reference case)**
- **Uniform Temp** through the cross-section: EN 1993-1-2:2005 - simplified method
- **Average** temperature



MECHANICAL RESULTS

❑ **5. INFLUENCE OF THE NON-UNIFORM TEMPERATURE - Column**

- **Uniform temperature** (EC3): leads to *conservative results* (premature failure)
- **Average temperature**: leads to *unsafe results* (no failure is observed until the end of the analysis)



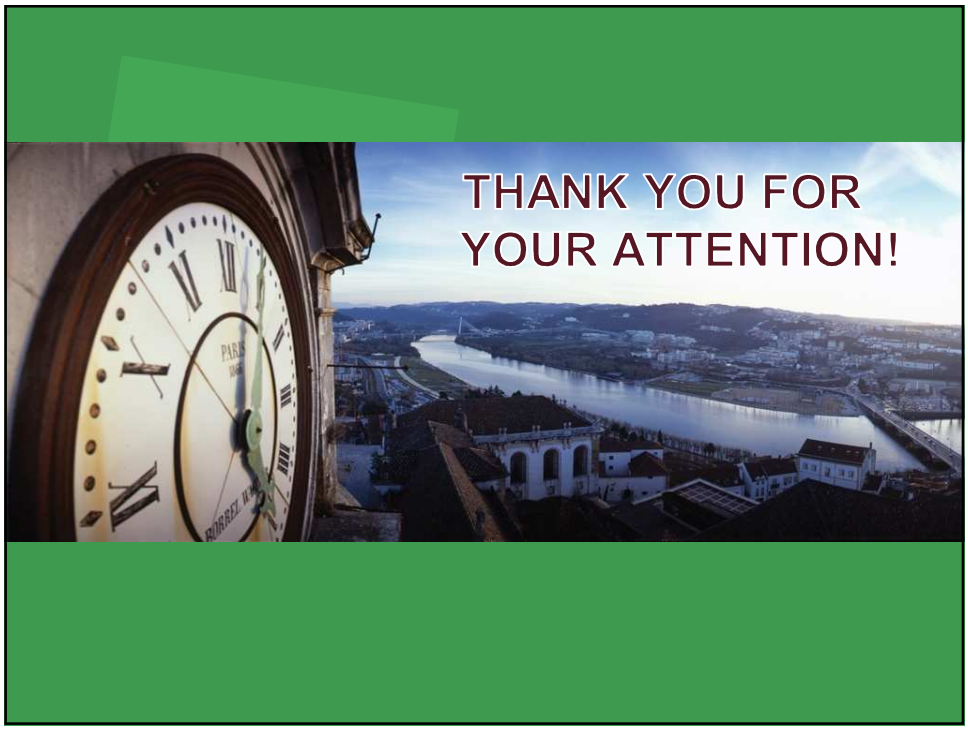
CONCLUDING REMARKS

❑ **SAFIR and ABAQUS performed well the *heat transfer analysis***

❑ **SAFIR and ABAQUS showed a good ability to simulate steel structural behaviour under fire conditions using beam elements**

❑ **Some of the differences between the results of the 2 programs could be explained by:**

- **Temperature gradients in cross-sections approximated in ABAQUS**
- **Difficulty to simulate the behaviour of springs with SAFIR (no dedicated finite element)**


THANK YOU FOR
YOUR ATTENTION!