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INTERFACE MODEL TO FIRE-THERMOMECHANICAL PERFORMANCE-BASED ANALYSIS OF STRUCTURES UNDER FIRE CONDITIONS

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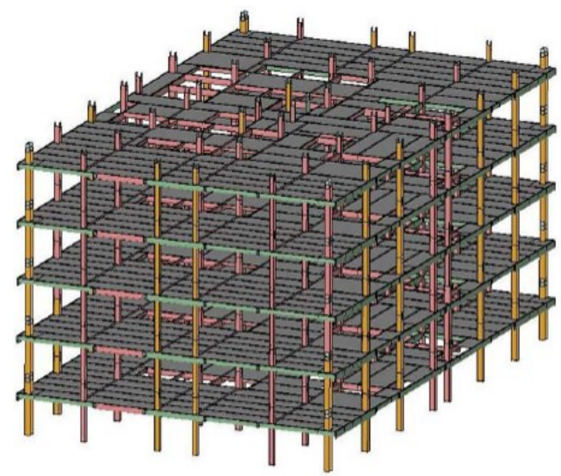
Introduction

Traditionally, the behavior of structures under fire conditions have been achieved by prescriptive simplified procedures, widely available at international codes and standards: **AISC-LRFD (2005), EN 1991-1-2 (2002), EN 1993-1-2 (2005).**

Advanced Numerical Models

Finite Element Method

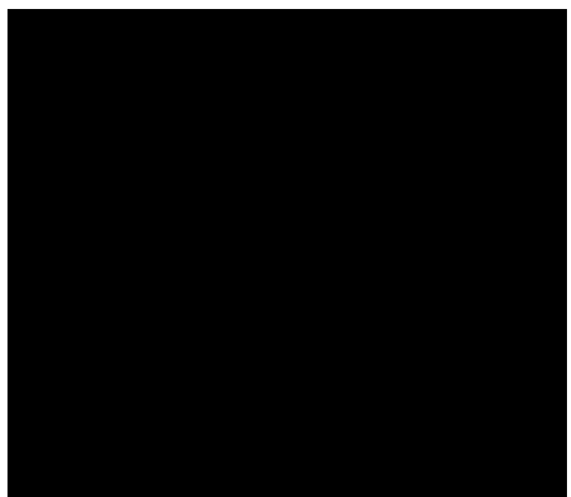
Global Behavior
Large Displacements
Second Order Effects



Simplified representation of thermal exposure conditions

Temperature-time curves

- **EN 1991-1-2: 2002**
- **AISC-LRFD: 2005**
- **ISO 834-11: 2014**



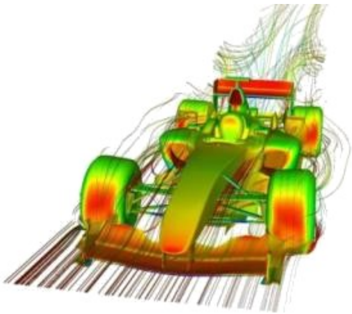
DO NOT
represent accurately
FIRE DEVELOPMENT

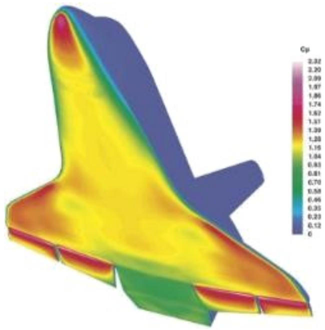
Introduction

Advanced Numerical Models

Computational Fluid Dynamics (CFD)

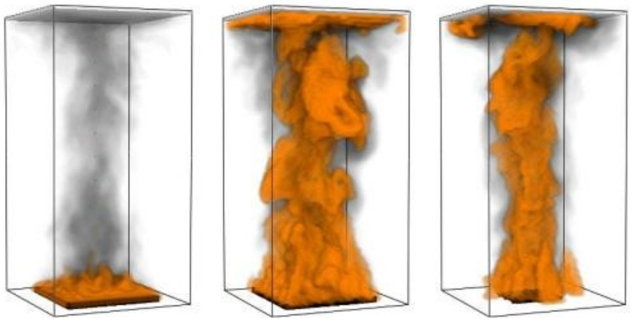
Analysis of systems involving
fluid flow
heat transfer
computer-based simulation





Reliable description of fire evolution

Gas temperatures
Velocities (pressures)
Chemical species (smoke)



- Even with all the efforts related to develop **each side separately**, a coupled fire-thermomechanical analysis (CFD-FEM) is a **relatively new area of research**
- This coupling is not trivial, the **intrinsic differences** between those two models, e.g., algorithms, time scales, mesh sizes, etc., **make this an encouraging task**

Objective

Fire-Thermomechanical Interface (FTMI) model

to performance-based analysis of structures under fire

This automated code improves the reach of the fire engineering allowing the simulation of the behavior of global structures, discretized with shell and/or solid elements, under fire conditions.

Fire | **Thermomechanical**

CFD — Reliable fire simulation → **FEM** — Spatial temperature distribution → **FEM** — Structural behavior due to heating and colling down of the structure

Interface

Thermal exposure conditions

- mesh sizes and shapes
- algorithms
- time steps

Fire Dynamics Simulator | **Ansys**

Objective

Fire-Thermomechanical Interface (FTMI) model

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Summary

Methodology

Surface thermal exposure

Models which geometries do not match perfectly

Heat flux into FEM models

Application

FTMI verification case

H-profile column

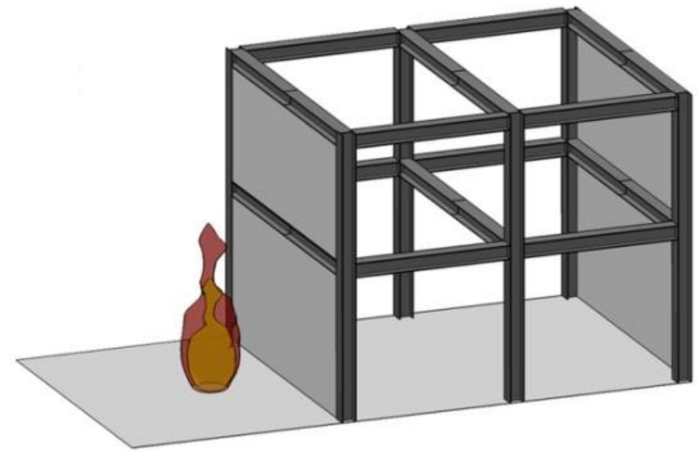
Conclusions

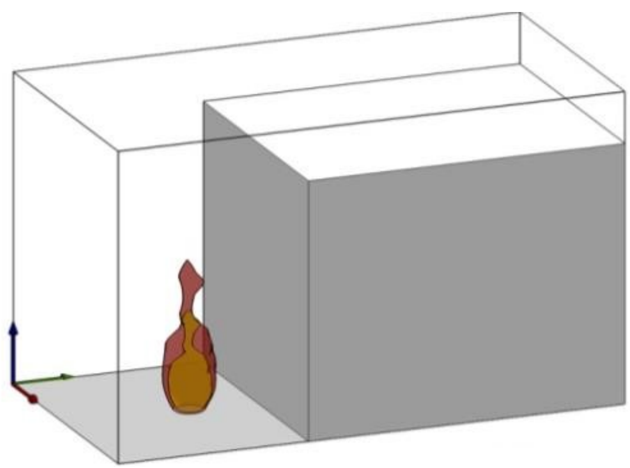
Methodology

Fire-thermomechanical model is related to a domain that includes the **structure** itself and its components, **combined with the surroundings**

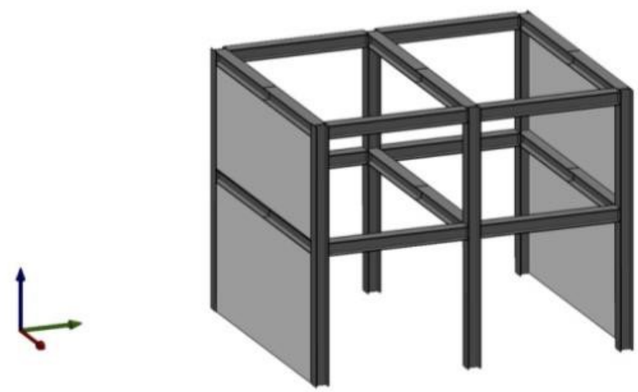
Unfortunately, this coupled fluid-solid problem needs **distinct techniques** to address the **physical phenomena involved**

FTMI decomposes this domain into **two parts**: the first one is devoted to **fire simulation** and the second is about the **thermomechanical behavior**





Fire Simulation

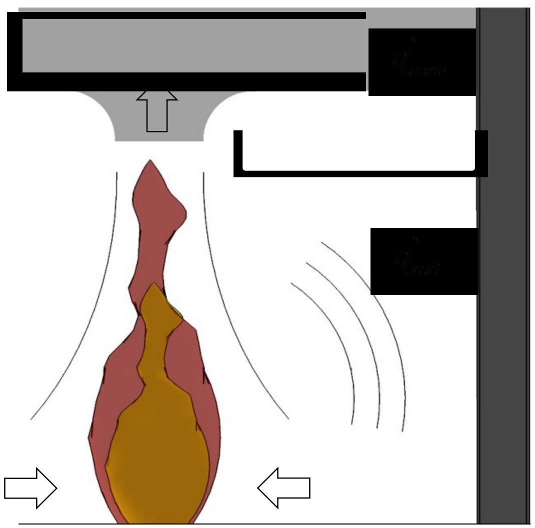


Thermomechanical Model

Methodology

Thermal Energy:
Radiation and **Convection**

$$q''_{tot} = q''_{rad} + q''_{conv}$$



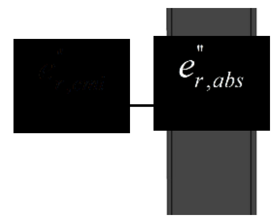
Convective heat flux

$$q''_{conv} = h\left(T_g - T_s\right)$$

Newton cooling down law

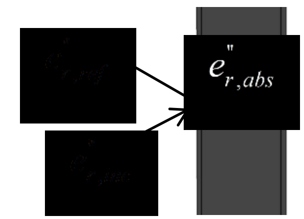
Radiative heat flux

$$q''_{rad} = e''_{r,abs} - e''_{r,emi}$$



Radiative energy balance

$$e''_{r,abs} = \alpha e''_{r,inc}$$



$$e''_{r,emi} = \varepsilon\sigma(T_s + 273)^4$$

Stefan-Boltzmann law

$$q''_{rad} = \alpha e''_{r,inc} - \varepsilon\sigma(T_s + 273)^4$$

$$\alpha = \varepsilon$$

Kirchhoff law

$$q''_{rad} = \varepsilon\left[e''_{r,inc} - \sigma(T_s + 273)^4\right]$$

Total heat flux

[redacted] $= \varepsilon\left[e''_{r,inc} - \sigma(T_s + 273)^4\right] + h\left(T_g - T_s\right)$

Even advanced fire simulation models are NOT capable of calculate accurately the temperature distribution on solids

Methodology

Adiabatic Surface Temperature

Exposed surface

Ideal Surface
Exposed to the same heating conditions

$$-\left(\varepsilon\left[e''_{r,inc} - \sigma\left(T_{AST}+273\right)^4 \right] + h\left(T_g - T_{AST}\right) = 0 \right)$$

[redacted] $= \varepsilon\left[e''_{r,inc} - \sigma\left(T_s+273\right)^4 \right] + h\left(T_g - T_s\right)$

T_{AST} from fire simulation
(WICKSTRÖM *et al.*, 2007)

Combining the complexity of fire models into a scalar variable

$$q''_{tot} = \varepsilon\sigma\left[\left(T_{AST}+273\right)^4 - \left(T_s+273\right)^4 \right] + h\left(T_{AST} - T_s\right)$$

Surfaces Thermal Exposure

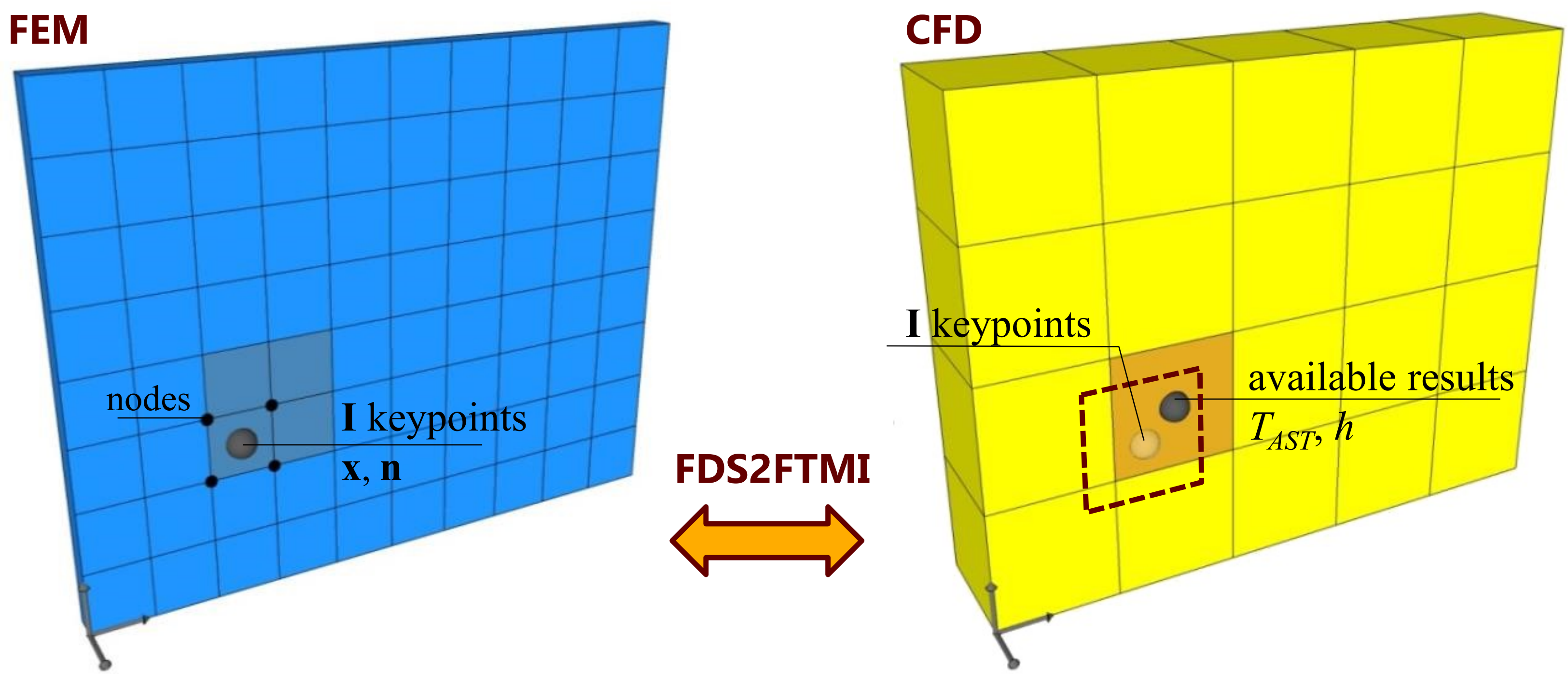
The **present methodology** also uses the **heat transfer coefficient (h)** to achive a **correct definition** of the **total heat flux**

Methodology

Models which geometries do not perfectly match

The connection between the exposed face of **each thermomechanical element** and the **fire simulation results** is acomplished by a **colection of spots** (**I**, of coordinates **x**) localized at the center of each face

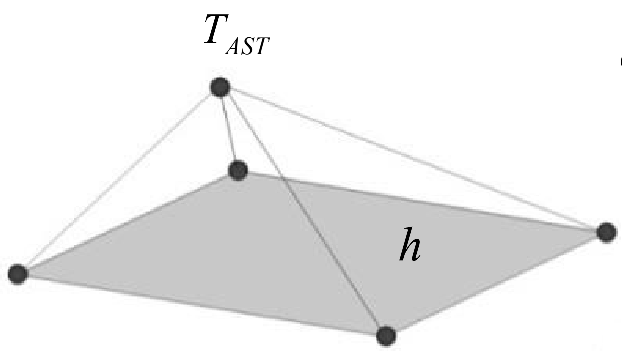
The **element size** needed to achieve a **correct solution** at the thermomechanical model can lead to an **unfeasible fire simulation**



Methodology

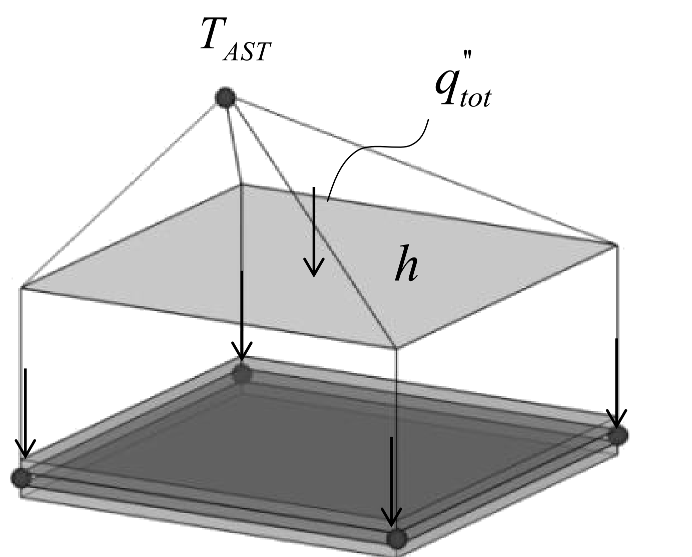
Heat flux into FEM models

At the FEM model, the main target is create an **iterative solution** capable to use the **surface temperature** to evaluate the **heat flux** at each node of the exposed surface.



SURF152

$$q''_{tot} = \varepsilon\sigma\left[\left(T_{AST}+273\right)^4-\left(T_s+273\right)^4\right]+h\left(T_{AST}-T_s\right)$$



$$\mathbf{q}_{nodes} = \frac{q''_{tot}\cdot A_{elem}}{n_{nodes}}\cdot\mathbf{n}$$

Application

Verification of **FTMI**

Steel panel is exposed to a localized fire to verify FTMI

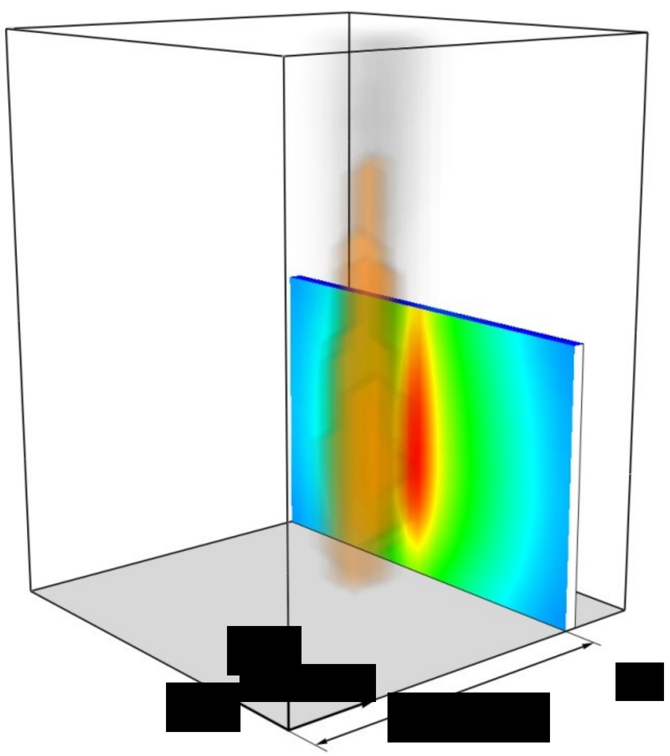
Analyze the **effects of the simplifications** related to the **interface** between geometries that **do not match perfectly**

Fire simulation domain is 1.5x1.5x2.0m and the fire scenario is the **leakage of 0.1 l/min of methane at a velocity of 2m/s, at 30cm from the panel**

Panel A is plane (parallel to *yz*, x=1.2m), with **1.5m width** (*y axis*), **1.0m height** (*z axis*) and **1cm thick** (*x axis*).

Main target: **verify** if FTMI is capable to **address accurately** the **heat transfer phenomena** through the **surface thermal exposure**

Panel A

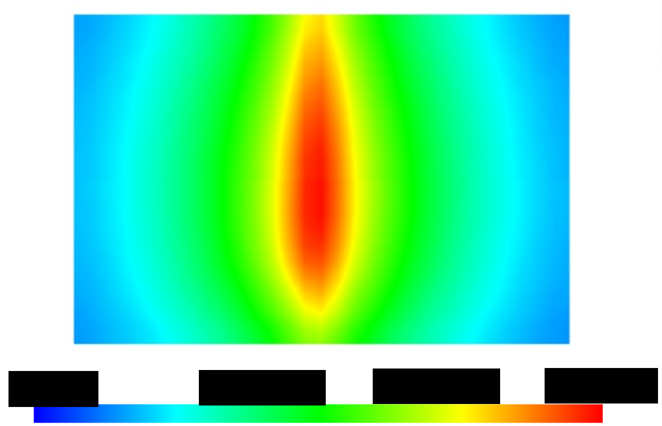


Application

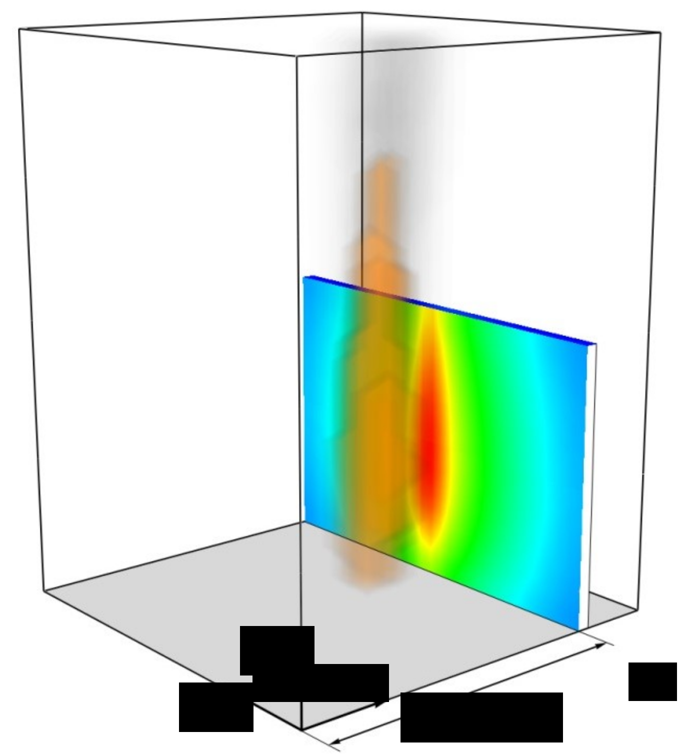
Verification of **FTMI**

The metalic panel **temperature distribution** obtained bt **FTMI and FDS** are **compared** in order to evaluate about the accuracy of FTMI

For this example, the thermal model was **adapted** to consider only the **heat conduction at the x direction** (unidirectional heat conduction model)



Panel A

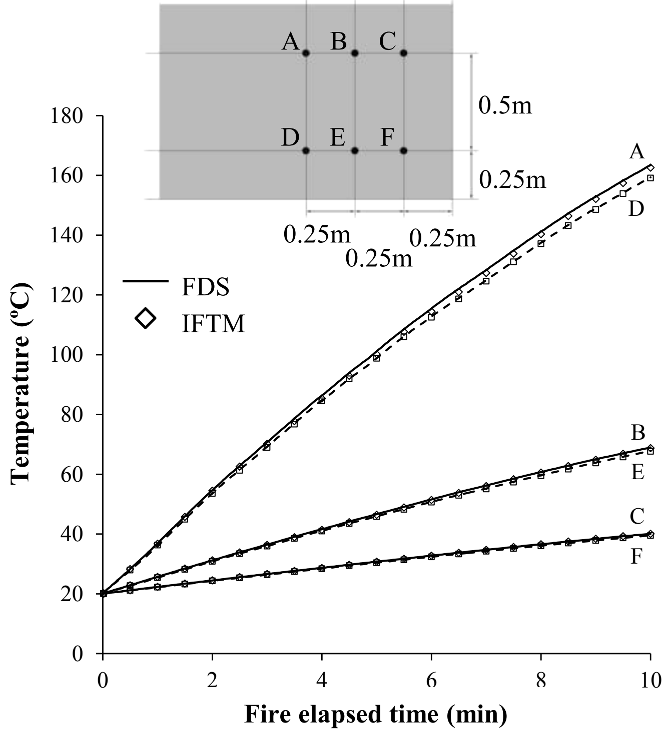


Application

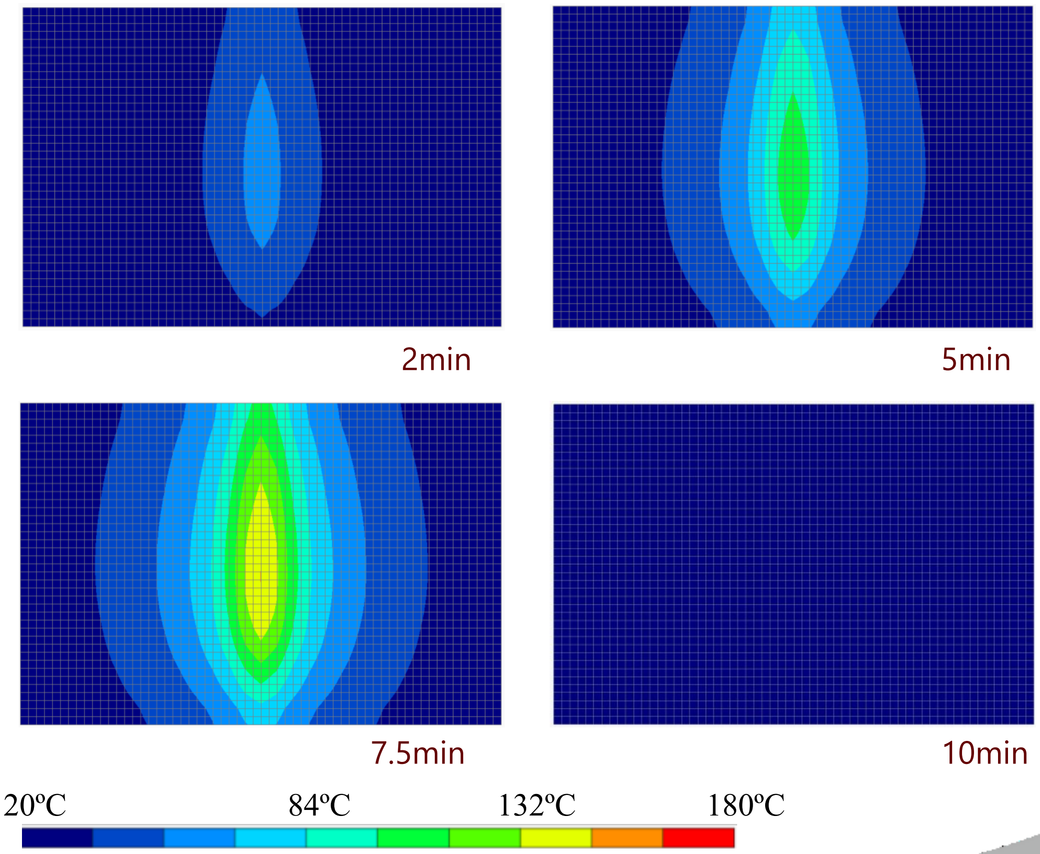
Verification of **FTMI**

Panel A

The **maximum difference** between the models is about **0.5%**



FTMI was capable of process the surface's heating condition accurately



Application

Verification of **FTMI**

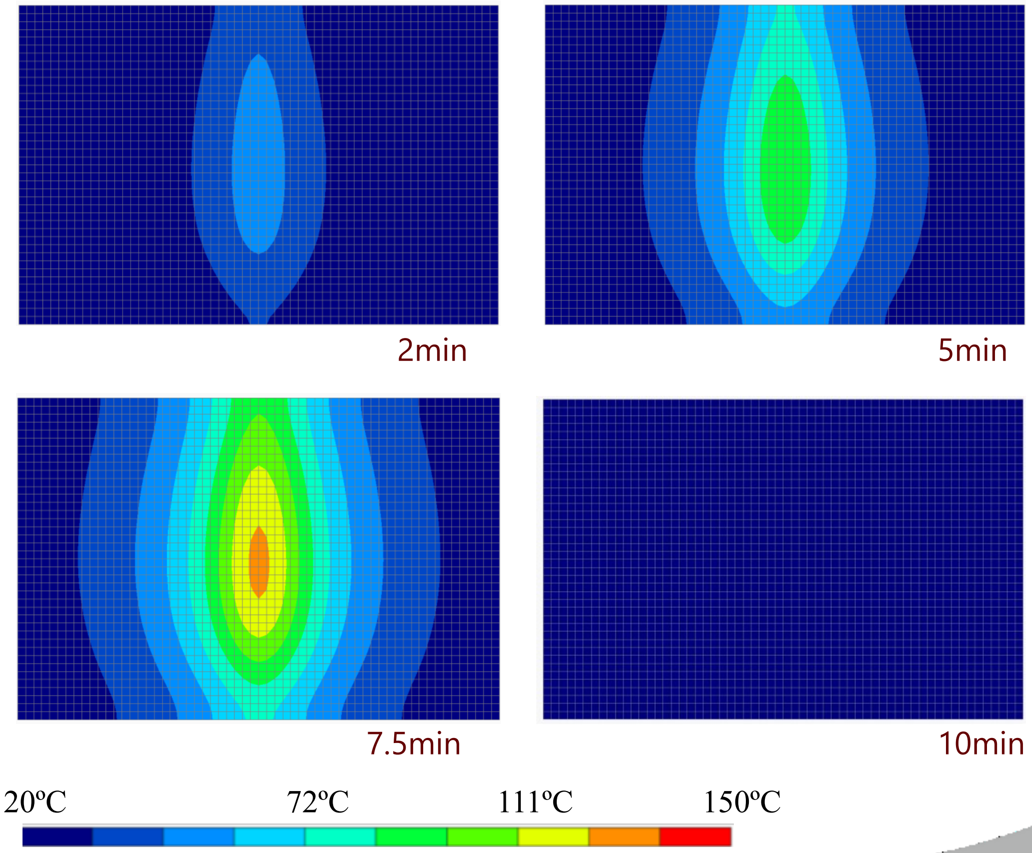
Panel A

After the verification between **FDS and FTMI** is a **logical exercise** ask about the need for a **complex methodology** to achieve a temperature profile already provided by FDS

The temperature distribution provided by FDS **cannot represent accurately** the **heat conduction phenomena in solids**

To evaluate this comparison the **thermal model was simplyfied** just to check if FTMI is capable of **address correctly the complexity of heat transfer phenomena**

The maximum temperature achieved was 154ºC at 10min of fire elapsed time (85% of maximum temperature obtained by previous model - 181.5ºC)



Application

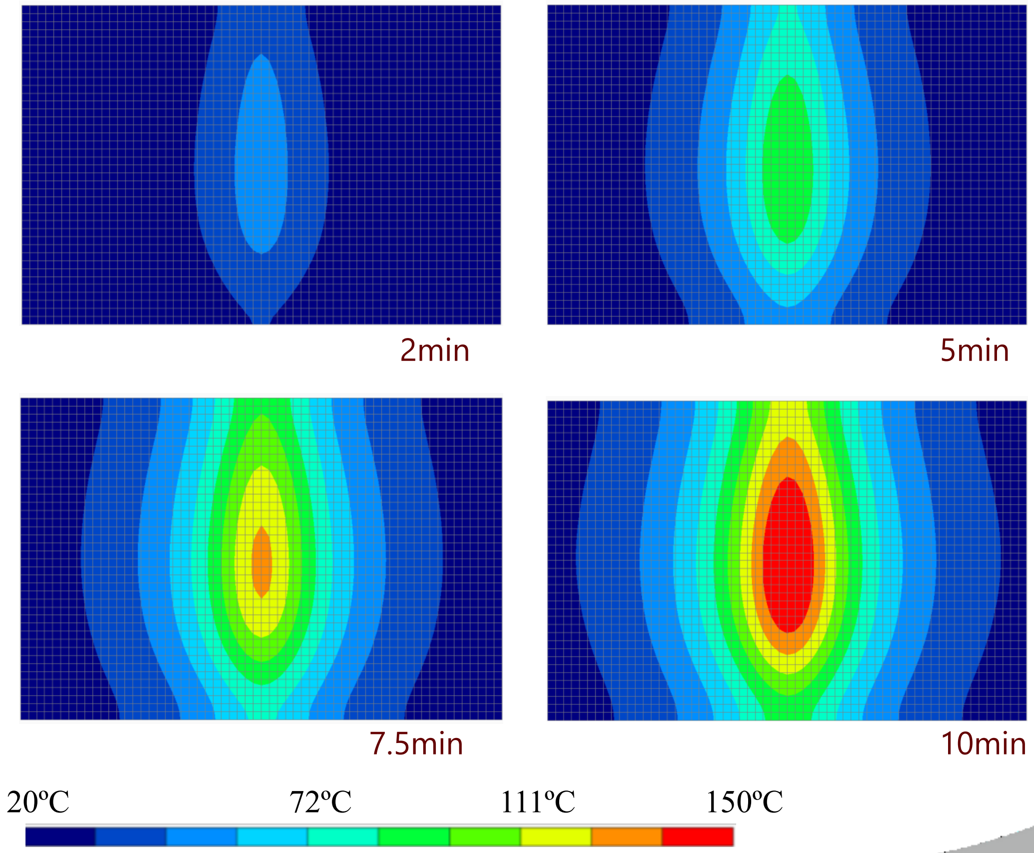
Verification of **FTMI**

Panel A

In this study case, the structure was represented by a **plane surface, aligned with the Cartesian axis**; however structures geometries are **very complex**

Even **simple panels** usually have **stiffeners** or **adjacent elements** that can change the temperature field

The maximum temperature achieved was 154ºC at 10min of fire elapsed time (85% of maximum temperature obtained by previous model - 181.5ºC)



Application

H-profile column

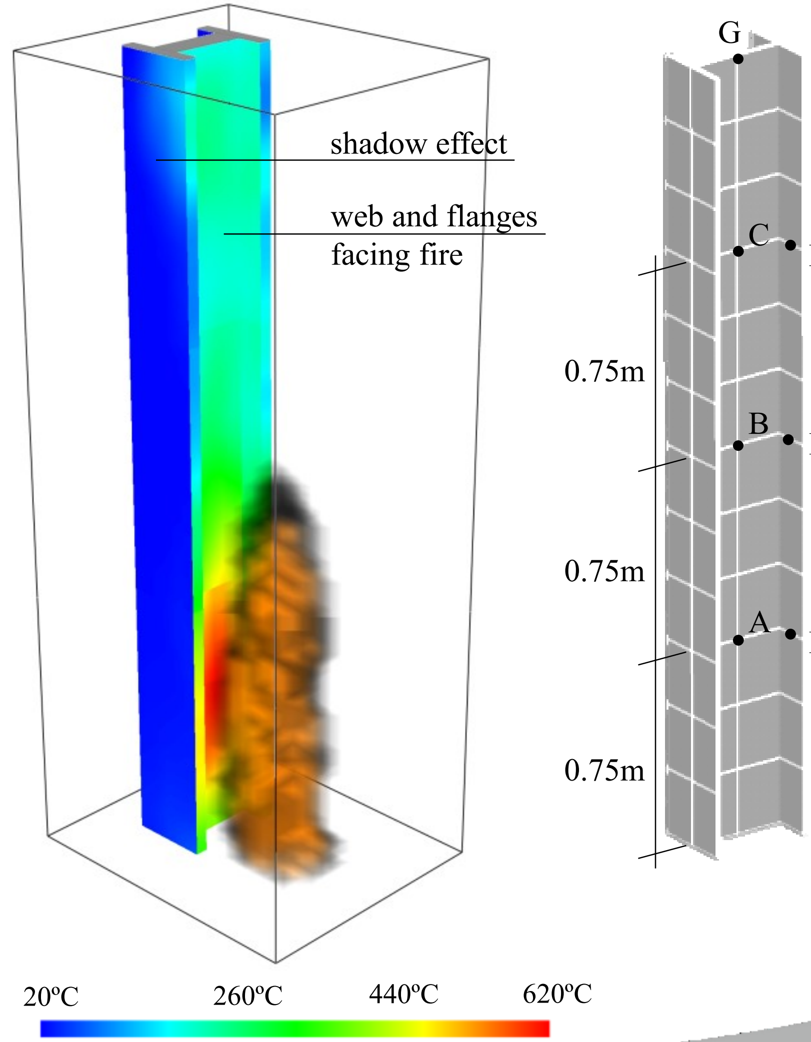
In this case a **simple supported** H-profile column is exposed to a localized fire

The steel column is **3m height** and the cross section is **0.3m (flange) x 0.4m (web)**, with a 12.5mm thickness web and 16mm thickness flanges

The fire scenario is a **200kW** pool fire (20x20cm) located 40cm (from pool center) to the web

The column is subjected to a vertical load of **325kN**, which correspond to **1/50** of the **Euler's buckling critical load**

Each side of these shell elements will have a different **thermal exposure (shadow effect), incident radiation and gas temperatures** around the surface

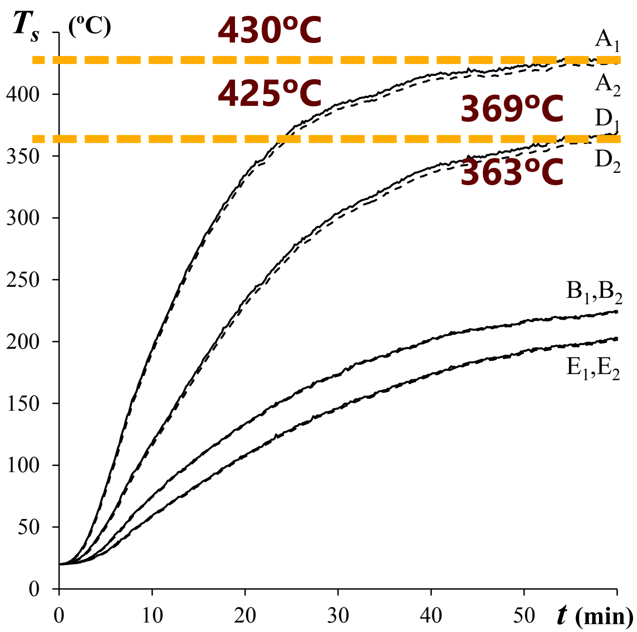


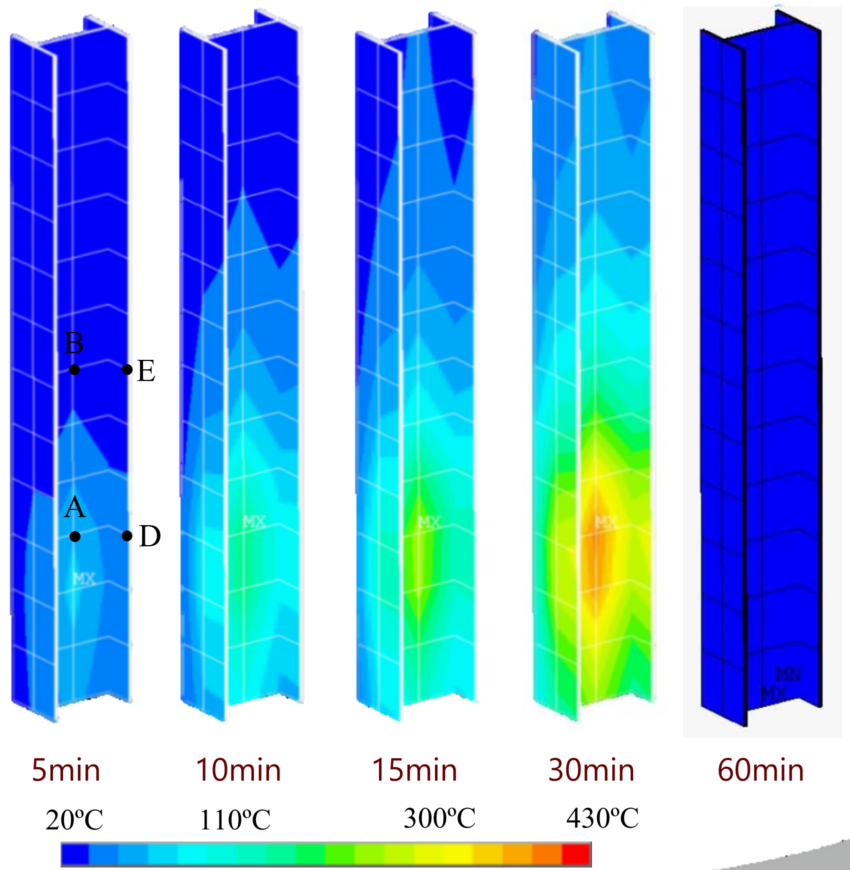
Application

H-profile column

The **maximum temperatures** are achieved at points **close to the fire source**, as A and D

The temperature **decreases with the distance** from fire source and those points are more affected by the **thermal conduction**



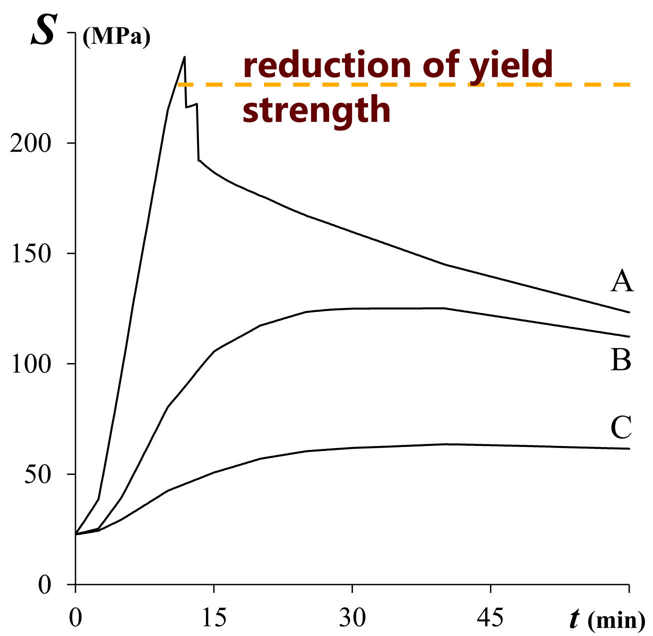


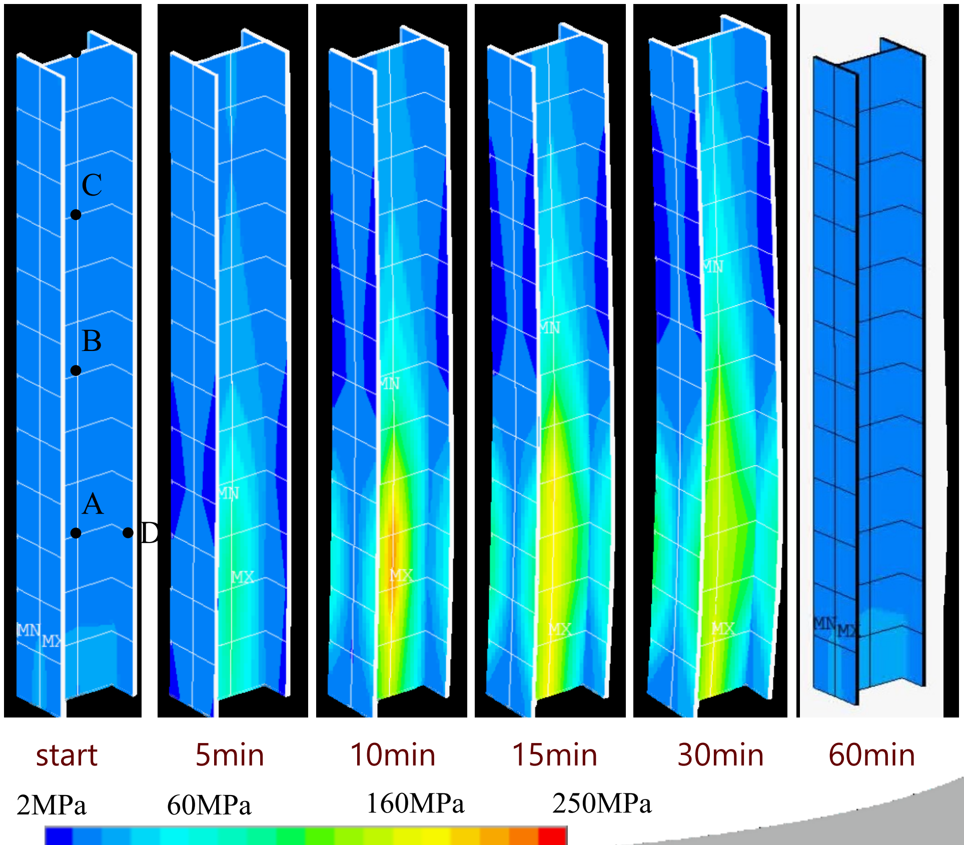
Application

H-profile column

At the beginning of the fire, the **stress concentration** is located at the areas **close to the fire source**

The **expansion of the heated flange** areas start to create a **bending moment** originated by the **temperature gradient**





Application

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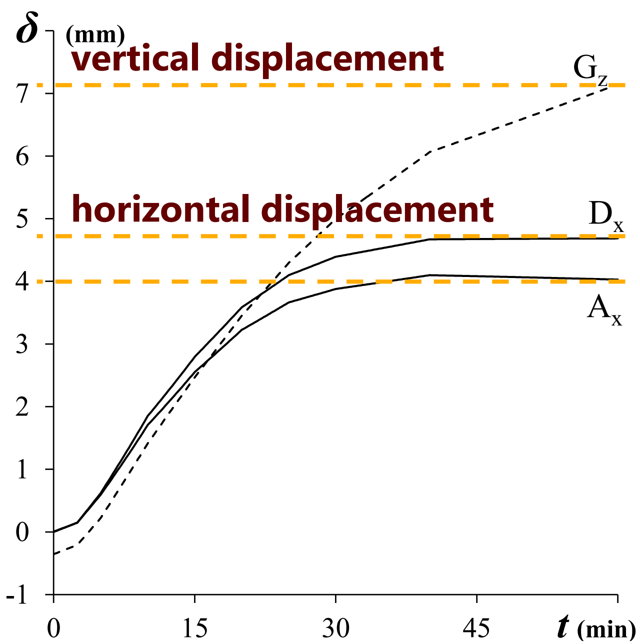
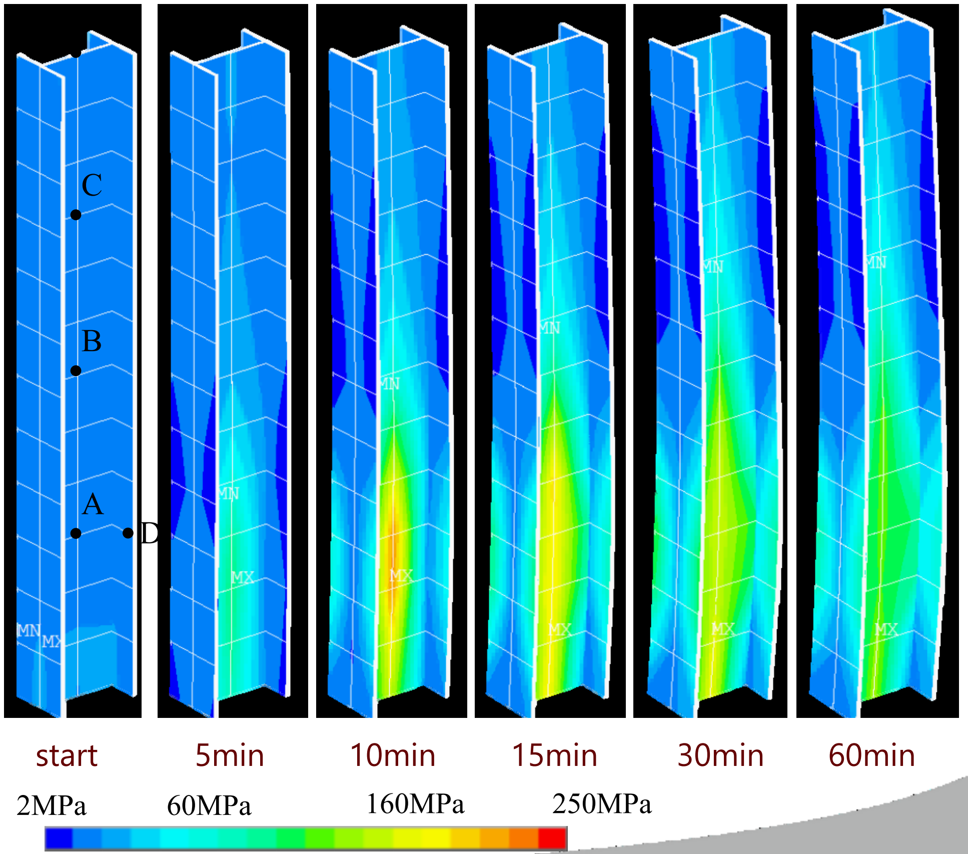


During the analysis of **global structures** this expansion can lead to **additional forces** at other members.



Conclusions

The main goal of this work is to provide a **Fire-Thermomechanical Interface (FTMI)** model devoted to **performance-based analysis** of structures under fire conditions

The application cases **verified** that the proposed procedure can **precisely evaluate** the **interface between CFD and FEM models**

The addition of the **heat transfer coefficient distribution** and the definition of the thermal exposure helped to **reproduce correctly the heat flux at the FEM model**

The **automated code (fds2ftmi)** was able to **extract the variables from the FDS results** files and **generate the boundary conditions to ANSYS**, by **APDL scripts**, using solids and shell elements

The presented results **demonstrated** that this **methodology can improve** the reach of the fire engineering producing **reliable performance-based analysis** of structures under fire

THANK YOU FOR YOUR ATTENTION!

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