VI International Workshop Structures in Fire

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A REAL FIRE IN A SMALL APARTMENT – A CASE STUDY –

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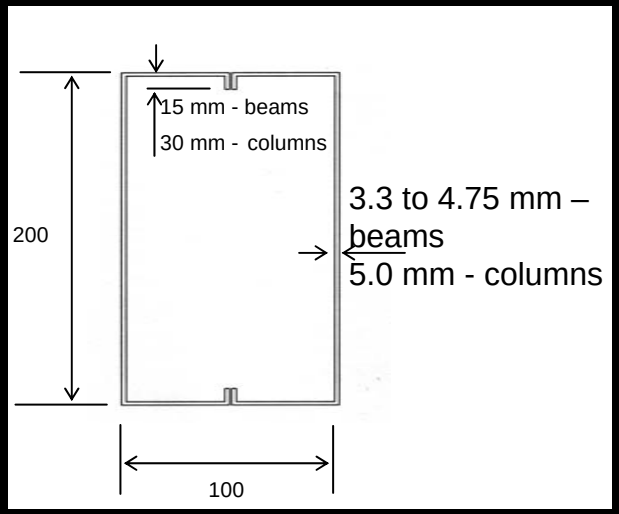
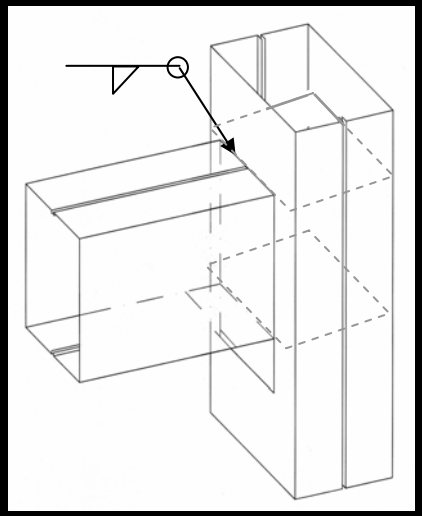
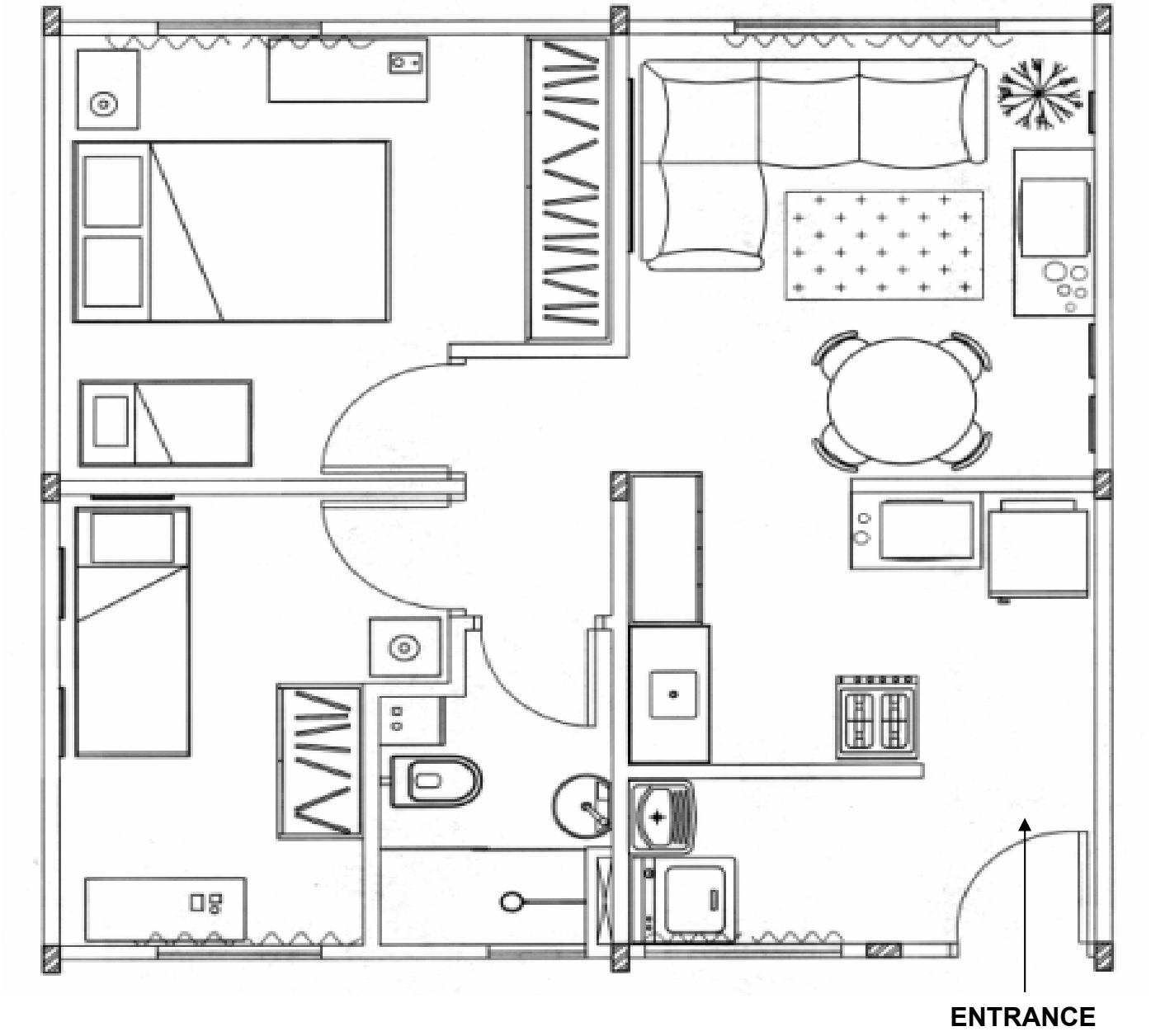
The four storey steel framed building studied was erected in 1988, in Limeira city (State of Sao Paulo). It constitutes four identical blocks. Each block has four floors, with eight apartments per floor. These apartments are very simple, have 44.29 m^2 total area, and contain two bedrooms, a living room, kitchen, a bath-room and a small service area.

The structure is cold formed steel

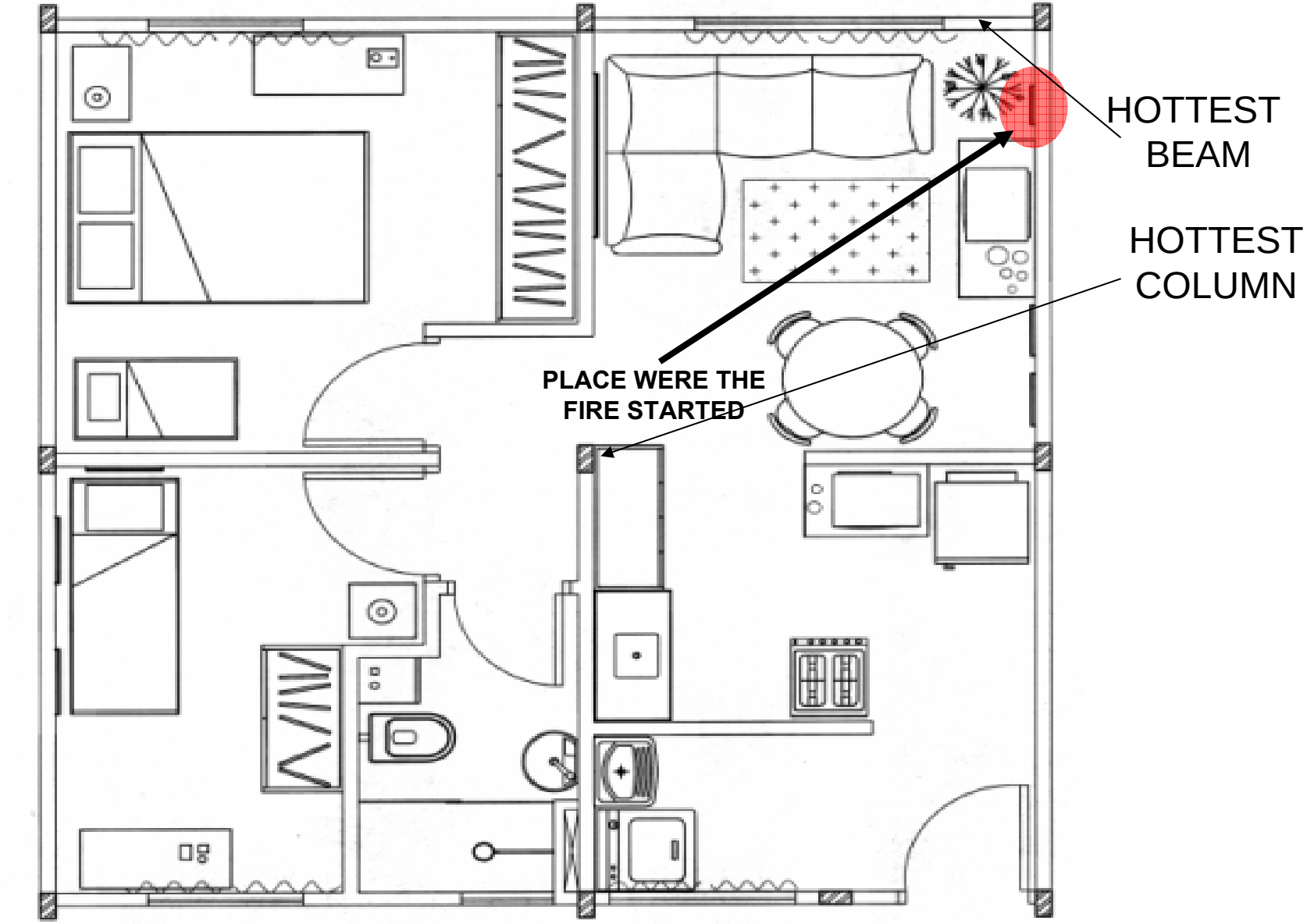




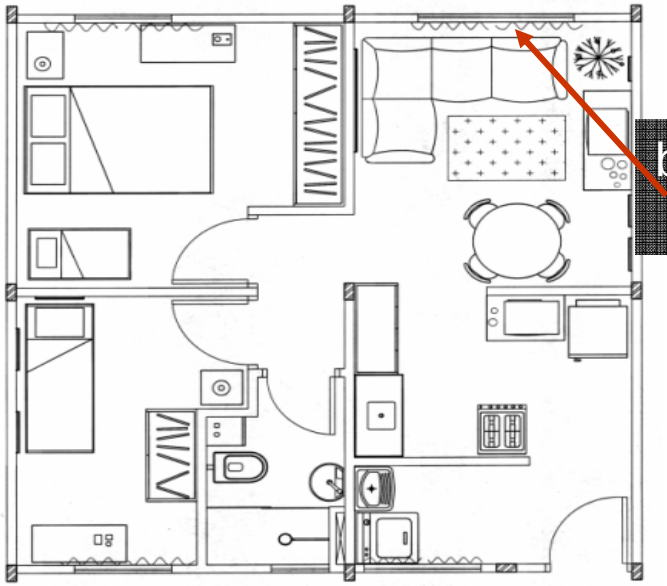
The Brazilian regulation allows that buildings of social interest, with less than 750 m^2 area and 12 m height, can dispense structural verification in fire situation



building plant and furniture arrangement,

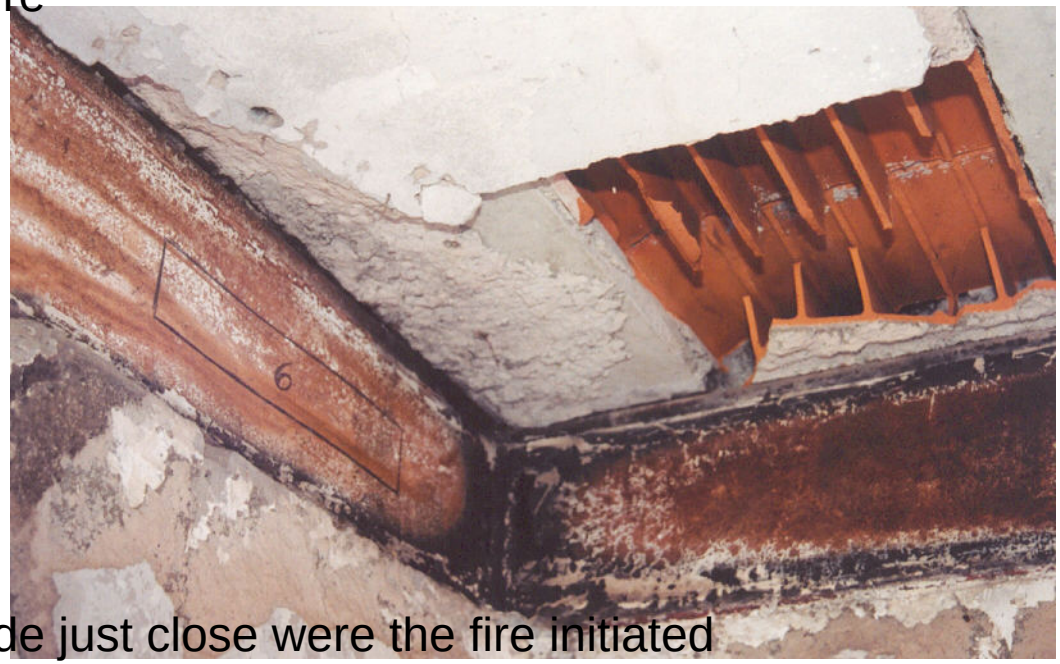


In January 2002, a fire started in the fourth floor apartment.
The fire destroyed all living room furniture and covering. part of all inner masonry was demolished in the after fire due to small cracks and fissures The family who slept in the bedrooms was saved, but had risk of dead by smoke of a child.



behind of the sofa
approx. 1300°C

despite the fire not had been effectively controlled,
- the fire didn’t spread to other apartments neither heat for other rooms
- the fire didn’t damage the steel structure



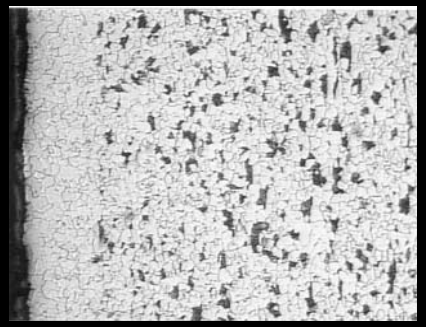
The composite slab started to degrade just close were the fire initiated

This real fire allowed to the authors to face a more scientific evaluation of the fire effects

The original structural design was not found

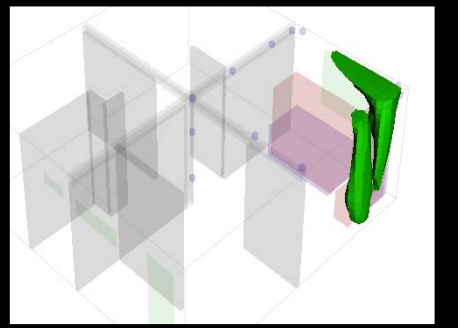
ANALYSES

- Observation in loco

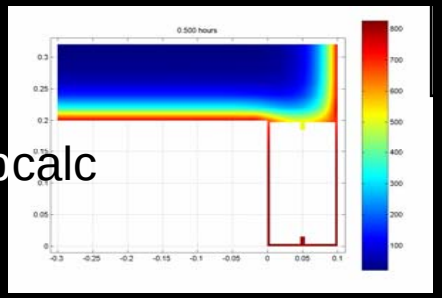


- Metallographic tests

- CFD fire model by software Smartfire



- FEM thermal analysis by software Supertempcalc



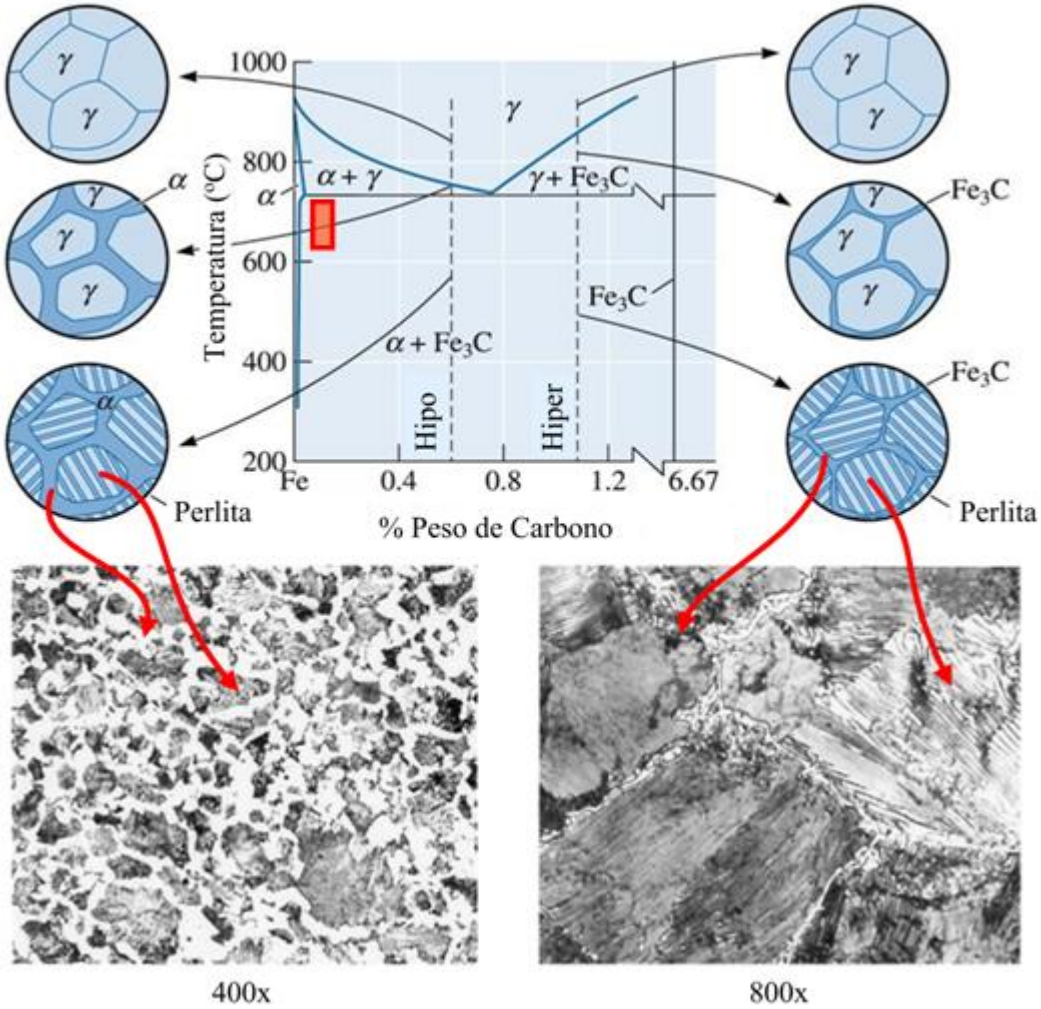
- Simplified structural analysis by Brazilian softwares

$$N_{fi,Rd} = \frac{\rho_\theta \, A_{eff} \, k_{y,\vartheta} \, f_y}{1.2}$$

Observations, photos and measurements was done in loco

Is There as Metallurgical Steel History?

- Up to 600 °C – properties were recovered
- From 600 °C to 723 °C – small loss of mechanical properties (cementite coalescence)
- Upper than 723 °C – mechanical properties were partially lost (grain growth)



METALLOGRAPHIC ANALYSES

Sample's chemical composition.

Element	A1 (cold)	A2	A3	A4	A6	A7	A8
%C	0,119	0,117	0,108	0,112	0,114	0,106	0,106
%Mn	0,432	0,398	0,394	0,398	0,398	0,395	0,386
%P	0,094	0,096	0,099	0,104	0,096	0,093	0,086
%S	0,012	0,008	0,013	0,014	0,008	0,007	0,006
%Si	0,453	0,437	0,480	0,493	0,435	0,426	0,415
%Al	0,045	0,060	0,056	0,057	0,060	0,059	0,058
%Nb	0,013	0,015	0,015	0,015	0,015	0,015	0,014
%V	0,006	0,005	0,006	0,006	0,005	0,005	0,005
%Ti	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005
%Cu	0,204	0,200	0,219	0,215	0,199	0,200	0,201
%Cr	0,869	0,848	0,890	0,896	0,844	0,841	0,830
%Mo	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005	<0,005
%B	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001	0,0001
%Ni	0,013	0,013	0,012	0,012	0,013	0,013	0,013

weathering steel

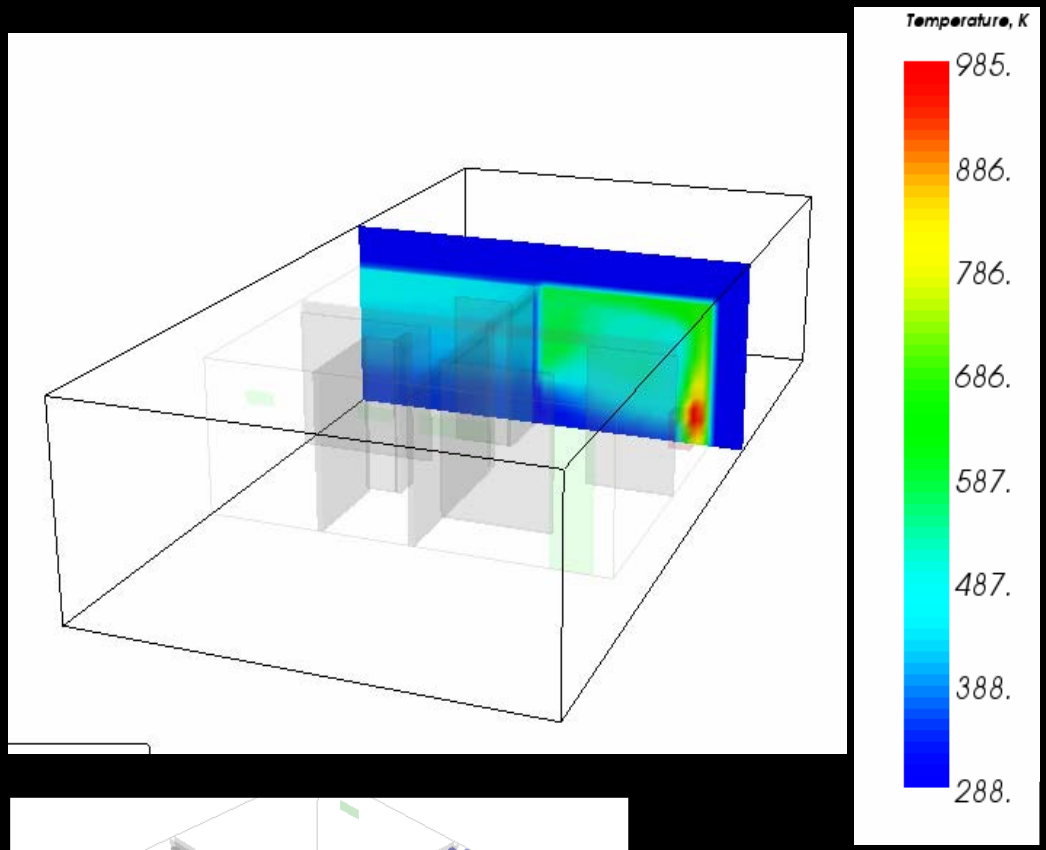
Tensile properties for the test specimens

Sample	Properties				
	Yield strength (MPa)	Ultimate Strength (MPa)	Elongation,% (200 mm)	Decarburizing thickness (μm)	Grain size (ASTM)
1	402	529	30	50	11
2	394	517	29	200	11
3	400	525	32	120	11
4	389	507	31	120	11
6	444	557	27	40	11
7	445	558	27	Nil	11
8	406	533	28	150	11

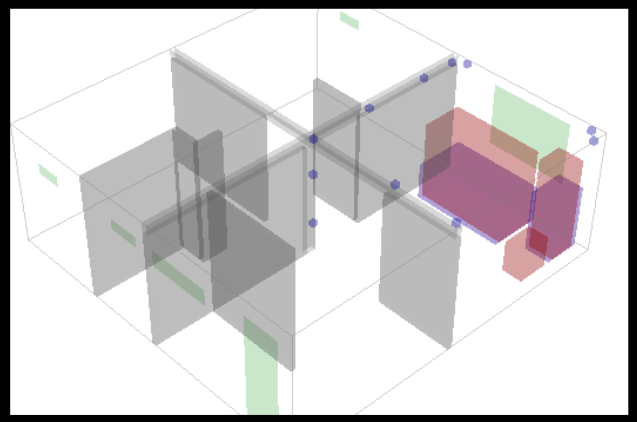
$f_y \approx 390$ MPa

Column $\theta \leq 550$ °C Beam $600 \leq \theta \leq 723$ °C

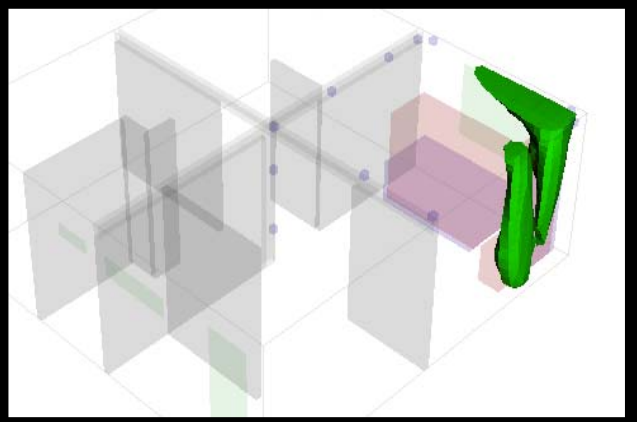
CFD ANALYSES (SMARTFIRE)



Compartmentation effect over temperature distribution (5 min)

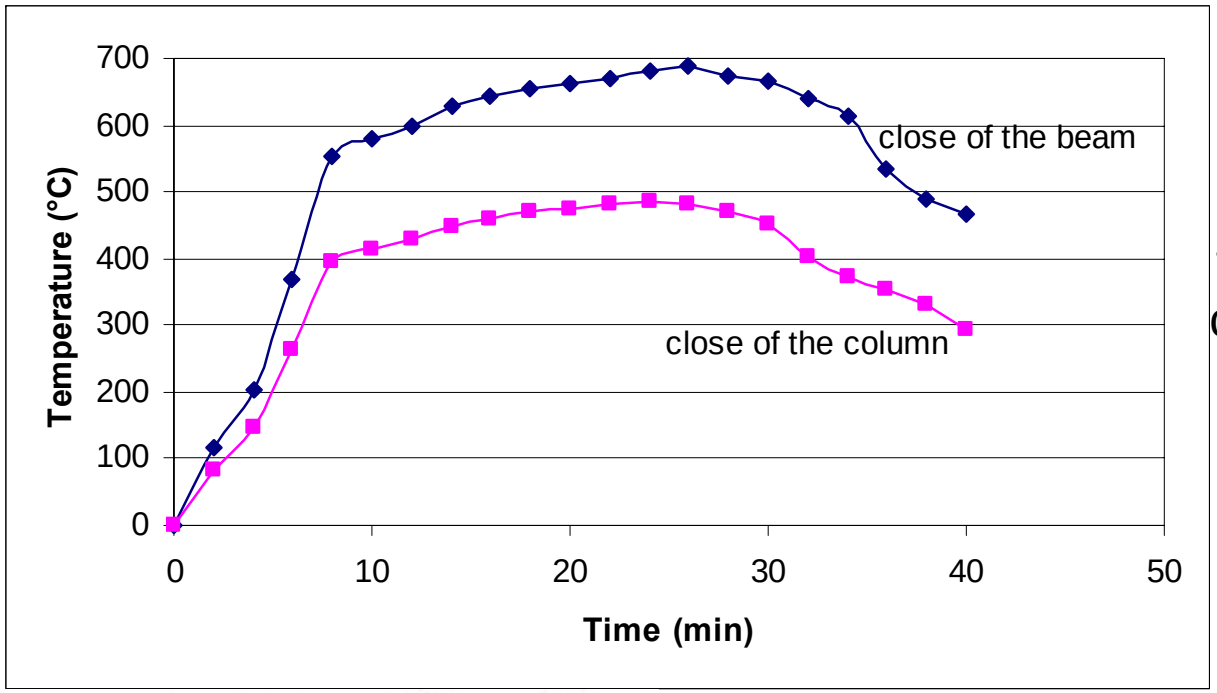


SMARTFIRE graphical interface, showing volume controls

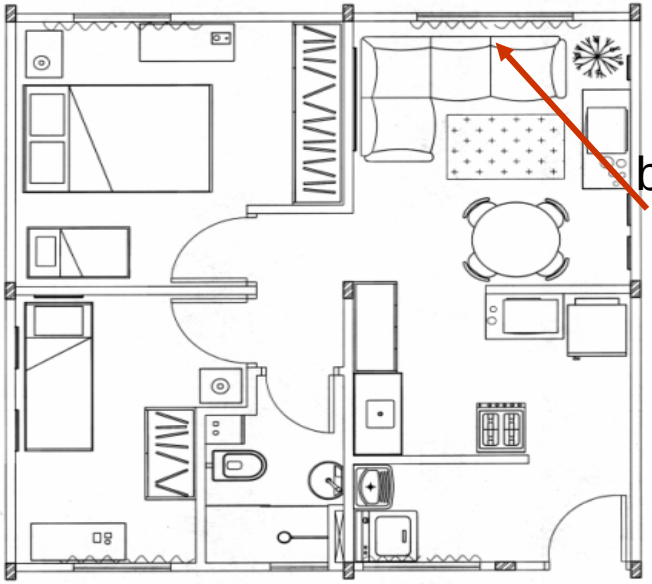


SMARTFIRE fire scenario (2 min)

CFD ANALYSES (SMARTFIRE)

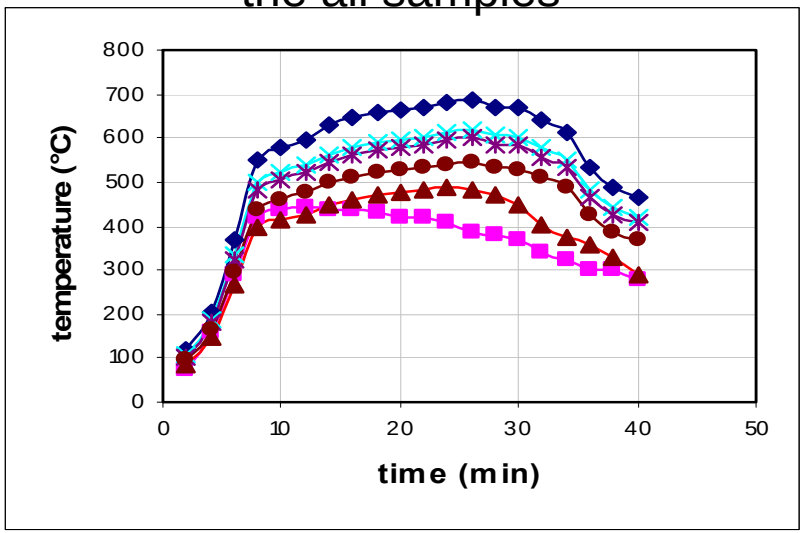


temperature of the hot gases close of the beam and column

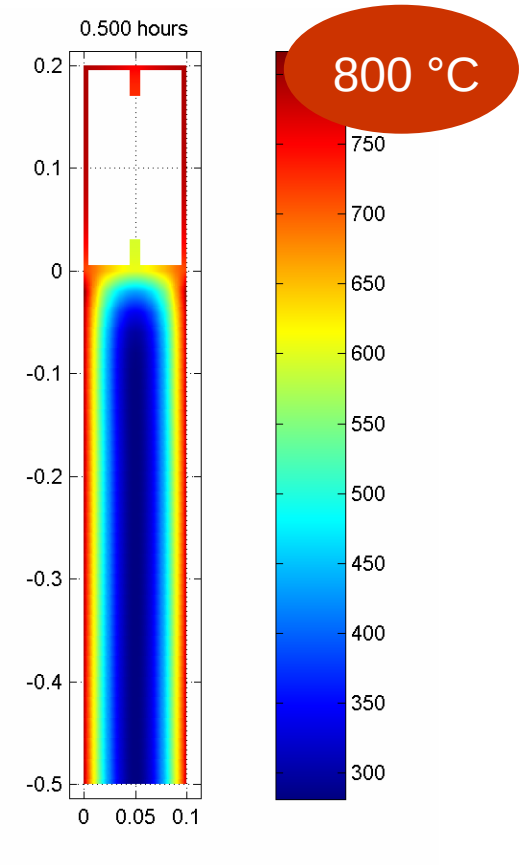


behind of the sofa approx. 1300°C

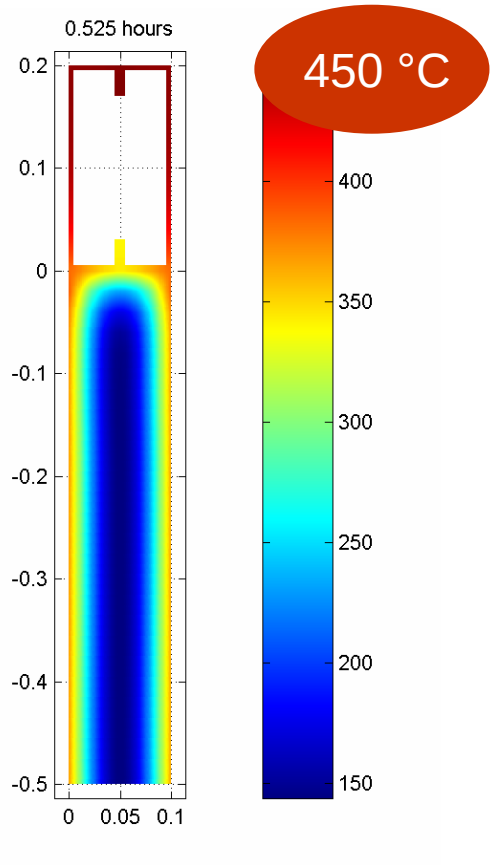
temperature of the gases close of the all samples



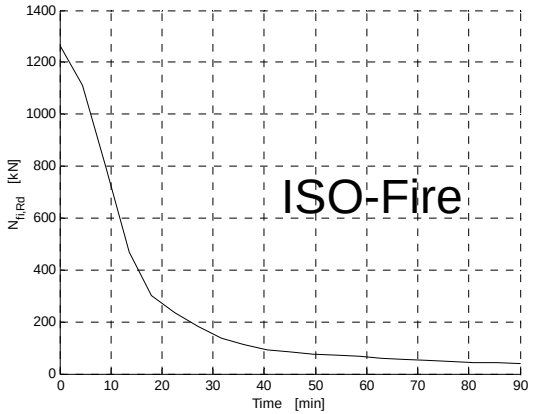
THERMAL ANALYSES (SUPERTEMPCALC)

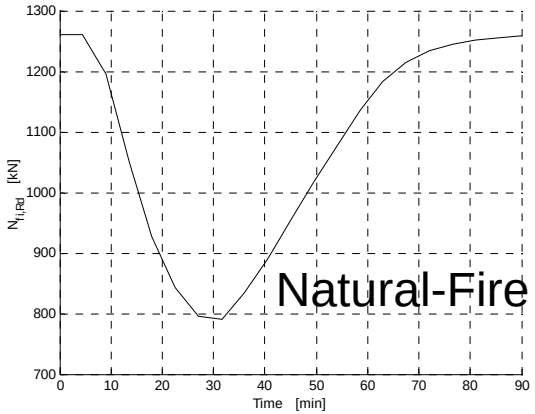


Temperature at 30 min
on the central column and wall
(ISO-Fire).



Temperature at 31.5 min
on the central column and wall
(Natural-Fire)

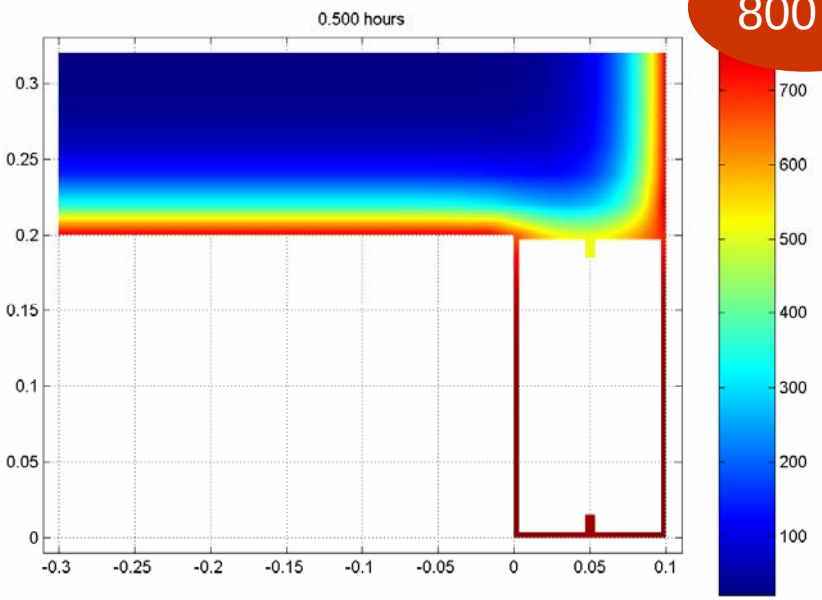




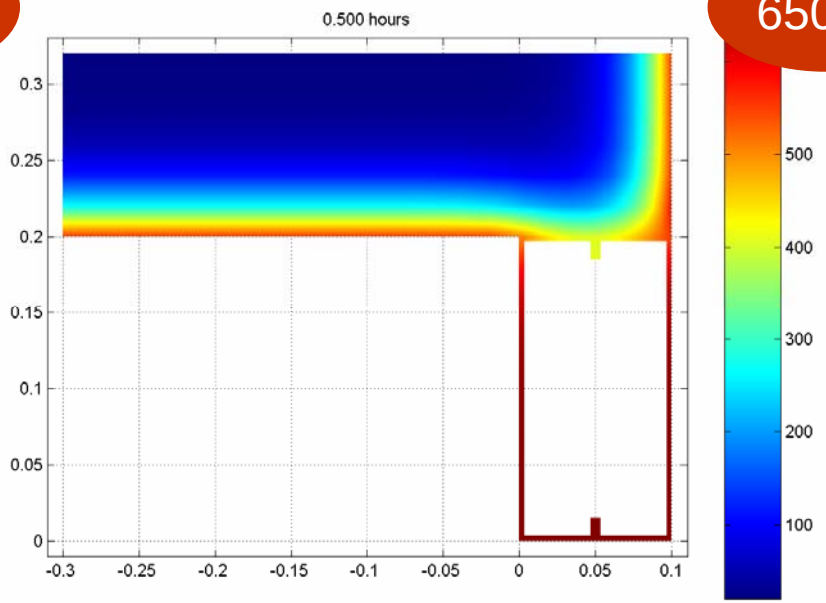
Column
θ (equivalent) ≤ 400 °C

Resistance for uniform
compression vs. time
on the column with wall

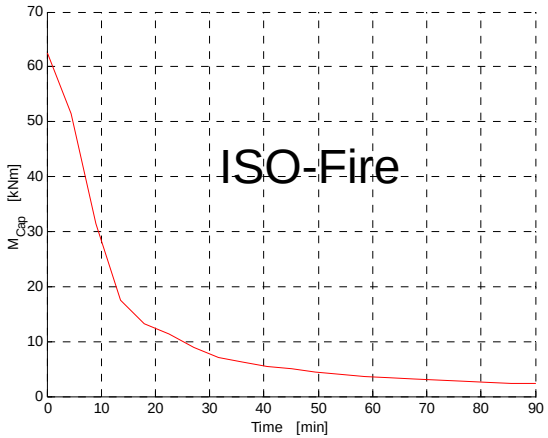
$N_{fi,Rd} = A\ f_y\ k_{y,\theta}$

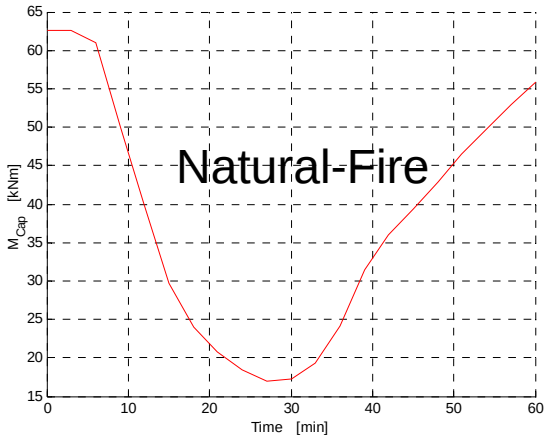


Temperature at 30 min on the beam under a slab (ISO-Fire).



Temperature at 30 min on the beam under a slab (Natural-Fire).

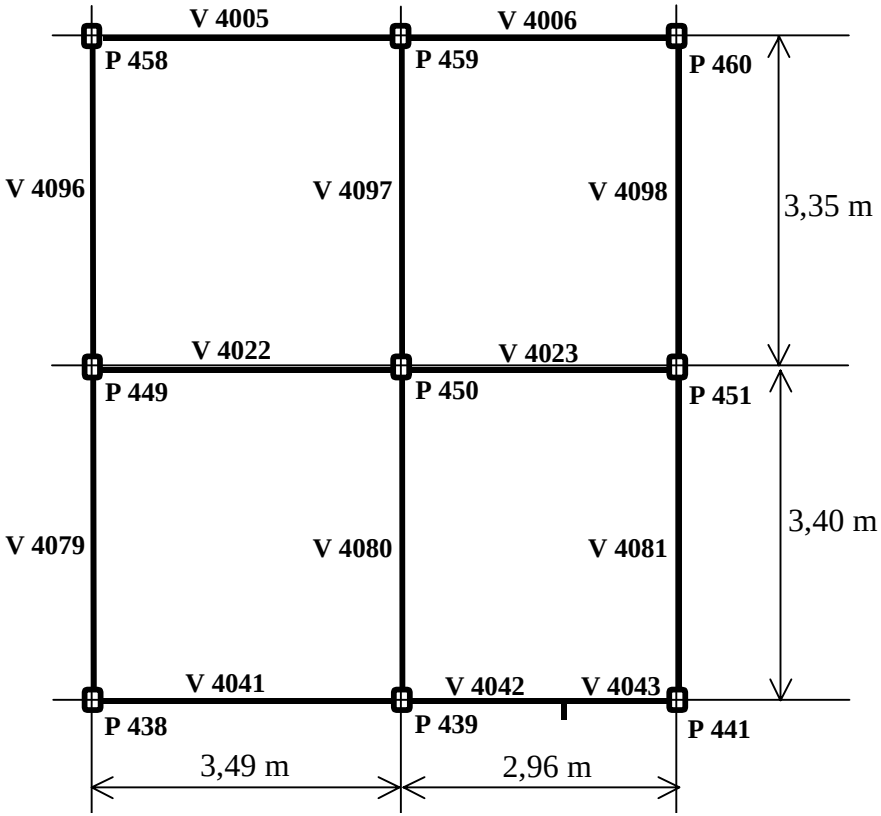




Beam
θ (equivalent) ≤ 610 °C

Resistance for bending moment vs. time on the beam under a slab $M_{fi,Rd} = W_{pl}\ f_y\ k_{y,\theta}$

SIMPLIFIED STRUCTURAL VERIFICATION (BRAZILIAN SOFTWARE)



The compartmentation efficiency and the heat transfer between steel and slab or wall lead to a thermal gradient in the structural elements. That gradient and, consequently, the efforts were not considered in this structural analysis.

The actions from the axial deformation and the little minor inertia bending moment were also not considered.

SIMPLIFIED STRUCTURAL VERIFICATION (BRAZILIAN SOFTWARE)

accidental combination

$$F_{fi,d} = \sum_{i=1}^{n} \gamma_{gi,fi} F_{Gi,fi,k} \text{"+"} F_{Q,exc} \text{"+"} \psi \sum_{j=1}^{m} \gamma_{q,fi} F_{Qi,fi,k}$$

combined bending and compression

$$\varphi_E = \frac{N_{fi,Sd}}{N_{fi,Rd}} + \frac{M_{x,fi,Sd}}{\left(1 - \frac{N_{fi,Sd}}{N_{ex,fi}}\right) \mathrm{W}_{\mathrm{el,x}}\ \mathrm{k}_{\mathrm{y}\theta}\ f_y} \leq 1{,}0$$

$$\varphi_R = \frac{N_{fi,Sd}}{A\ k_{y,\theta}\ f_y} + \frac{M_{x,fi,Sd}}{\mathrm{W}_{\mathrm{el,x}}\ \mathrm{k}_{\mathrm{y}\theta}\ f_y} \leq 1{,}0$$

fire situation – class 4

$$N_{fi,Rd} = \frac{\rho_\theta\ A_{eff}\ k_{y,\vartheta}\ f_y}{1.2}$$

$$M_{fi,Rd} = \frac{W_{el,eff}\ k_{y,\theta}\ f_y}{1.2}$$

column

temperature	1st floor		4th floor	
	φ_E	φ_R	φ_E	φ_R
550 °C	1.03	0.59	0.44	0.36
382.5 °C	0.62	0.34	0.26	0.21
650 °C	2.64	1.21	1.14	0.89
712 °C	5.02	2.03	1.81	1.39
723 °C	5.35	2.19	1.89	1.47

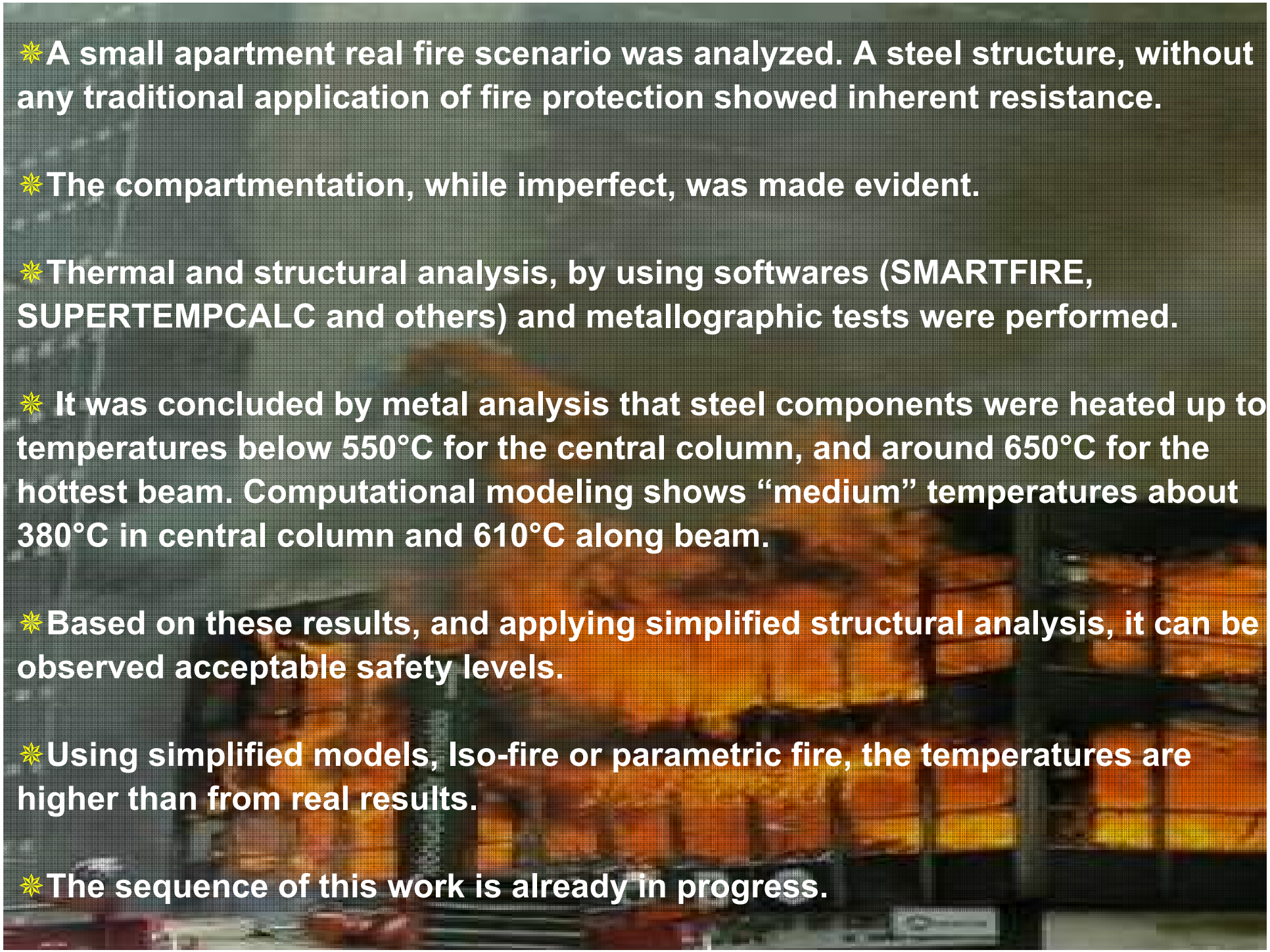
beam

temperature	φ_R
610 °C	0.53
650 °C	0.63
723 °C	0.94

SUMARY

	Metallogr.	Smartfire + Supertemp calc	Isofire 15 min	Isofire 30 min	Parametric curve (max)	Isofire + Supertemp calc (resistance)
Beam (°C)	600 ≤ θ ≤ 723	610	655	815	998	723 (13 min)
Column (°C)	≤ 550	382.5	600	780	995	595 (1st floor – 5,7 min)


FINAL REMARKS



- A small apartment real fire scenario was analyzed. A steel structure, without any traditional application of fire protection showed inherent resistance.
- The compartmentation, while imperfect, was made evident.
- Thermal and structural analysis, by using softwares (SMARTFIRE, SUPERTEMPCALC and others) and metallographic tests were performed.
- It was concluded by metal analysis that steel components were heated up to temperatures below 550°C for the central column, and around 650°C for the hottest beam. Computational modeling shows “medium” temperatures about 380°C in central column and 610°C along beam.
- Based on these results, and applying simplified structural analysis, it can be observed acceptable safety levels.
- Using simplified models, Iso-fire or parametric fire, the temperatures are higher than from real results.
- The sequence of this work is already in progress.