cost Integrated Fire Engineering and Response

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Application of Fire Safety Engineering to a tall building

***Iolanda Del Prete**, PhD Student*
***Prof. Emidio Nigro**, Supervisor*

Di.St. – Department of Structures for Engineering and Architecture
University of Naples "Federico II"
ITALY

Introduction: Fire Safety Engineering

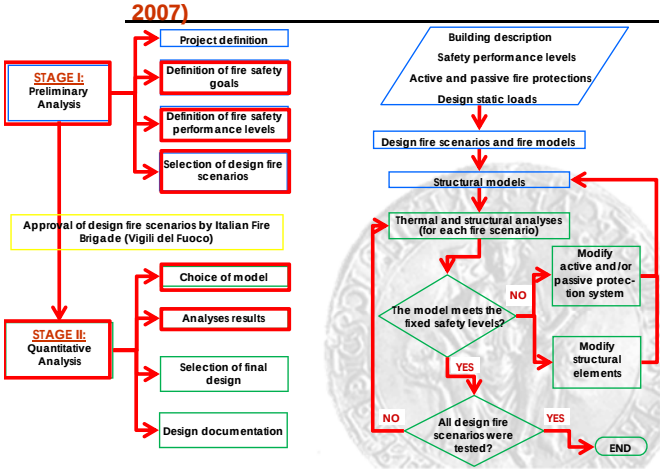
The "Fire Safety Engineering" (FSE) is the application of engineering principles, rules and expert judgement based on a scientific assessment of the fire phenomena, the effects of fire and both the reaction and behaviour of peoples, in order to:

- save life, protect property and preserve the environment and heritage,
- quantify the hazards and risks of fire and its effects,
- evaluate analytically the optimum protective and prevention measures necessary to limit, within prescribed levels, the consequences of fire (ISO/TR 13387-1).

A branch of Fire Safety Engineering is Structural Fire Engineering.

Structural Fire Engineering deals with specific aspects of passive fire protection in terms of analysing the thermal effects of fires on buildings and designing members for adequate load bearing resistance and to control the spread of fire (C. Bailey).

Italian performance-based code (D.M. 09-05-2007)



Case Study: An Italian tall office building

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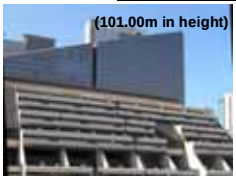
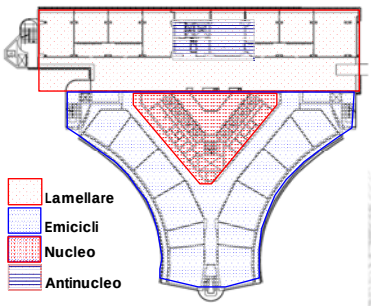
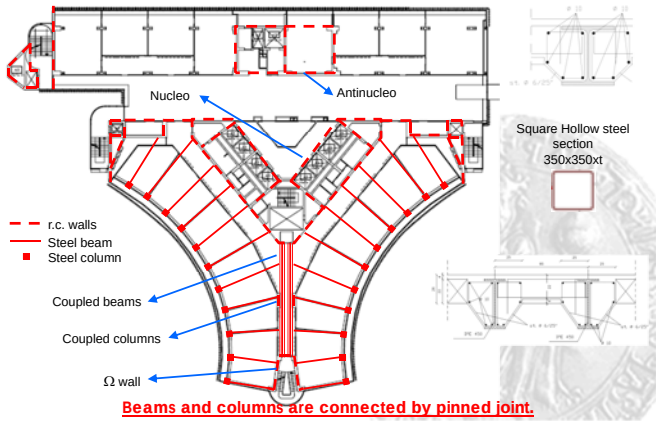




Case Study: Building description

Tower A



Beams and columns are connected by pinned joint.

Case Study: Fire Protection Systems

Active fire protection system

- fire sprinklers system;
- fire hydrants;
- fire extinguishers;
- 4 fire exits on external stairways;
- 1 fire exit on internal separated stairways with 2 fire doors REI 120;
- 3 fire compartments;

no smoke or heat evacuation systems

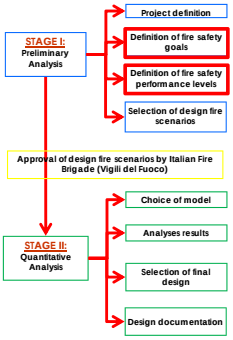
Passive fire protection system

- steel beams are protected by suspended ceiling with gypsum boards;
- columns are protected by gypsum boards.

Fire Safety Performance Levels

Fire Safety Goals

The main objective of fire safety checks concerns the mechanical resistance and stability, in fire situation, of the structure.

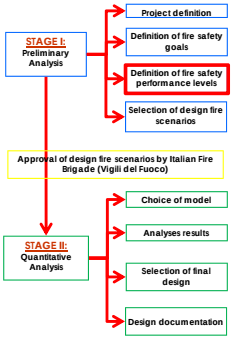


Level I	fire resistance is not required, where consequences are acceptable or where risk is negligible
Level II	maintaining the fire resistance requirements, which ensure the lack of partial and/or complete structural collapse, for a sufficient time with evacuation of occupants
Level III	maintaining the fire resistance requirements, which ensure the lack of partial and/or complete structural collapse, for a sufficient time with emergency management
Level IV	limited damage of the structures after fire exposure
Level V	complete servicebility of structures after fire exposure

Case Study: Safety Performance Levels

Fire Safety Goals

The main objective of fire safety checks concerns the mechanical resistance and stability, in fire situation, of the tower.



Performance level

Highest risk scenario — *High probability scenario*

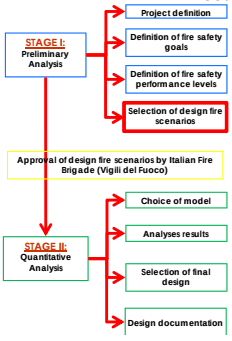
Level III maintaining the fire resistance requirements, which ensure the lack of partial and/or complete structural collapse, for the entire duration of the fire

Level IV limited damage of the strutures after the fire exposure

Case Study: Design Fire Scenarios definition

Fire Scenario

qualitative description of the course of a fire with time identifying key events that characterise the fire and differentiate it from other possible fires. It typically defines the ignition and fire growth process, the fully developed stage, decay stage together with the building environment and systems that will impact on the course of the fire (EN1991-1-2)



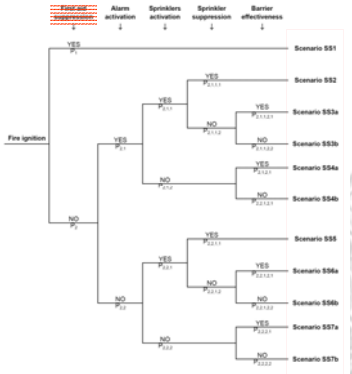
the choice of the design fire scenarios is carried out by Fire Risk Assessment, that takes into account the probability and consequence of the fire scenario

R=PxC

The Fire Risk Assessment is performed through the *Event Tree approach*, according to ISO-16732 Guidelines

Case Study: Design Fire Scenarios definition

Main events:



Secondary events:

- ✓ doors state (open or closed)
- ✓ windows state (open or closed)

Taken into account by the fire model

Probability of occurrence of each event and consequence value of each fire scenario are obtained both by direct estimation from available data and engineering judgment.

Selection of Design Fire Scenarios: Probability of occurrence

1st Event : first aid suppression

Available statistic data show that the probability of detecting fire manually and automatically is 69%. By considering that in 4% of cases, there's no manual or automatic detection system, this probability reaches 72%.
By considering a probability of success equal to 87%,
p(1st Event)=62%

2nd Event: smoke detector effectiveness

Smoke detectors reliability decreases during time, if maintenance operations aren't provided. In the examined case, by considering that system works for a year, and one maintainance operation is provided for each year, it can be assumed
p(2nd Event)=70%

3th -4th Event: sprinkler activation and effectiveness

Statistic analyses, carried out in USA (with reference to time period 2003-2007), show that, during fire event in building with office use, sprinkler activates in 96% of cases, and the system is effectiveness in 99% of cases.
p(3th Event)=96% - p(4th Event)=99%

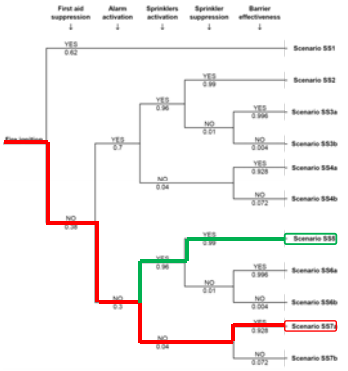
5th Event: barrier effectiveness

Available data show that barrier effectiveness, in building provided by sprinkler, is equal to 99,6%, while is equal to 92,8% in other cases.
p(5th Event)=99,6%

Case Study: Design Fire Scenarios definition

Numerical index of consequence							
Scenario	*1st event*	*2nd event*	*3th event*	*4th event*	*5th event*	*Damage (%)*	*Decription*
SS1	YES					0%	Damage is limited to thing involved in fire
SS2	NO	YES	YES	YES		0.08%	Damage is limited to ½ room
SS3a	NO	YES	YES	YES	YES	0.3%	Damage is limited to 2 rooms
SS3b	NO	YES	YES	NO	NO	0.3%	Damage is limited to 2 rooms
SS4a	NO	YES	NO	NO	YES	2.5%	Damage is limited to the compartment (15 rooms)
SS4b	NO	YES	NO	NO	NO	5.0%	Damage is limited to the entire floor (30 rooms)
SS5	NO	NO	YES	YES		0.3%	Damage is limited to 2 rooms
SS6a	NO	NO	YES	NO	YES	2.5%	Damage is limited to the compartment (15 rooms)
SS6b	NO	NO	YES	NO	NO	5.0%	Damage is limited to the entire floor (30 rooms)
SS7a	NO	NO	NO	NO	YES	50.0%	Collapse of a part of building
SS7b	NO	NO	NO	NO	NO	100.0%	Collapse of entire building

Case Study: Design Fire Scenarios definition



Fire Risk Assessment and Performance levels

Risk Ranking

Scenario	Probability	Consequence	Risk	Risk Ranking
SS1	0.6200	0.00	0.0000	11
SS2	0.2528	0.06	0.0202	5
SS3a	0.0025	0.30	0.0008	8
SS3b	0.0000	0.30	0.0000	10
SS4a	0.0099	2.50	0.0247	4
SS4B	0.0008	5.00	0.0038	6
SS5	0.1083	0.30	0.0325	3
SS6a	0.0011	2.50	0.0027	7
SS6b	0.0000	5.00	0.0000	9
SS7a	0.0042	50.00	0.2116	1
SS7B	0.0003	100.00	0.0328	2

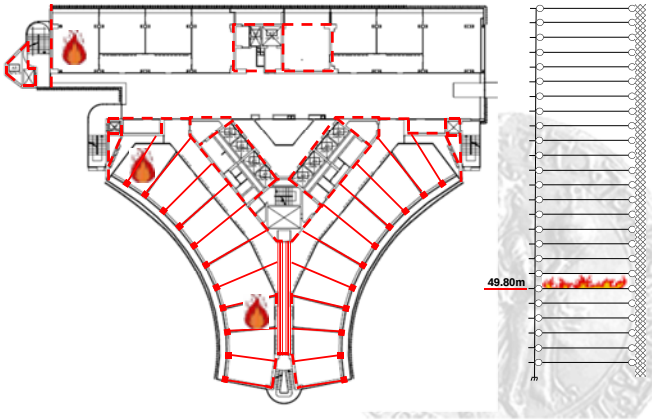
P x C = R

Performance level III: limited damage

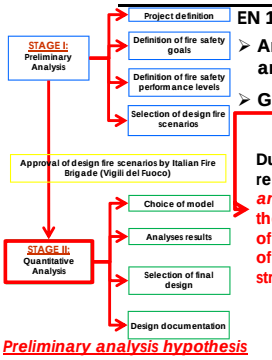
Performance level IV: resistance for all fire exposure time

Case Study: Design Fire Scenarios definition

Tower A



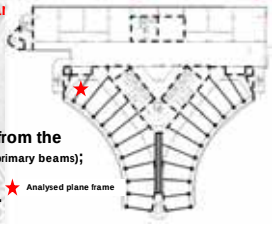
Case Study: Preliminary structural analyses - substructures



EN 1993-1-2 – Verification methods:

- **Analysis of part of the structure (substructure analysis)**
- **Global structural analysis**

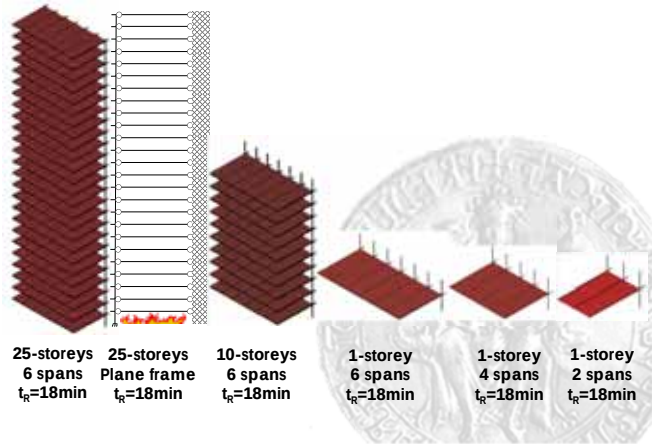
Due to the building's large size, in order to reduce the computational time the *substructure analysis* is adopted, which permit to evaluate the structural fire response through the modelling of significant par of the entire structure



Preliminary analysis hypothesis

- **25-storeys spatial and plane frame extracted from the "Emicicli" zone** (RC slab is designed as simply supported by primary beams);
- **standard time-temperature ISO834;**
- **two fire locations (Scenario A and Scenario B).**
- **unprotected elements**

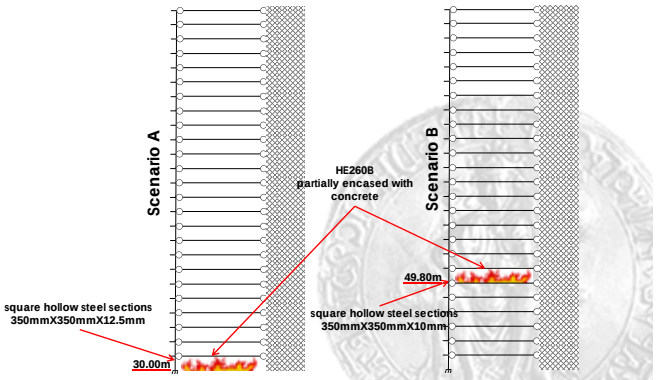
Case Study: Preliminary structural analyses - substructures



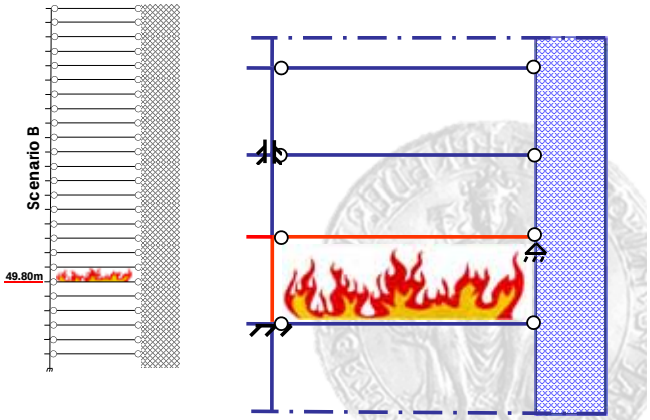
25-storeys 6 spans t_R=18min | **25-storeys Plane frame t_R=18min** | **10-storeys 6 spans t_R=18min** | **1-storey 6 spans t_R=18min** | **1-storey 4 spans t_R=18min** | **1-storey 2 spans t_R=18min**

Case Study: Preliminary structural analyses - substructures

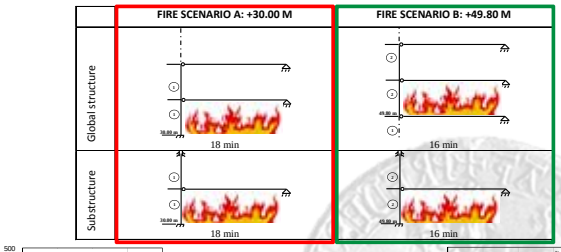
Fire Scenario (ISO834 fire curve)

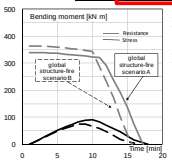


Case Study: Preliminary structural analyses - substructures



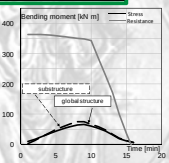
Case Study: Preliminary structural analyses - substructures





- *columns are the weakest element in the structure*
- *the minimum fire resistance occurs when fire involves the thinnest column with highest section factor (Fire Scenario B)*

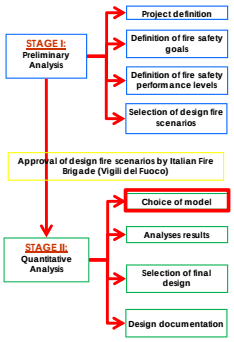
Θ_{cr} (column)=630°C



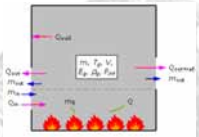
The substructures are able to represent the global structural behaviour.

Case Study: choice of fire model

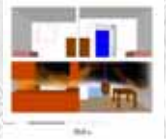
The post-flashover fire is obtained through different models:



✓ **one-zone model**, which assumes homogeneous temperature, density, internal energy and pressure of the gas in the compartment, applying **Ozone** (provided by University of Liege) and **C-FAST** (provided by NFPA)



✓ **CFD model** applying **FDS** (provided by NIST)



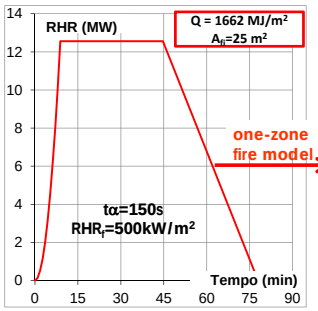
Case Study: Fire Scenario SS7a – One zone model

Fire Model

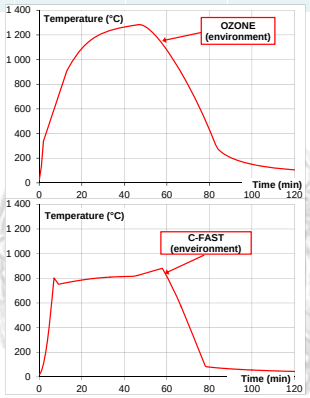
Fire involved in a single room (25m²)

First aid suppression	Alarm activation	Sprinkler activation	Sprinkler suppression	Barrier effectiveness
NO	NO	NO	-	YES

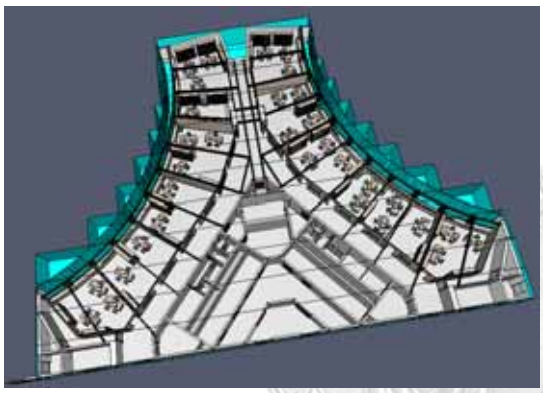
EN1991-1-2



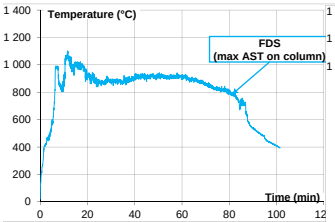
one-zone fire model

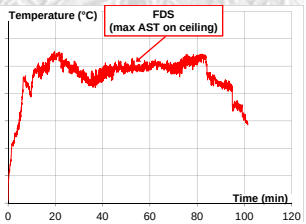


Case Study: Fire Scenario SS7a – CFD model



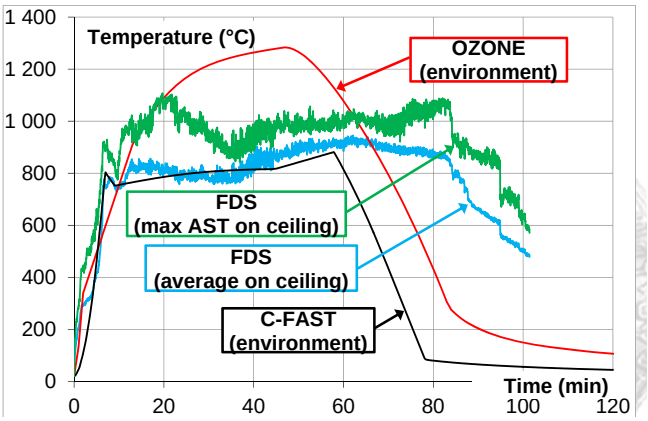
Case Study: Fire Scenario SS7a – CFD model



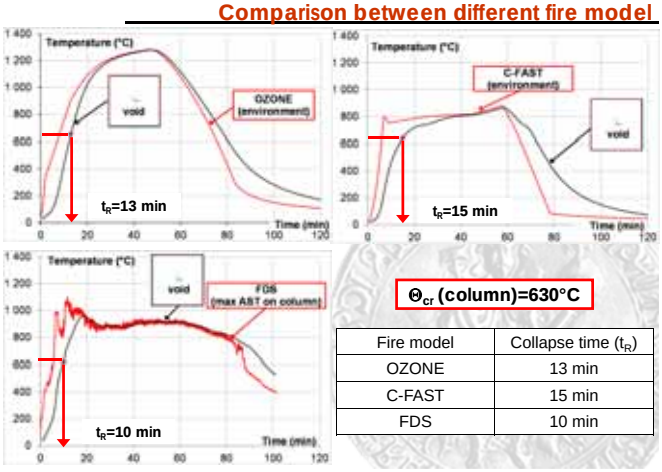


Case Study: Fire Scenario SS7a –

Comparison between different fire models



Case Study: Fire Scenario SS7a – Comparison between different fire model

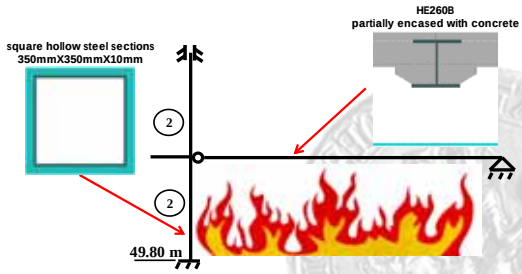


Θ_{cr} (column)=630°C

Fire model	Collapse time (t_R)
OZONE	13 min
C-FAST	15 min
FDS	10 min

Case Study: Preliminary structural analyses - substructures

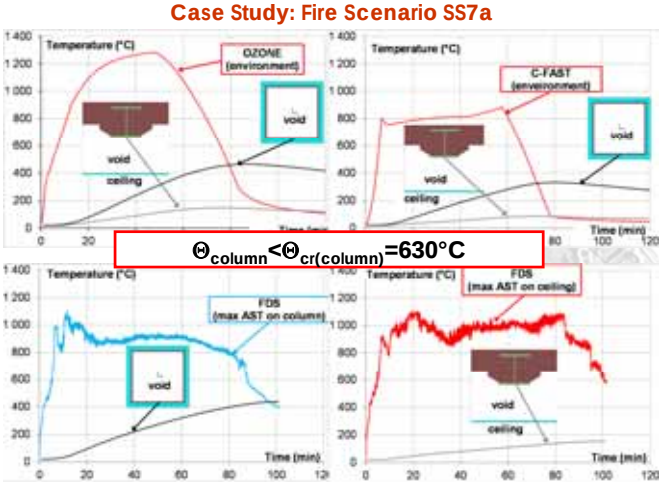
Adopted Substructure



Passive fire protection system

- steel beams are protected by suspended ceiling with gypsum boards;
- columns are protected by gypsum boards.

Case Study: Fire Scenario SS7a



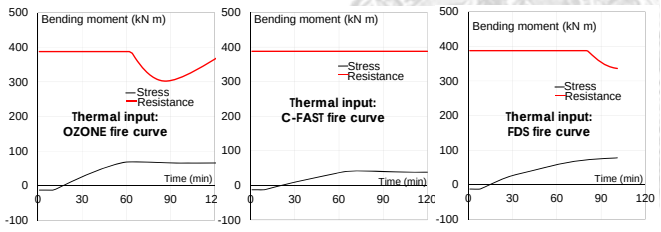
$\Theta_{column}<\Theta_{cr(column)}=630°C$

Case Study: Fire Scenario SS7a

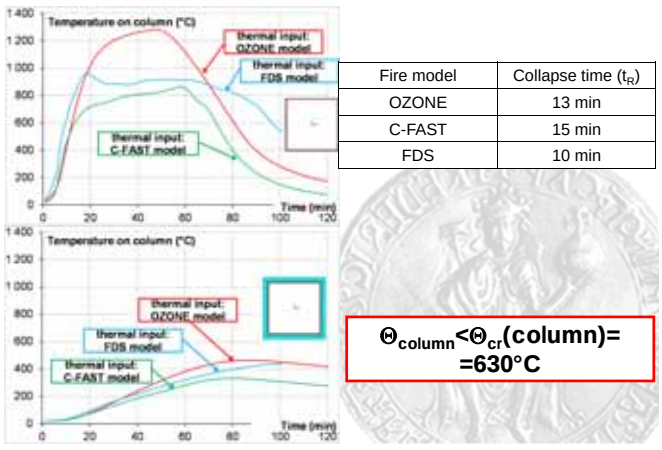
Thermo-mechanical analyses
(with non linear software SAFIR developed at University of Liegi)

$\Theta_{column}<\Theta_{cr(column)}=630°C$

Performance level III: maintaining the fire resistance requirements, which ensure the lack of partial and/or complete structural collapse, for the entire duration of the fire is satisfied



Summary of the results in SS7a scenario

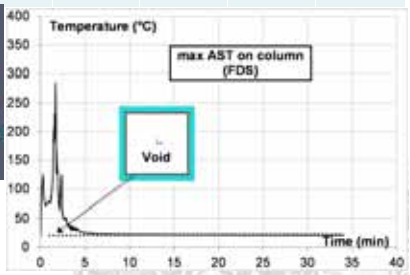


Fire model	Collapse time (t_R)
OZONE	13 min
C-FAST	15 min
FDS	10 min

$\Theta_{column}<\Theta_{cr}(column)=$ $=630°C$

Case Study: Fire Scenario SS5

Fire scenario	First aid suppression	Alarm activation	Sprinkler activation	Sprinkler suppression	Barrier effectiveness
SS5	NO	NO	YES	YES	YES



In fire scenario SS5 the fire is extinguished after some time.

Performance level IV:
limited damage of the strutures after the fire exposure is satisfied

Summary and Conclusions

- This presentation is devoted to the application of Structural Fire Engineering (according to Italian and European Codes) to a tower of an existing tall building
- The identification of design fire scenarios is carried out by means of Fire Risk Assessment, applying the event tree approach according to ISO-16732 Guidelines.
- Due to the building's large size, in order to reduce the computational time the substructure analysis is adopted
- Different fire models are used: analyses results show that thermo-mechanical behaviour of structure under different fire models is quite similar, therefore the use of simplified model, as one zone model, is justified
- Analyses results of the highest risk fire scenario (SS7a) and of the most probable fire scenario (SS5) show that, Performance levels are satisfied

Thanks for your attention