TRAINING SCHOOL , June 6-9 2013, Naples

Current Research at University of Naples

- Structural behaviour of composite steel-concrete buildings in fire
- Simplified fire design methods for steel-concrete composite members (e.g. Annex F of EN1994-1-2)

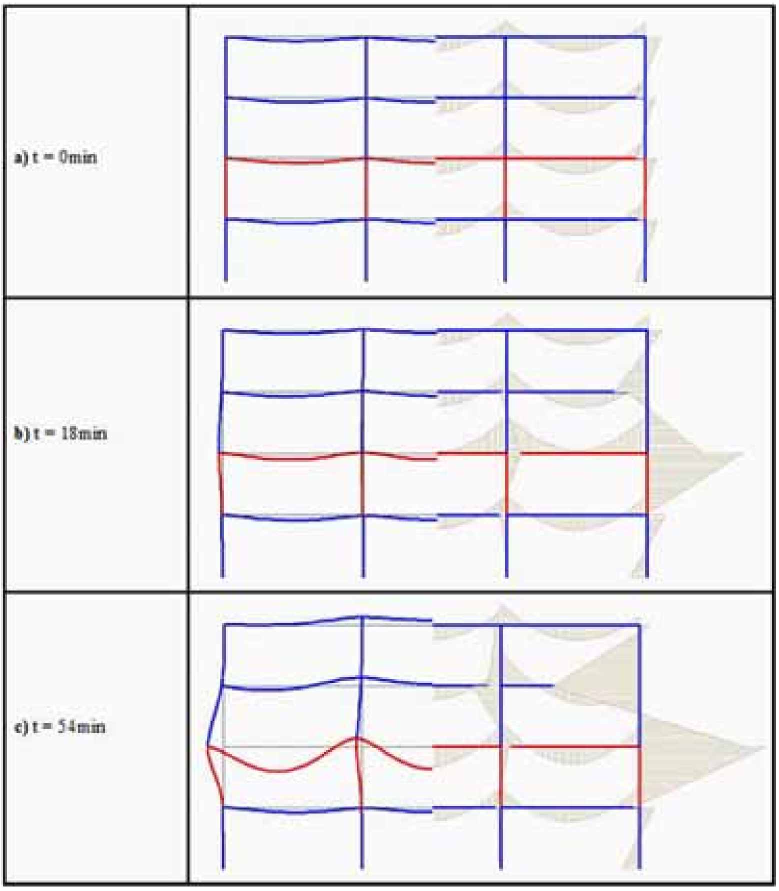
- Fire tests and theoretical analysis of concrete slabs reinforced with FRP bars (will be presented by Antonio Bilotta in TS)

- Applications of Structural Fire Safety Engineering to car parks
- FSE and Fire Risk Assessment approach (will be presented by Iolanda Del Prete in TS, but some general concepts will be given in this presentation)

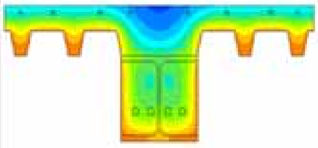
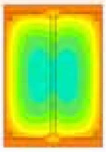
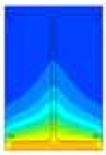
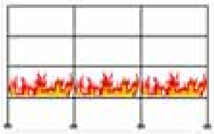
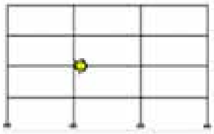
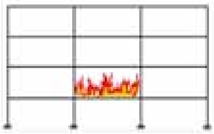
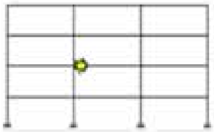
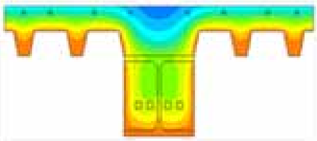
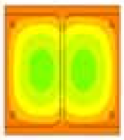
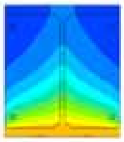
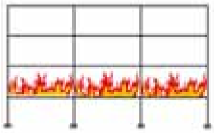
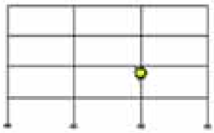
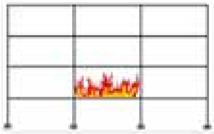
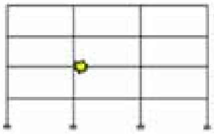
WG1 - Emidio Nigro
WG2 - Giuseppe Cefarelli
WG3 - Antonio Bilotta
Iolanda Del Prete
Anna Ferraro
Domenico Sannino

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

Structural behaviour of composite steel-concrete buildings in fire



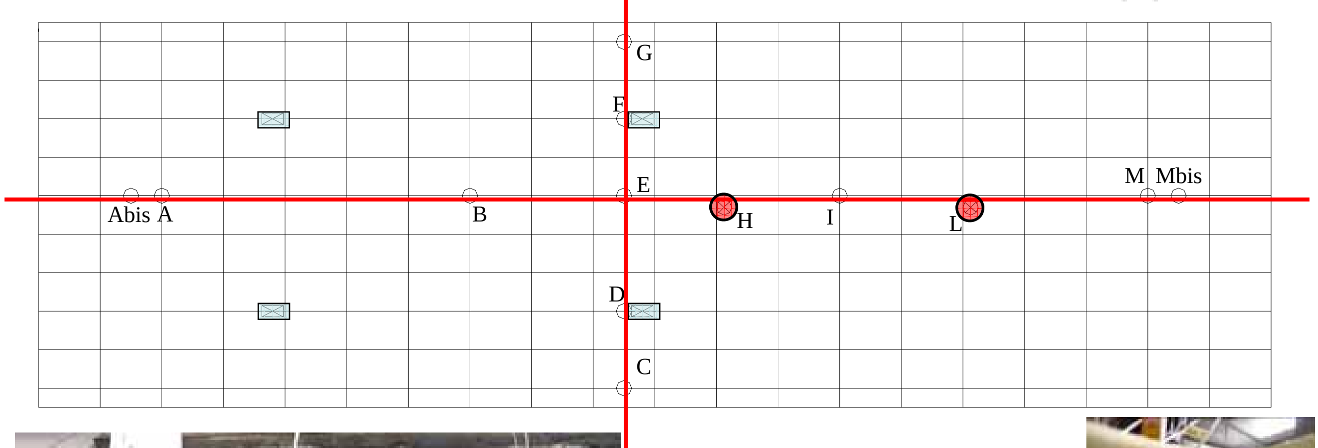
Structural behaviour of composite steel-concrete buildings in fire

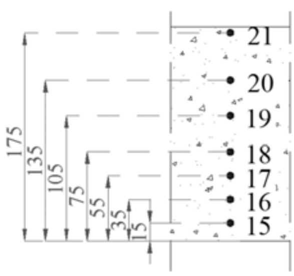
Seismic zone	Section type – Beam	Section type – Column	Fire scenario	Single member analysis – Collapse time	Single member analysis – Failure section
2	HE260B 	HE500B  		111 min	
				111 min	
4	HE240B 	HE280B  		60 min	
				116 min	

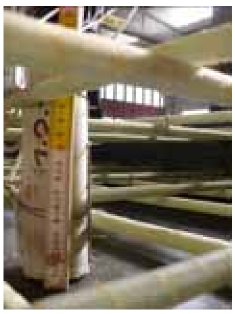
Full-scale experimental fire tests on concrete slabs reinforced with FRP bars

Instrumentation

over 40 thermocouples for each slab

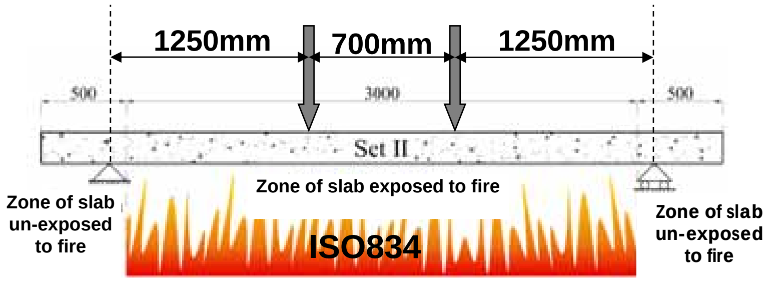


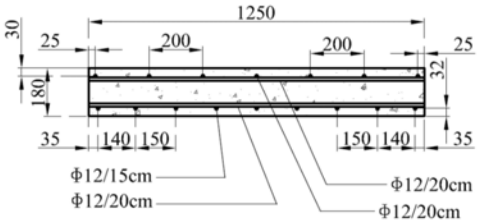




Full-scale experimental fire tests

Load





Fire Load level ⟶ $\eta_{fi} = M_{Ed,fi,t} / M_{Rd}$

S1, S4, S7 ⟶ 10% di M_{Rd} (own weight)

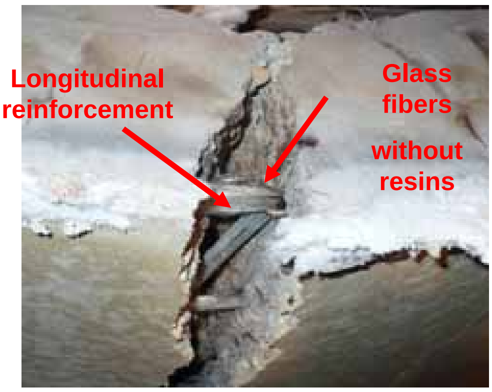
S2, S5, S8 ⟶ 40% di M_{Rd} (F=17.5kN)

S3, S6, S9 ⟶ 60% di M_{Rd} (F=17.5kN)

Observations after tests

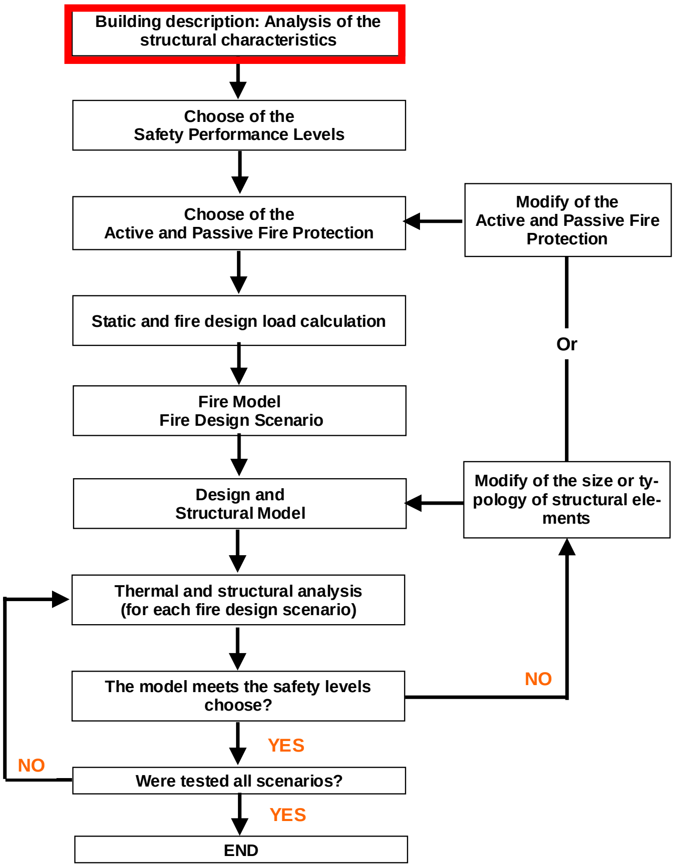
Slabs S4-S5-S6: Fiber failure at midspan

Inside the furnace: bars c = 51mm, L_{unexp} = 500mm



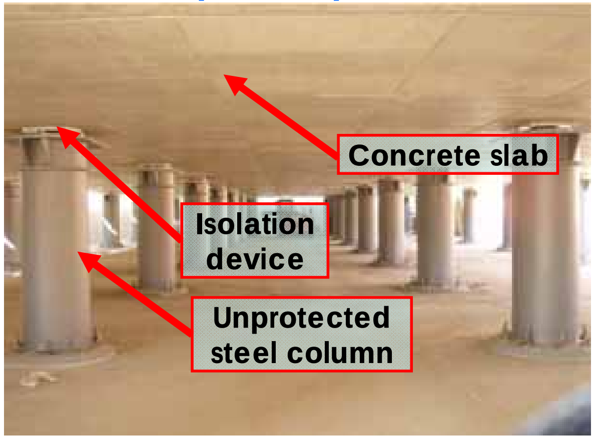
Section: end of slab

Application of FSE to Car Parks of C.A.S.E. Project for L'Aquila



C.A.S.E. Project – L'Aquila (Italy)

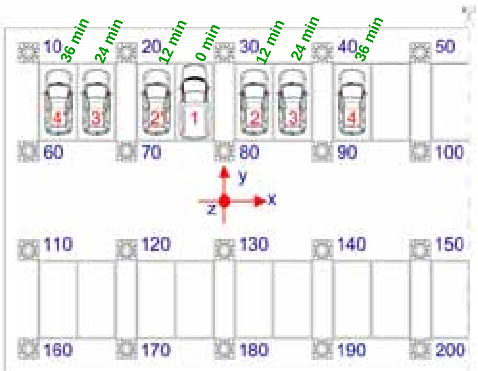
Open car park



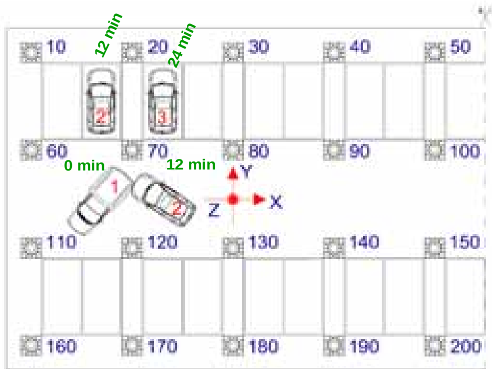
Design Fire Scenarios

Localised fire (Pre-flashover) From INERIS (2001) guideline

Fire scenario L1

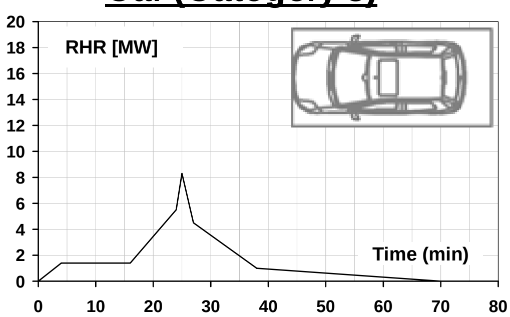


Fire scenario L2

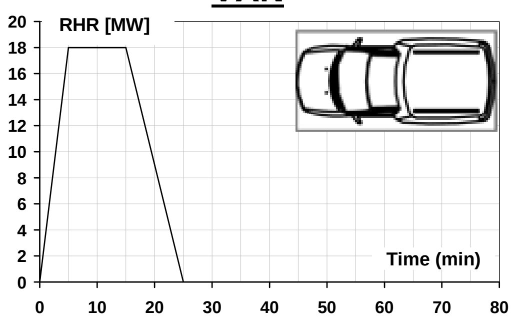


RHR curves From CEC agreement 7215-PP/025

Car (Category 3)



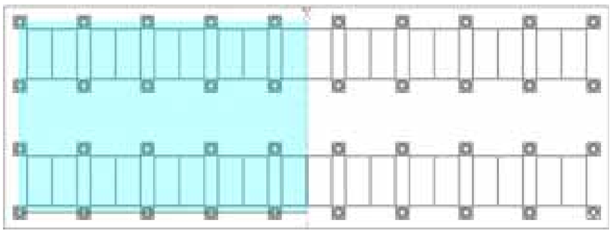
VAN



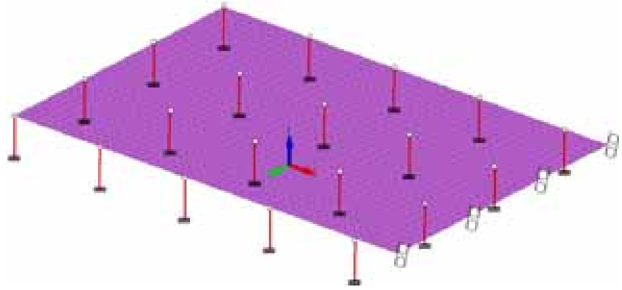
Structural models

Global analyses with non linear software SAFIR2007

Substructure

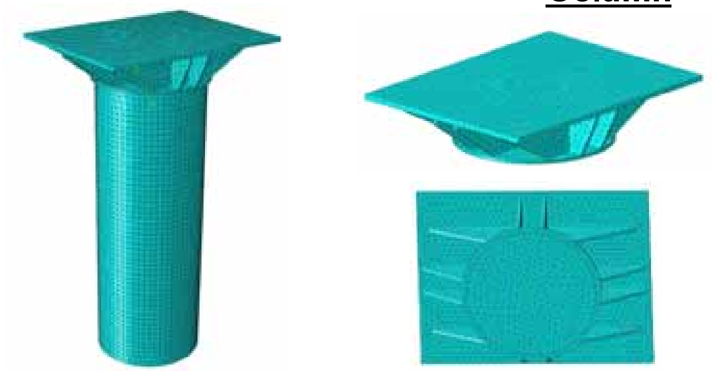


Static scheme



3D-Detailed analyses with software ABAQUS/standard

Column



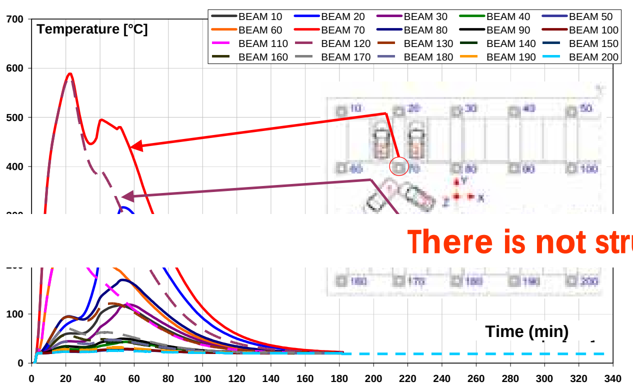
Loads on column corresponding to actions from global analysis

Performance Level 4:
Checks in terms of resistance and limitation of damage (differential vertical displacements in the columns)

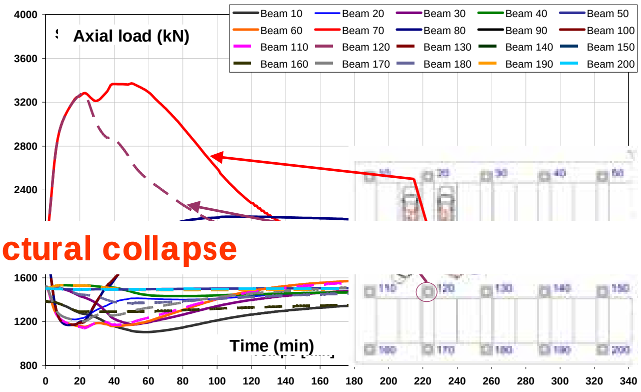
Global Analyses Results

Fire scenario L2 – Global Analysis

Temperatures vs time

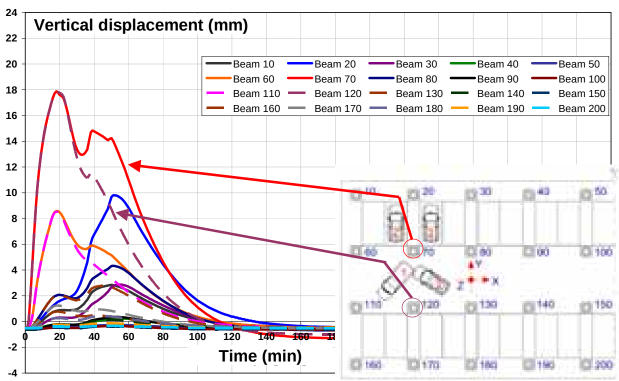


Axial loads vs time

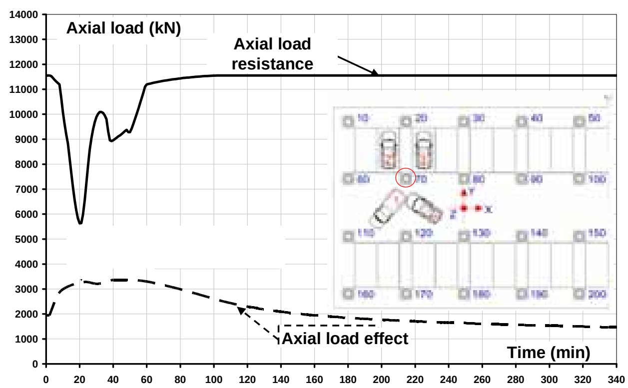


There is not structural collapse

Displacements vs time



Axial load resistance vs time



Integrated Fire Engineering and Response

COST action network number TU0904 in domain Transport and Urban Development

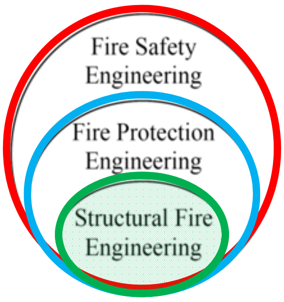
TRAINING SCHOOL , June 6-9 2013, Naples

Selection of Fire Scenarios and Performance Levels through Fire Risk Assessment Approach

Emidio Nigro

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

Introduction: Fire Safety Engineering



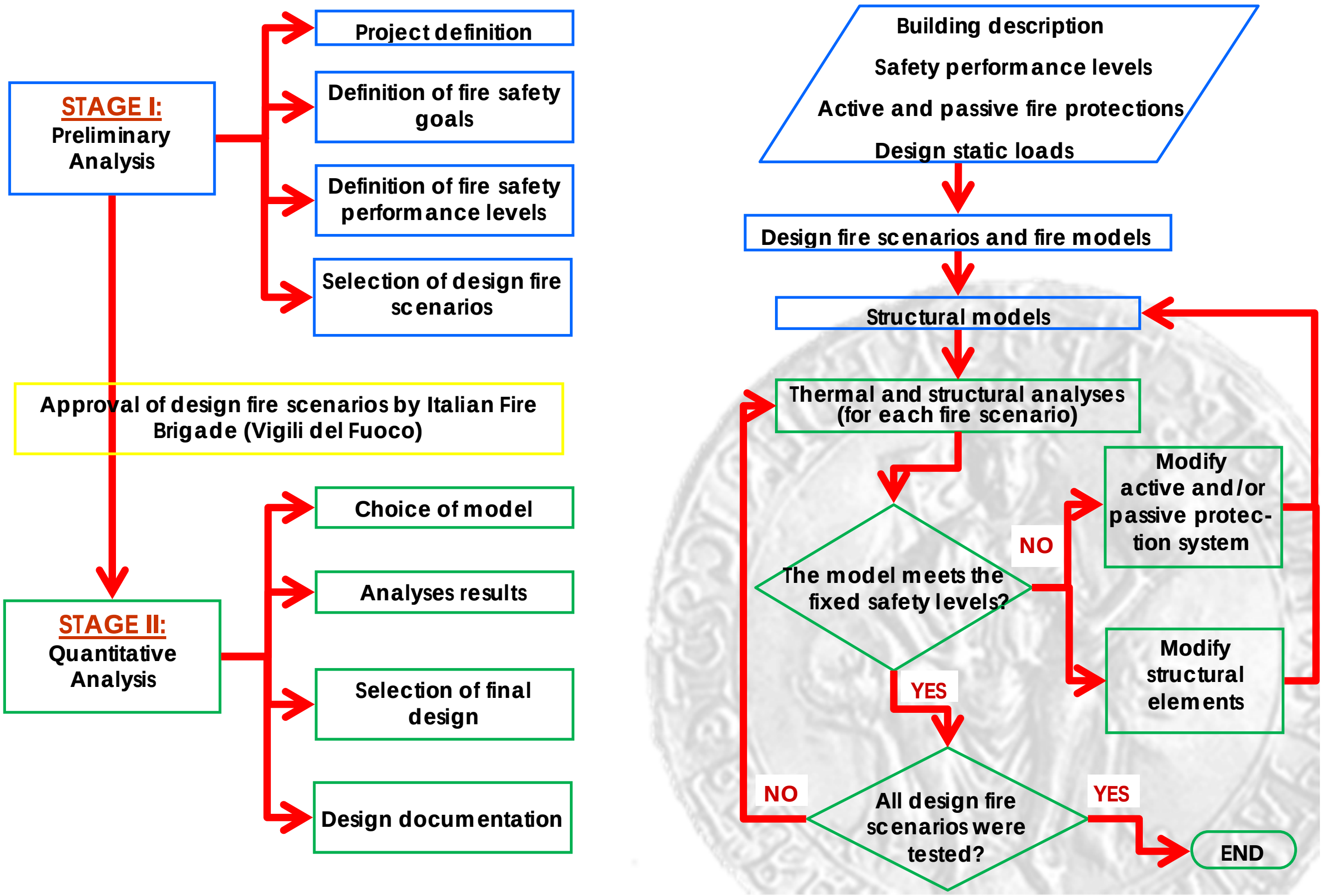
The "Fire Safety Engineering" (FSE) is the application of engineering principles, rules and expert judgement based on a scientific assessment of the fire phenomena, the effects of fire and both the reaction and behaviour of peoples, in order to:

- 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 the 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).

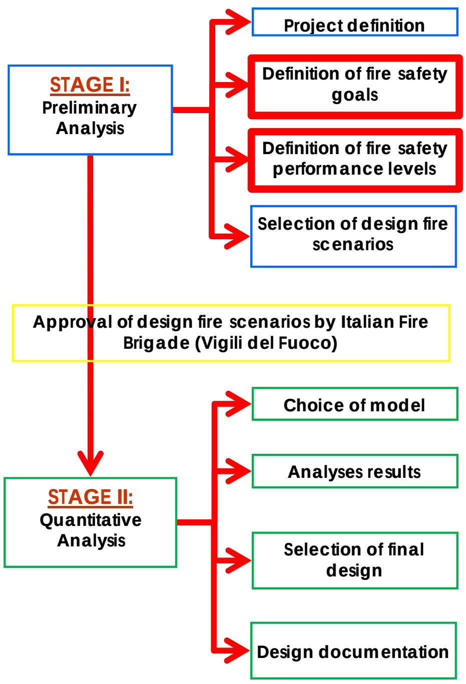
Italian performance-based code



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.

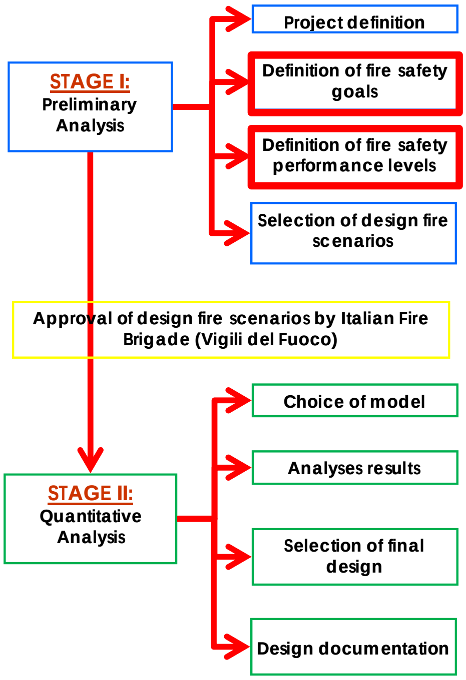


Level I	fire resistance is not required, where consequences are acceptable or where risk is negligible
Level II	maintaining the fire resistance requirements, which ensure the lack of partial and/or complete structural collapse, for a sufficient time with evacuation of occupants
Level III	maintaining 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

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 tower.



Performance levels

Highest risk scenario → **Performance 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 or for the entire duration of the fire

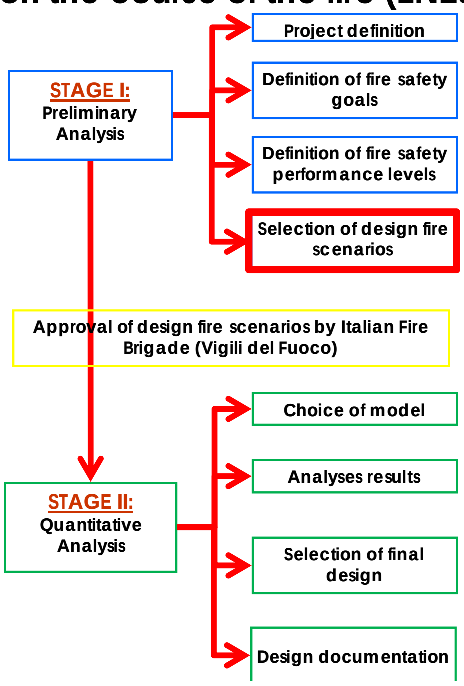
High probability scenario → **Performance Level IV**

limited damage of the structures after fire exposure

Selection of Design Fire Scenarios through Fire Risk Assessment

Fire Scenario

qualitative description of the development 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

$$R = P \times C$$

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

Selection of Design Fire Scenarios through Fire Risk Assessment

Fire Risk Assessment procedure

1. **identification of a comprehensive set of possible fire scenarios;**
2. **estimation of probability of occurrence of each fire scenario;**
3. **estimation of the consequence of each fire scenario;**
4. **estimation of the risk of each fire scenario (combination of the probability of a fire and a quantified measure of its consequence);**
5. **ranking of the fire scenarios according to their risk.**

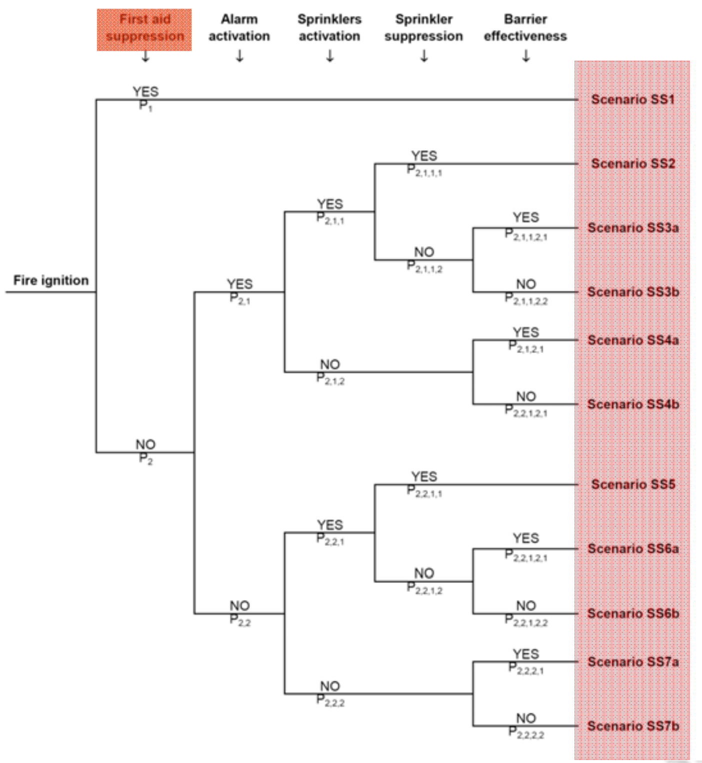
Event tree — **time-sequence path from the initiating condition through a succession of intervening events to an end-event.**

Technical references

- **ISO/TS 16732: "*Fire safety engineering – Guidance on fire risk assessment*". Draft 2010.**
- **ISO/DS 16733: "*Fire safety engineering - Selection of design fire scenarios and design fires*". 2005.**

Selection of Design Fire Scenarios

Main events:



Secondary events:

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

may be 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%

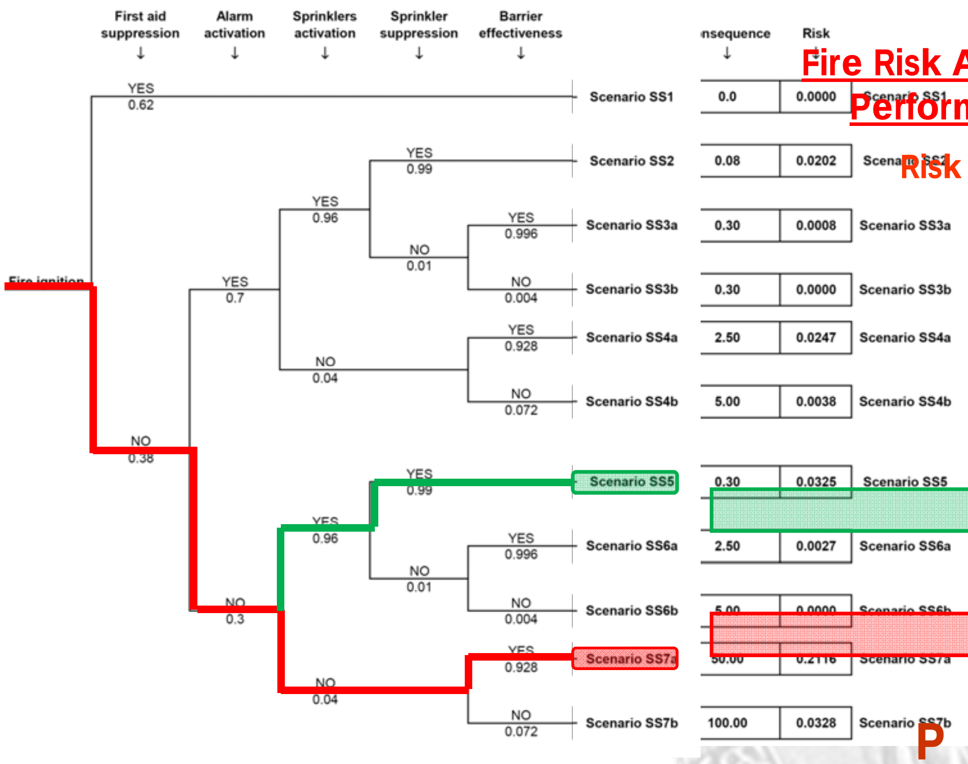
5th Event: barrier effectiveness

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%

Selection of Design Fire Scenarios: definition of consequences

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

Consequence	Risk	Risk Ranking
0.00	0.0000	11
0.06	0.0202	5
0.30	0.0008	8
0.30	0.0000	10
2.50	0.0247	4
5.00	0.0038	6
0.30	0.0325	3
2.50	0.0027	7
5.00	0.0000	9
50.00	0.2116	1
100.00	0.0328	2

P x C = R

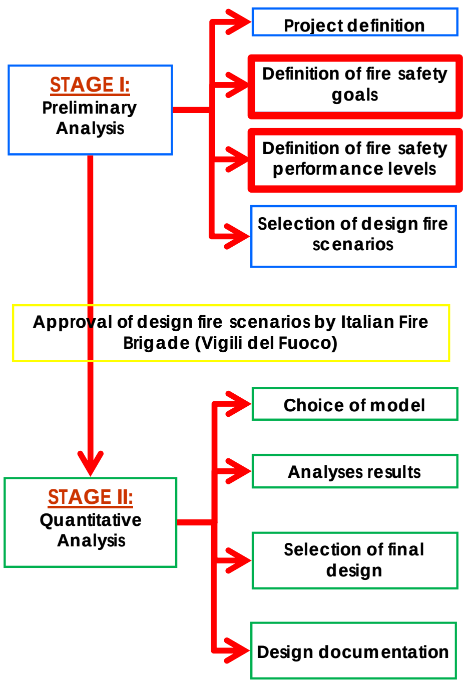
Performance Level IV : limited damage

Performance Level III : resistance for all fire exposure time

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 tower.



Performance levels

Highest risk scenario → **Performance Level III**

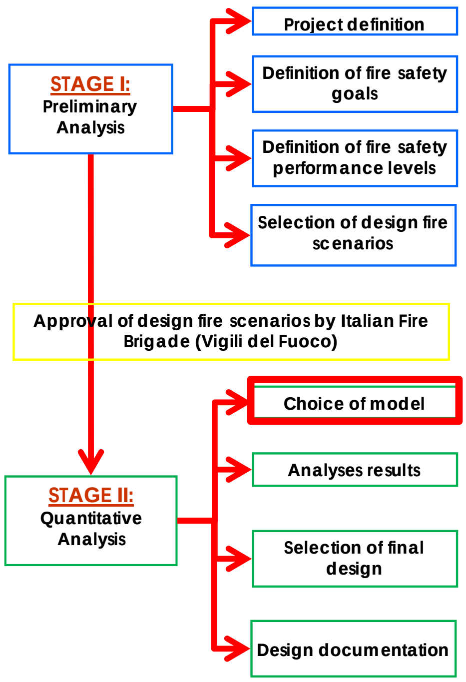
maintaining the fire resistance requirements, which ensure the lack of partial and/or complete structural collapse, for a sufficient time with emergency management or for the entire duration of the fire

High probability scenario → **Performance Level IV**

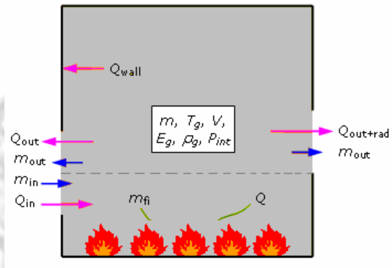
limited damage of the structures after fire exposure

Choice of the fire model

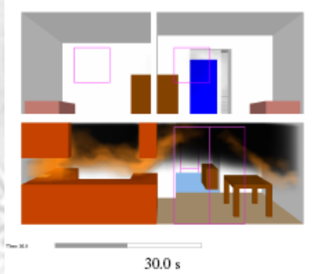
The post-flashover fire is obtained through different model:



✓ **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

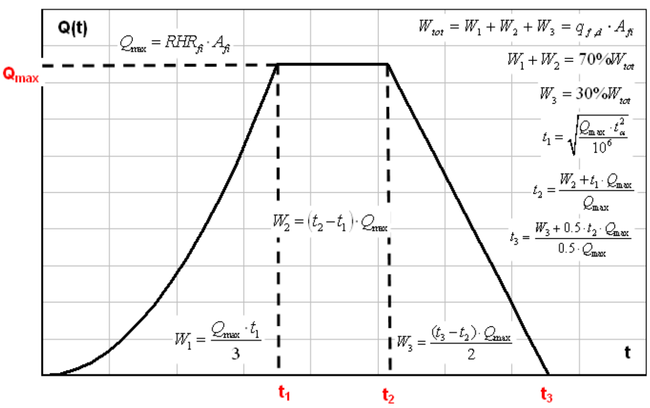


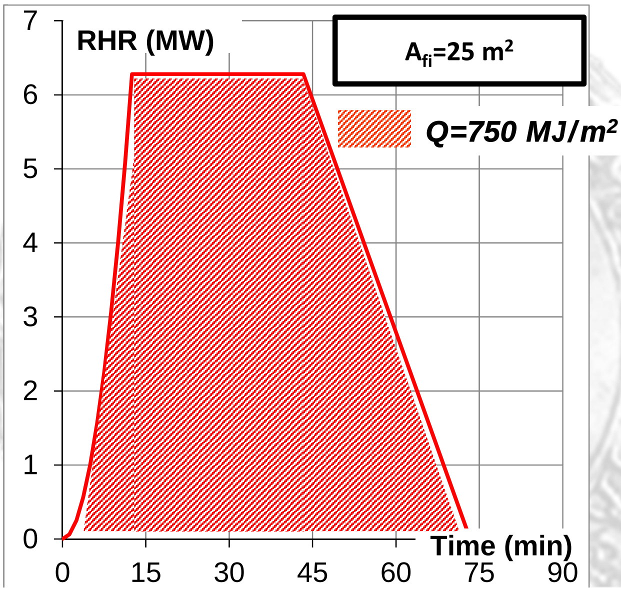
Table E.5 — Fire growth rate and RHR_f for different occupancies

Max Rate of heat release RHR_f			
Occupancy	Fire growth rate	t_α [s]	RHR_f [kW/m²]
Dwelling	Medium	300	250
Hospital (room)	Medium	300	250
Hotel (room)	Medium	300	250
Library	Fast	150	500
Office	Medium	300	250
Classroom of a school	Medium	300	250
Shopping centre	Fast	150	250
Theatre (cinema)	Fast	150	500
Transport (public space)	Slow	600	250

Table E.4 — Fire load densities $q_{f,k}$ [MJ/m²] for different occupancies

Occupancy	Average	80% Fractile
Dwelling	780	948
Hospital (room)	230	280
Hotel (room)	310	377
Library	1 500	1 824
Office	420	511
Classroom of a school	285	347
Shopping centre	600	730
Theatre (cinema)	300	365
Transport (public space)	100	122

NOTE Gumbel distribution is assumed for the 80 % fractile.



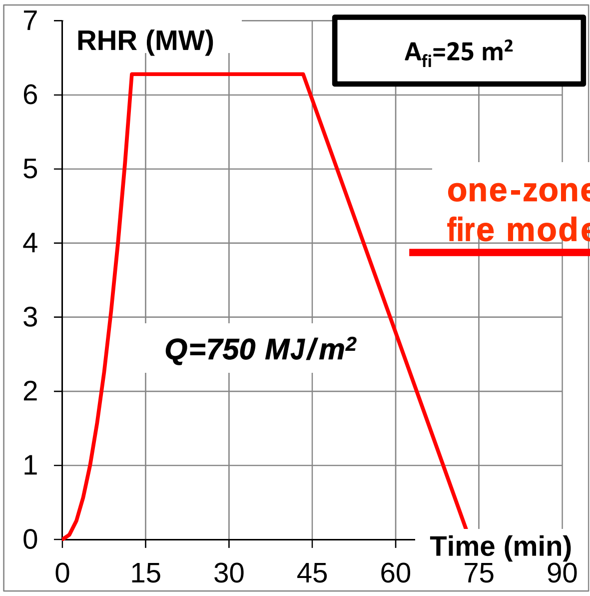
Case Study: Fire Scenario SS7a – One zone model

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

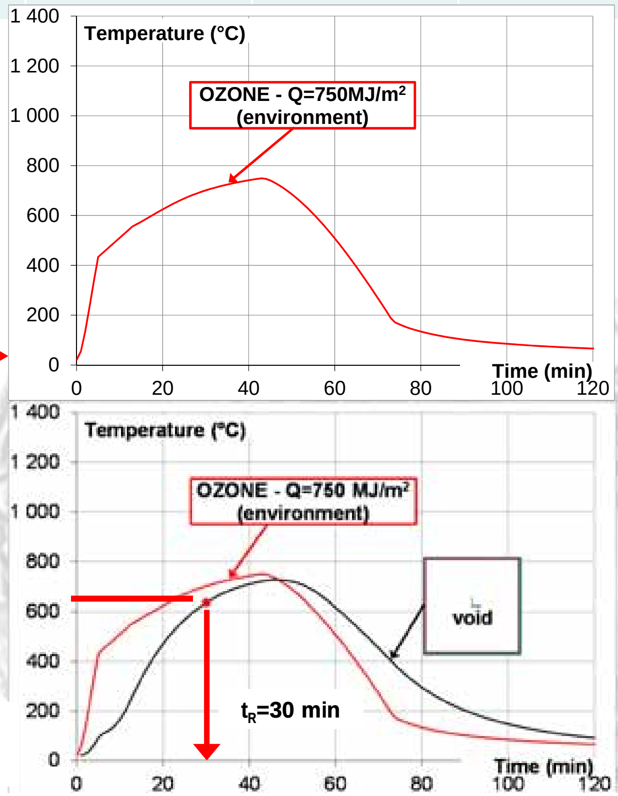
Fire Model

Fire involved in a single room (25m²)

EN1991-1-2



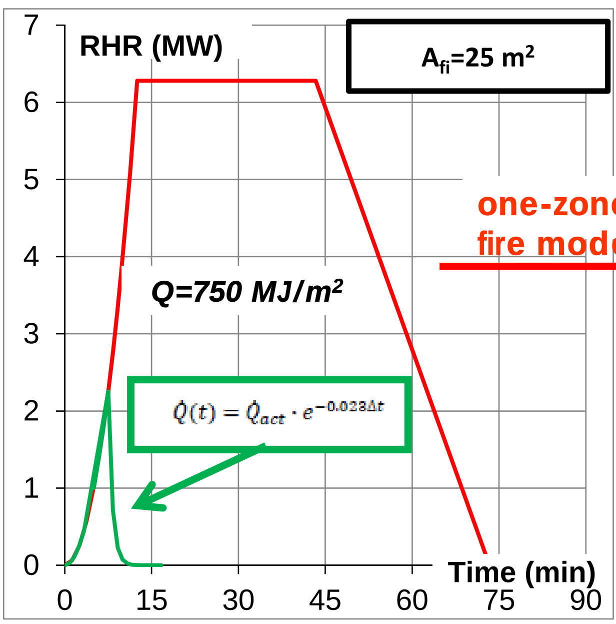
one-zone fire model



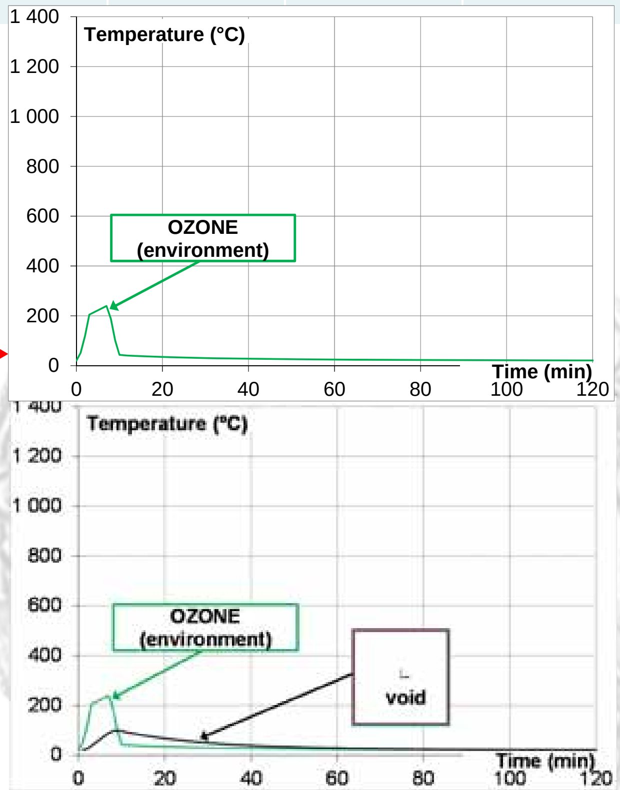
Column check with critical temperature
θ_{cr}=630°C

Case Study: Fire Scenario SS5

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



one-zone fire model



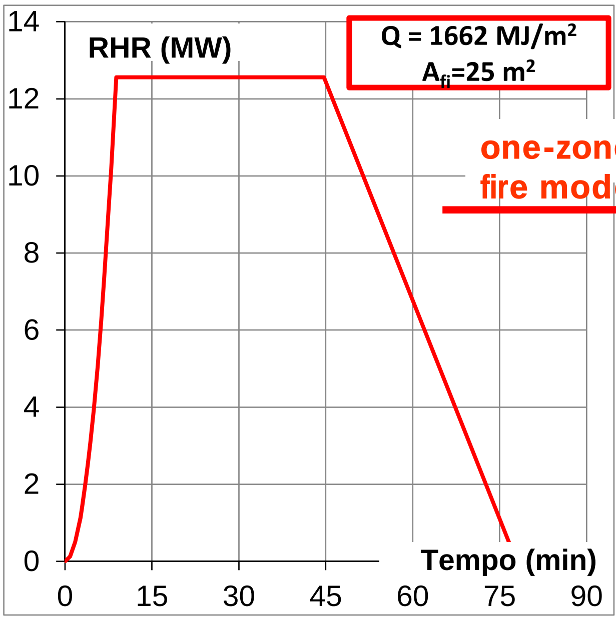
Case Study: Fire Scenario SS7a – One zone model

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

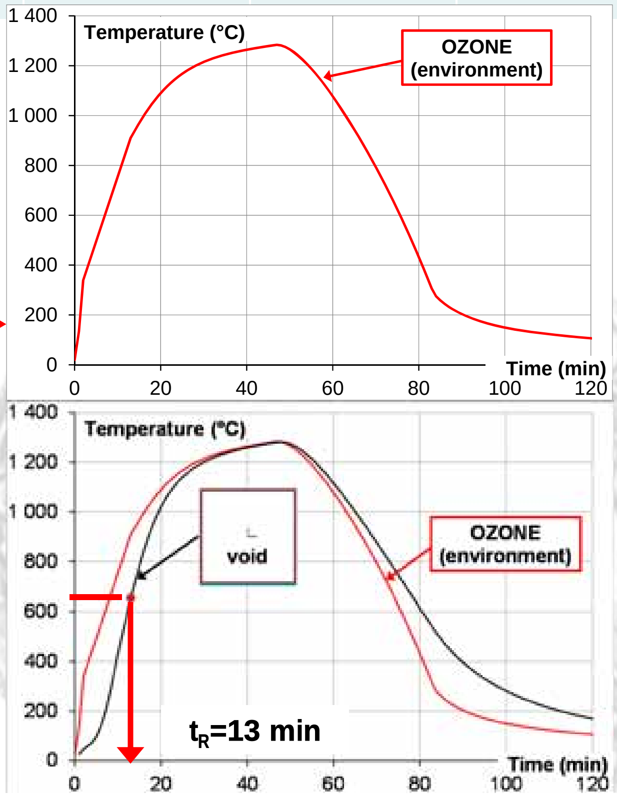
Fire Model

Fire involved in a single room (25m²)

EN1991-1-2

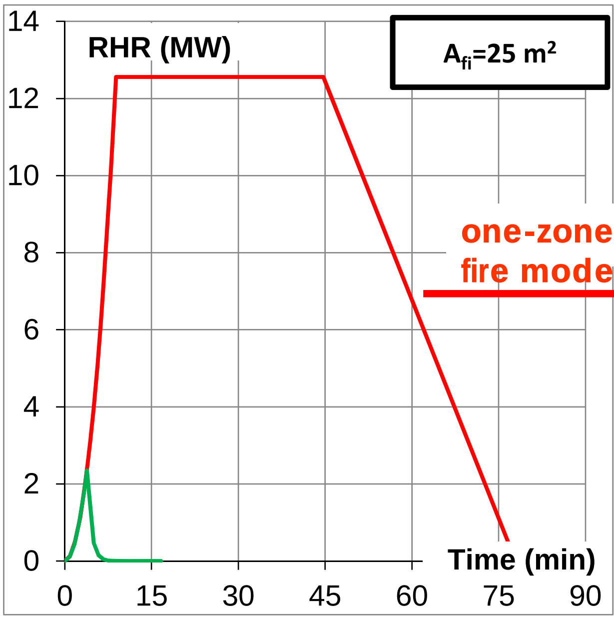


one-zone fire model

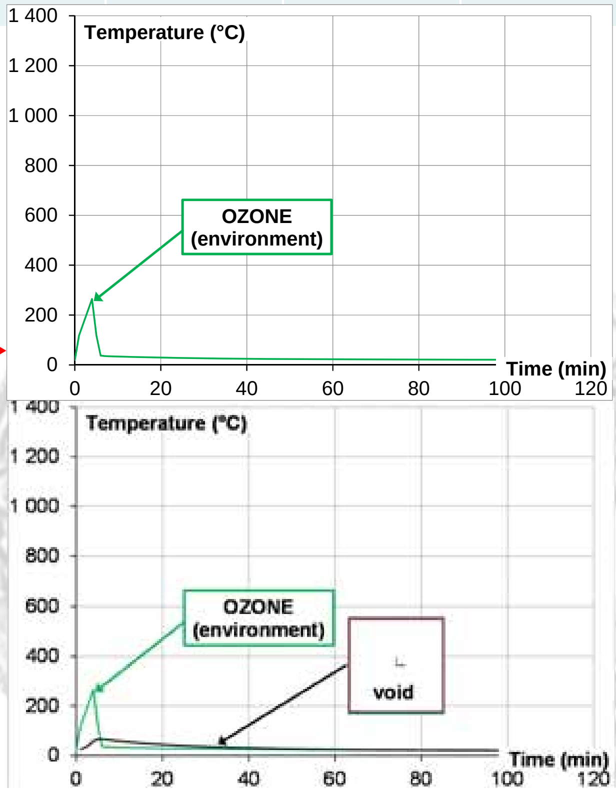


Case Study: Fire Scenario SS5

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



one-zone fire model



Fire model: EN1991-1-2 Approach

Table E.5 — Fire growth rate and RHR_f for different occupancies

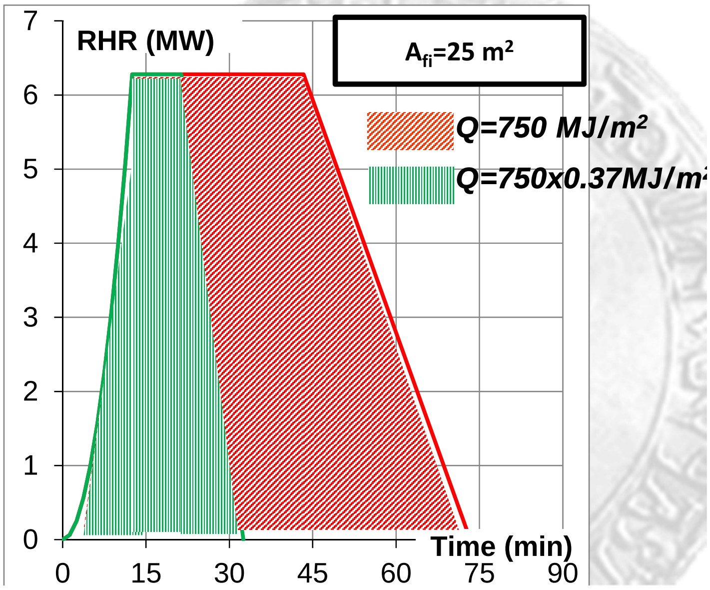
	Max Rate of heat release RHR_f		
Occupancy	Fire growth rate	$t_α$ [s]	RHR_f [kW/m²]
Dwelling	Medium	300	250
Hospital (room)	Medium	300	250
Hotel (room)	Medium	300	250
Library	Fast	150	500
Office	Medium	300	250
Classroom of a school	Medium	300	250
Shopping centre	Fast	150	250
Theatre (cinema)	Fast	150	500
Transport (public space)	Slow	600	250

Table E.2 — Factors δ_{ni}

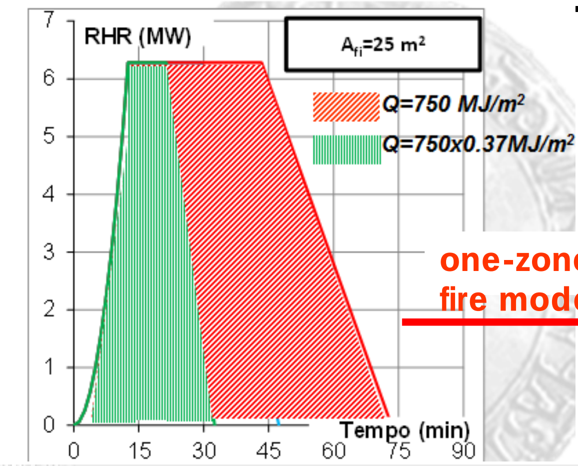
δ_{ni} Function of Active Fire Fighting Measures									
Automatic Fire Suppression		Automatic Fire Detection			Manual Fire Suppression				
Automatic Water Extinguishing System	Independent Water Supplies 0 | 1 | 2	Automatic fire Detection & Alarm by Heat	Automatic fire Detection & Alarm by Smoke	Automatic Alarm Transmission to Fire Brigade	Work Fire Brigade	Off Site Fire Brigade	Safe Access Routes	Fire Fighting Devices	Smoke Exhaust System
δ_{n1}	δ_{n2}	δ_{n3}	δ_{n4}	δ_{n5}	δ_{n6}	δ_{n7}	δ_{n8}	δ_{n9}	δ_{n10}
0,61	1,0 | 0,87 | 0,7	0,87 or 0,73		0,87	0,61 or	0,78	0,9 or 1 or 1,5	1,0 or 1,5	1,0 or 1,5

Table E.4 — Fire load densities $q_{f,k}$ [MJ/m²] for different occupancies

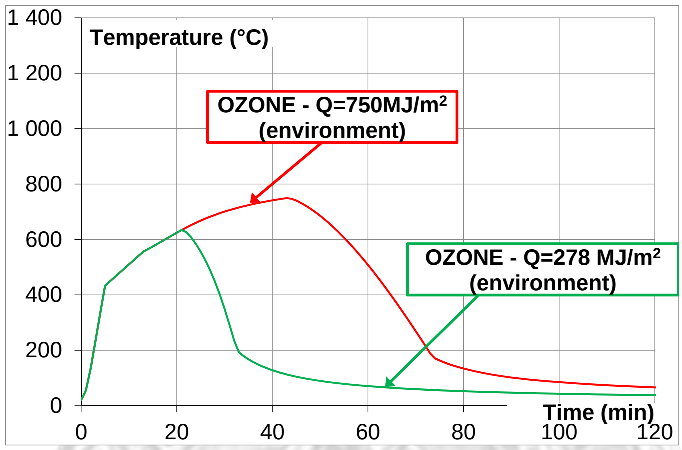
Occupancy	Average	80% Fractile
Dwelling	780	948
Hospital (room)	230	280
Hotel (room)	310	377
Library	1 500	1 824
Office	420	511
Classroom of a school	285	347
Shopping centre	600	730
Theatre (cinema)	300	365
Transport (public space)	100	122
NOTE Gumbel distribution is assumed for the 80 % fractile.		

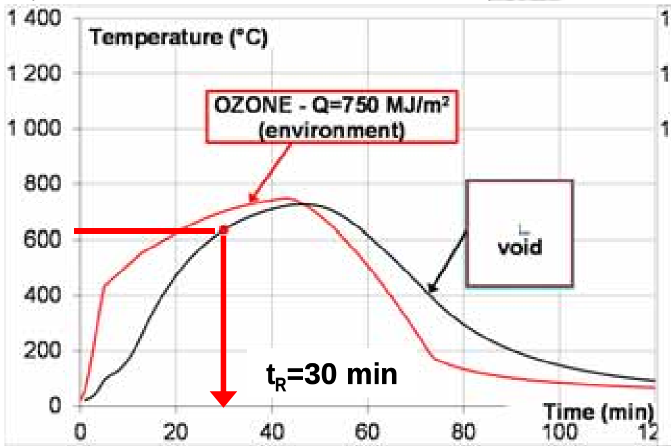


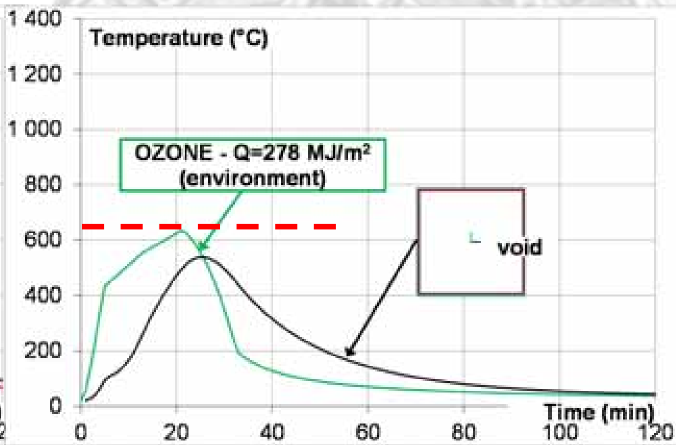
Fire model: EN1991-1-2 Approach



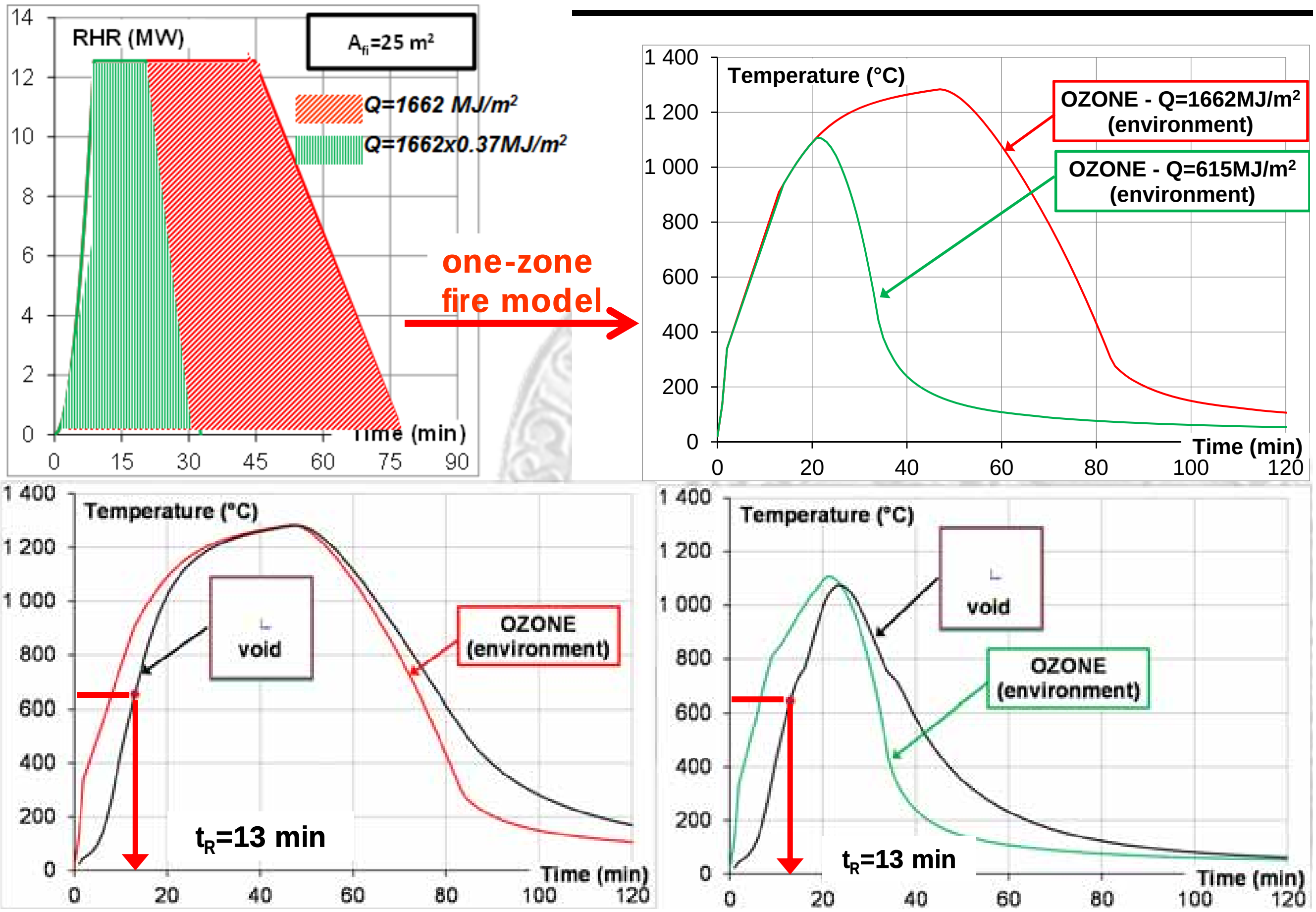
one-zone fire model







Comparison between Scenario SS7a and EN1991-1-2 Approach



Summary and Conclusions

- Fire Safety Engineering, in accordance with Italian and European standard, allows the definition of safety goals and different performance levels, associated to defined design fire scenarios.
- The identification of design fire scenarios is carried out by means of Fire Risk Assessment, applying the event tree approach and the risk ranking evaluation according to ISO-16732 Guidelines: it has been shown that different design fire scenarios may be related to different fire performance levels (e.g. resistance of structures for highest risk fire scenario and limited damage for the most probable fire scenario).
- The choice of design fire scenarios determines the identification of key events that characterise the fire and differentiate it from other possible fires.
- Traditional Eurocode approach concerns the mechanical resistance and stability of structures, with reference to a single fire event, in which the effective value of fire load is modified in a semi-probabilistic way by means of partial safety factors, in order to take into account the events that can affect fire development.
- A comparison between the two approaches has been proposed.

List of Reference (1/2)

- NIGRO E., A. FERRARO, G. CEFARELLI (2010). *Application of FSE approach to the structural fire safety assessment of steel-concrete composite structures*. In: Urban habitat construction under catastrophic events. Napoli, 16-18 settembre 2010, CRC Press, p. 255-260, ISBN/ISSN: 9780415606851
- NIGRO E., A. FERRARO, G. CEFARELLI (2010). *Member, substructure and global structural fire analyses of steel-concrete composite frames*. In: Urban habitat construction under catastrophic events. Napoli, 16-18 settembre 2010, CRC Press, p. 261-269, ISBN/ISSN: 9780415606851
- E. NIGRO, A. FERRARO, G. CEFARELLI. The influence of fire scenarios on the structural behaviour of composite steel-concrete buildings. APPLIED MECHANICS AND MATERIALS, Vol. 82 (2011), p. 368-373. ISSN: 1662-7482. ISBN-13 978-3-03785-217-0. doi:10.4028/www.scientific.net/AMM.82.368.

- Emidio NIGRO, Giuseppe CEFARELLI, Antonio BILOTTA, Gaetano MANFREDI, Edoardo COSENZA. *Fire resistance of concrete slabs reinforced with FRP bars. Part I: Experimental investigations on the mechanical behavior*. COMPOSITES: PART B-ENGINEERING, Vol. 42 (2011), p. 1739–1750. Elsevier. ISSN: 1359-8368. doi:10.1016/j.compositesb.2011.02.025.
- Emidio NIGRO, Giuseppe CEFARELLI, Antonio BILOTTA, Gaetano MANFREDI, Edoardo COSENZA. *Fire resistance of concrete slabs reinforced with FRP bars. Part II: Experimental results and numerical simulations on the thermal field*. COMPOSITES: PART B-ENGINEERING, Vol. 42 (2011), p. 1751–1763. Elsevier. ISSN: 1359-8368. doi:10.1016/j.compositesb.2011.02.026.
- E. NIGRO, G. CEFARELLI, A. BILOTTA, G. MANFREDI, E. COSENZA.. Behavior of FRP Reinforced Concrete Slabs in Case of Fire: Theoretical Models and Experimental Tests. ADVANCES IN STRUCTURAL ENGINEERING – A Multi-Science Publication. Vol. 15, N. 4, April, 2012, p. 637-652. ISSN: 1369-4332. doi: 10.1260/1369-4332.15.4.637.
- E. NIGRO, A. BILOTTA, G. CEFARELLI, G. MANFREDI, E. COSENZA. Performance under Fire Situations of Concrete Members Reinforced with FRP Rods: Bond Models and Design Nomograms. JOURNAL OF COMPOSITES FOR CONSTRUCTION - ASCE. Vol. 16, N. 4, August 1, 2012, pp. 395-406. ISSN: 1090-0268. doi: 10.1061/(ASCE)CC.1943-5614.0000279.

List of Reference (2/2)

- E. NIGRO, G. CEFARELLI, A. FERRARO, G. MANFREDI, E. COSENZA. Fire Safety Engineering for open and closed car parks: C.A.S.E Project for L'Aquila. APPLIED MECHANICS AND MATERIALS, Vol. 82 (2011), p. 746-751. ISSN: 1662-7482. ISBN-13 978-3-03785-217-0. doi:10.4028/www.scientific.net/AMM.82.746.
- E. NIGRO, G. CEFARELLI, A. FERRARO, G. MANFREDI, E. COSENZA. *Application of Structural Fire Engineering to Open and Closed Car Parks of C.A.S.E. Project for L'Aquila.* COST Action TU0904 – Integrated Fire Engineering and Response: Case Studies. p. 237-251. Editors: F. Wald, I. Burgess, G. Rein, L. Kwasniewski, P. Vila Real, K. Horova. CTU Publishing Production, Czech Technical University in Prague, March 2012. ISBN: 978-80-01-05004-0.

- E. NIGRO, G. CEFARELLI, A. FERRARO, I. DEL PRETE, D. SANNINO, G. MANFREDI. *Application of Structural Fire Engineering to an Italian Tall Office Building.* 7th International Conference on Structures in Fire (SIF'2012), Zurich, Switzerland, June 6-8, 2012, p. 13-22. Editors: M Fontana, A. Frangi, M. Knobloch. Printed and bound by ETH Zurich. DOI: 10.3929/eth-a-0070501097.Fire Safety Engineering, in accordance with Italian and European standard, allows the definition of safety goals and different performance levels, associated to defined design fire scenarios.

Thanks for your attention