COMPUTATIONAL MODELLING FOR PERFORMANCE BASED FIRE ENGINEERING (PBFE)

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Motivations of the present study

- Now days **common practice** in fire safety engineering is moving toward PBFE.
- **Complex structures** can not be designed against fire by prescriptive approaches but the investigation of their performance under fire needs the knowledge of **advanced computational methods**.
- The application of **PBFE** concepts to **complex structures** implies some additional difficulties with respect to the case of ordinary structures

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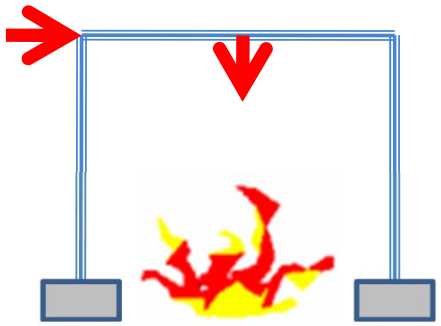
PBFE- Ordinary vs. Complex Structures

	STRUCTURE	FIRE SCENARIOS	FIRE PROPAGATION	COLLAPSE and PERFORMANCE
ORDINARY		Well defined and limited in number	Usually negligible	• Well defined • On single (key) elements
COMPLEX		Not easily definable	Application 2: NON negligible	Application 1: • Not easily definable • Structure as whole

- High redundant
- Complex geometry
- Extension
- Nonlinear behavior
- Complex compartimentation
- -----

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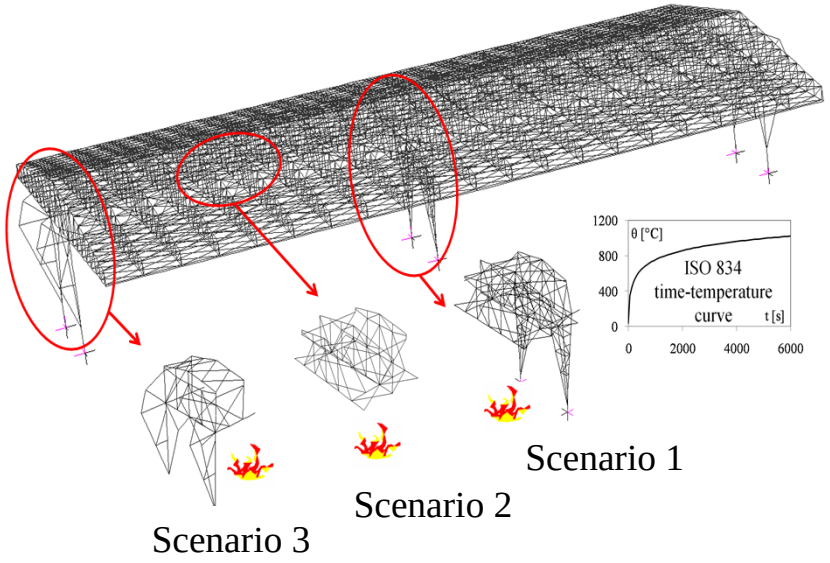
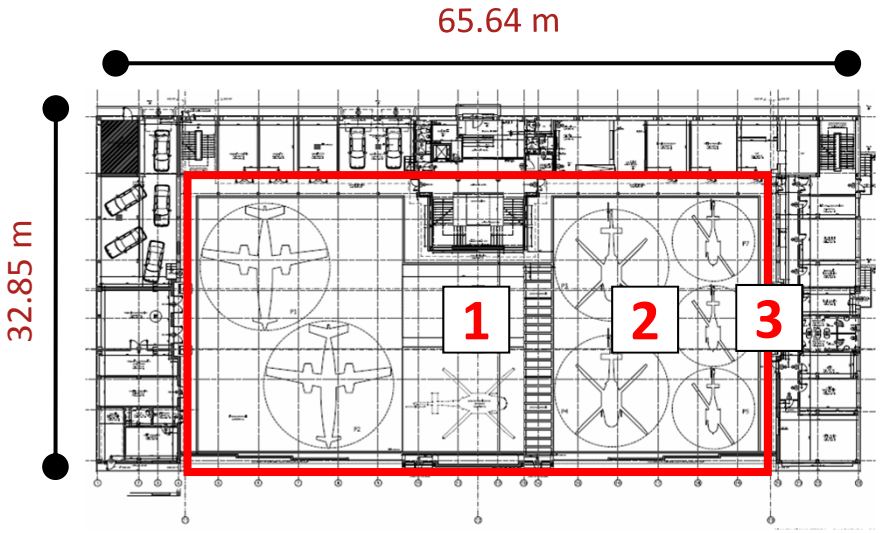
Application 1: a steel structure for Helicopters storage

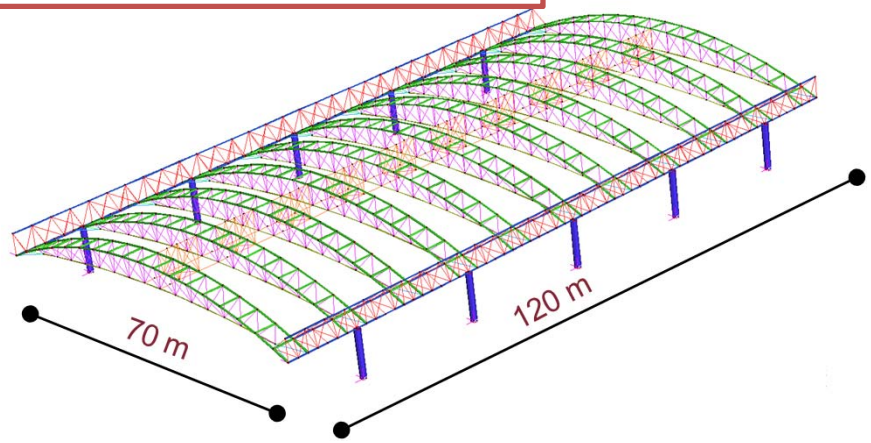
High redundant structure

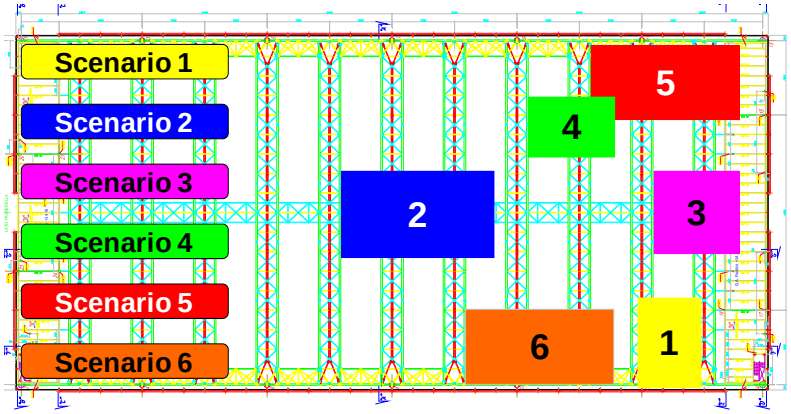




Application 2: a steel exhibition pavilion

A single fire compartment





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System approach: components

A decomposition of the structure is shown in figure, four principal components are identified and hierarchically ordered. A global or local failure of such substructures can be directly connected with the lack of performances hierarchically ordered in the same manner

Component damage definition

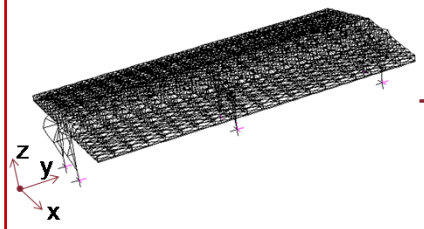
$$DM^{scenario}_{component} = \frac{\left(n^{\circ}_{\ collapsed\ elements}\right)^{scenario}}{\left(total\ n^{\circ} of\ elements\right)_{component}} \cdot 100$$

- irrelevant
- moderate
- average
- significant

DM- Performances connection

Failed Performance (evaluated on DM)

Structural assembly



Top roof → 4 → Serviceability/ damage

Trusses → 3 → Serviceability/ local collapse

Bottom diaphragm → 2 → Safety/ global collapse

Bearing frame → 1 → Robustness/ global collapse

Hierarchy

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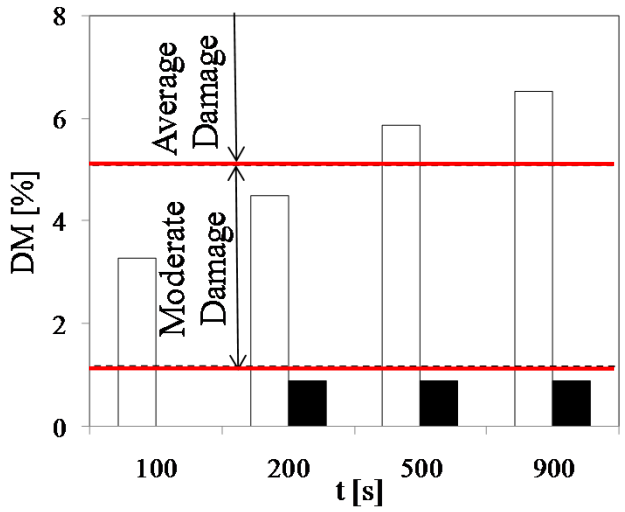
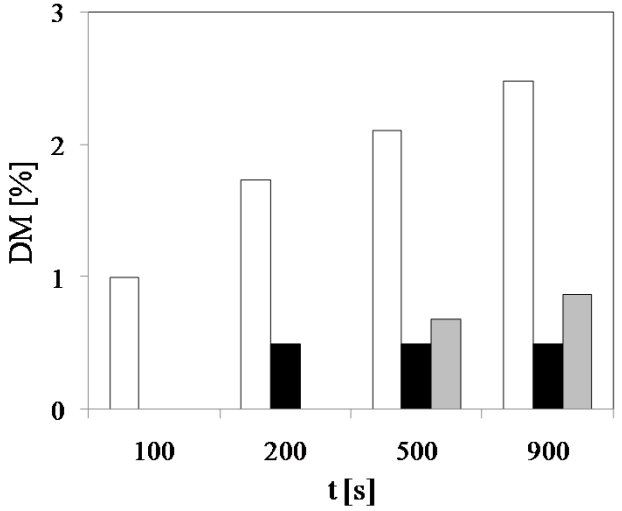
Components Performance (DM) evaluation

Hierarchy

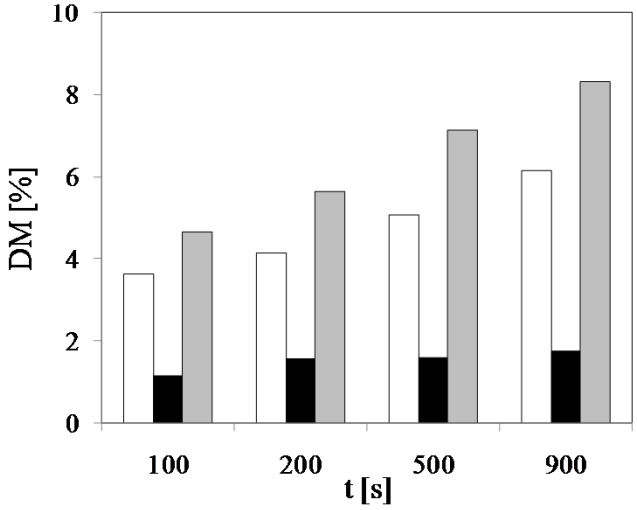
1

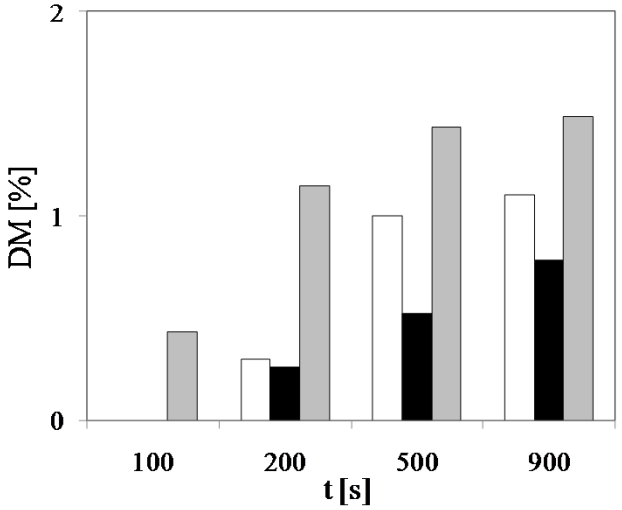




2

3





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Scenario 1 Scenario 2 Scenario 3

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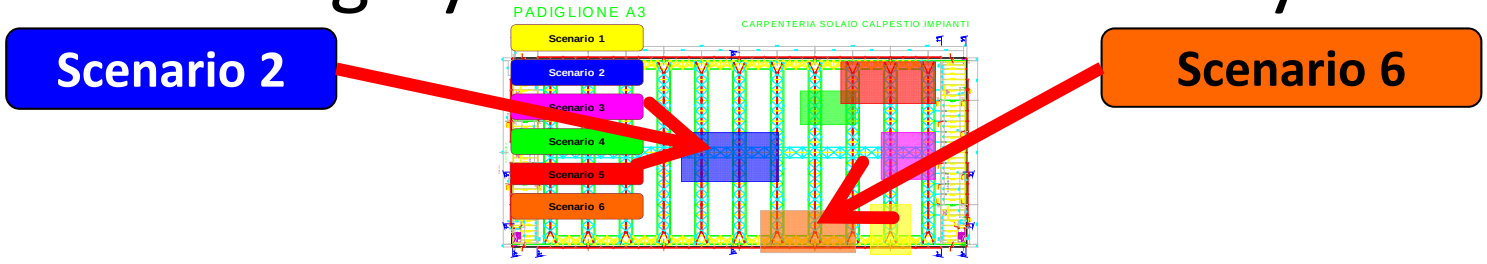
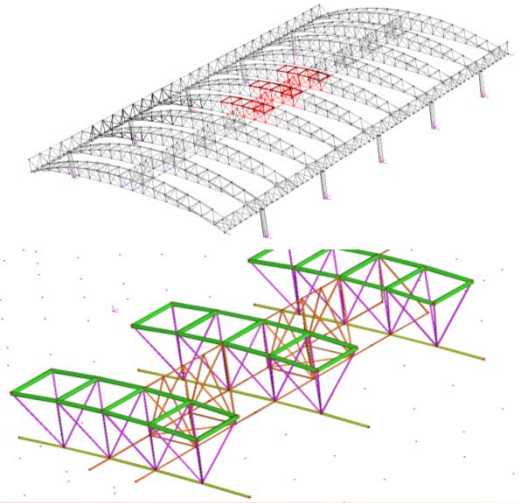
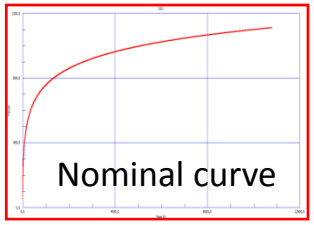
Fire modeling by the ISO 834 curve or by CFD

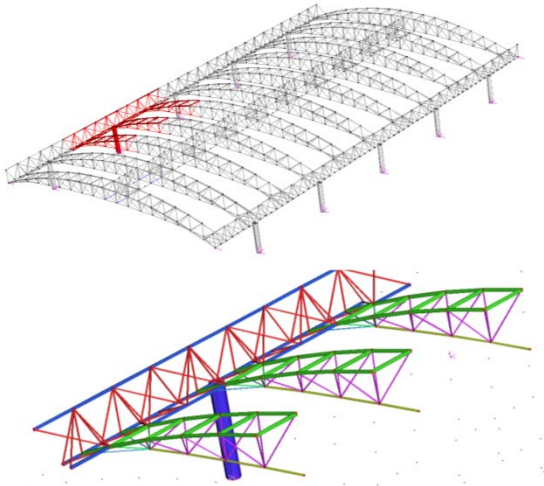


ISO 834 Nominal curve



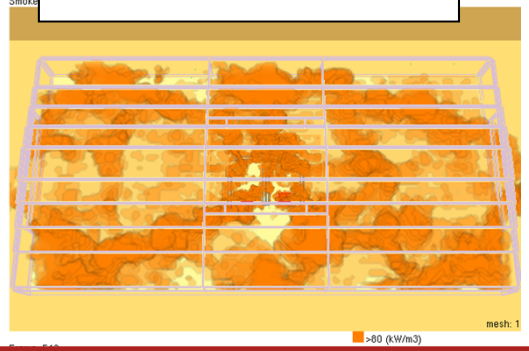
Heated elements are located only inside the tributary area of the scenario

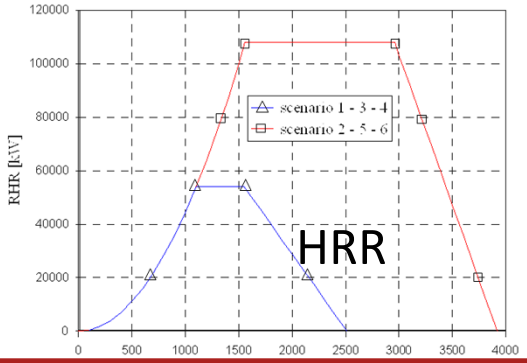




CFD simulations

flashover





NO flashover

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Conclusions and considerations

The **Performance-Based Design** (**PBD**) approach is the best way to conceive and assess complex structural systems under fire action.

Specific considerations are:

- the **system approach** is a powerful tool to rationally carry-out the **PBD** of complex structures. Concepts of these two frameworks can be profitably integrated in PBFD approach.
- Even though in complex situations simplified (**nominal fire**) and advanced methods (**CFD analyses**) for the fire modeling apparently conduct to similar results, a detailed description of the structural response highlights the great difference of the two methods in obtaining the structural response.

Acknowledgments

Filippo Gentili and **Chiara Crosti** from Sapienza University of Rome are gratefully acknowledged.

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- Now days **common practice** in fire safety engineering is moving toward PBFE.

- **Complex structures** can not be designed against fire by prescriptive approaches but the investigation of their performance under fire needs the knowledge of advanced computational methods.

- **Advanced computational methods** are now available.

Performance based fire design (PBFD)

Performance based structural codes

Rosowski, D.V. & Ellingwood, B.R., (2002).

Fundamental requirements (desired structural attributes)

- Safety
- Serviceability
- Integrity of subsystems
  - mechanical
  - electrical
  - illumination
- Robustness
- Durability

Non technical ***requirements***, expressing qualitatively a fundamental goal

e.g. building structures remain stable under extreme loads

Set of ***criteria*** to assure that the requirements are satisfied

e.g. design flexural strength shall exceed the maximum moment due to design loads

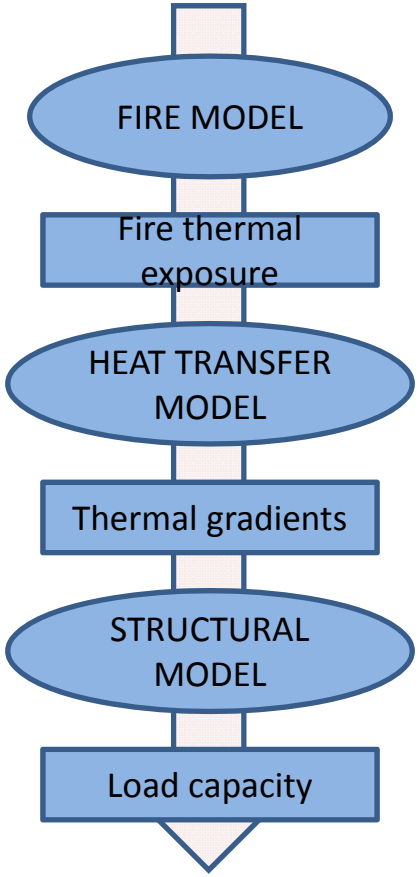
Methods of ***evaluation*** to measure the satisfaction of each criterion

e.g. analysis and test methods

Commentary to explain the rationale of each provision

Methods of evaluation to measure the satisfaction of each

Buchanan (2001)



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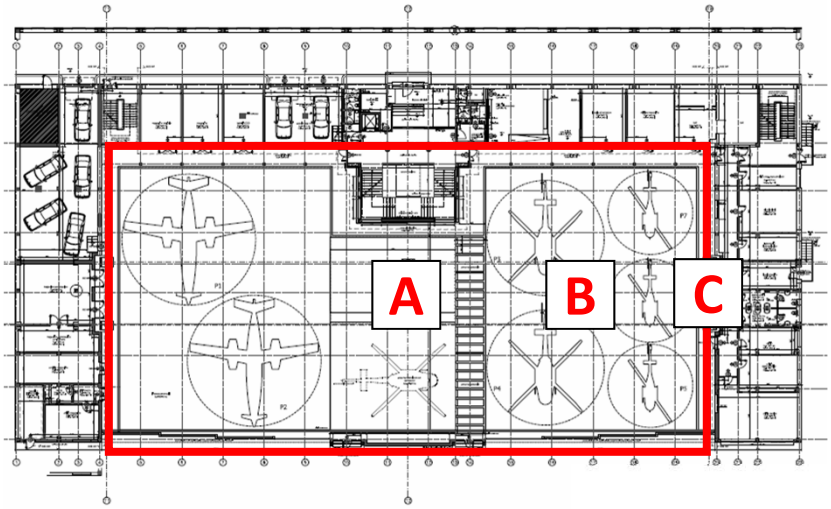
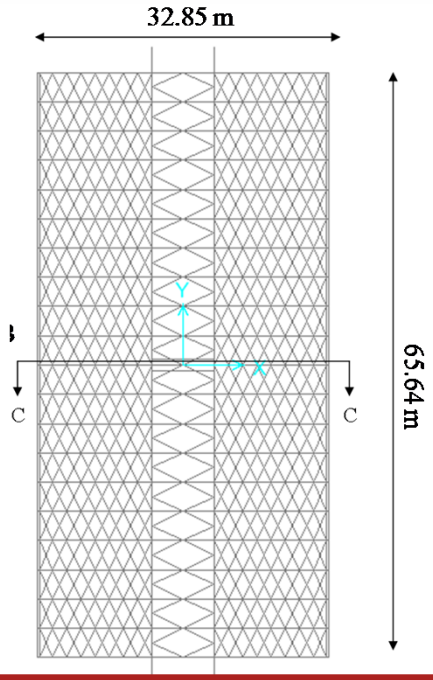
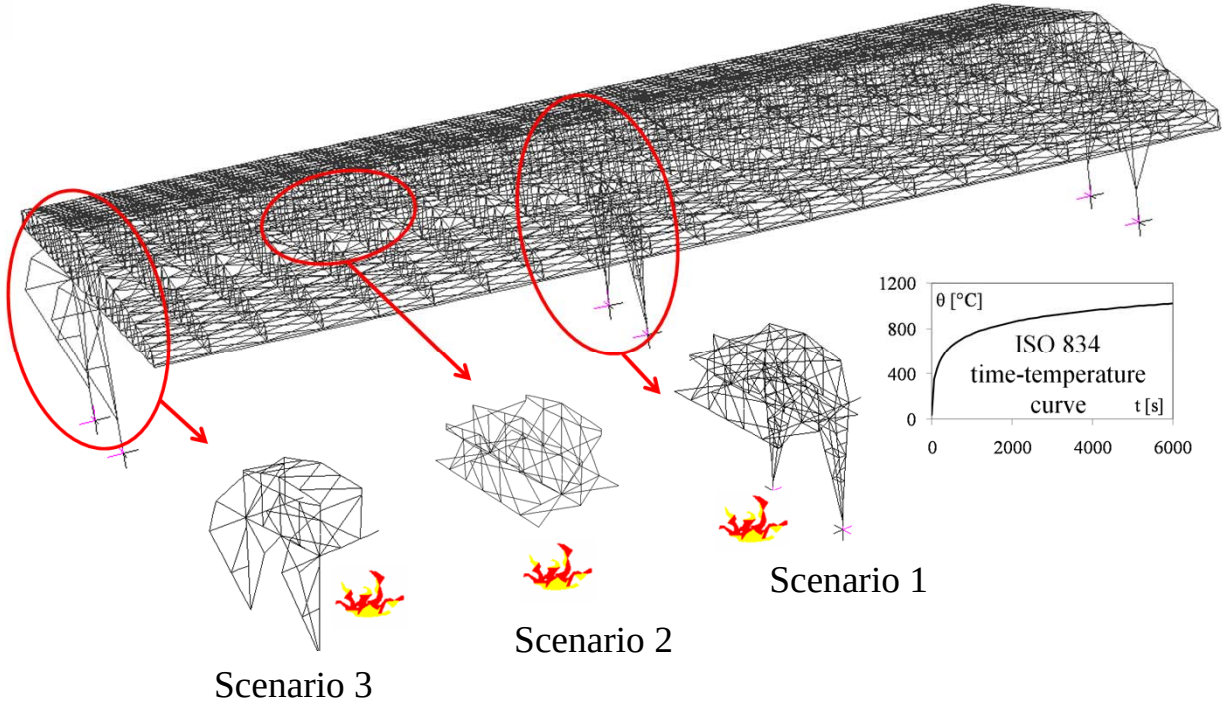
Application 1: a steel structure for Helicopters storage



Identification of fire risk prone areas in an industrial facility

- The central zone of the building (Area A).
- The central zone of the span (Area B).
- The outer zone (Area C).





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Performance Evaluation

N°	Performance requirement	Scenario 1	Scenario 2	Scenario 3	Performance result
1	No collapse for components of hierarchies 1 and 2 for 15 minutes	Dz_max (15min)= = 0.128 m the columns instability does not arise	Dz_max = =0.057 m the columns instability does not arise	Dz_max = = 0.102 m the columns instability does not arise	Satisfied
2	a) moderate damage (DM<5%) for components of hierarchies 1, 2, average damage (DM<10%) for components of hierarchy 3 b) No progressive collapse	$DM_{1,}$ >5% at t=500 s **FAIL** the progressive collapse does not arise	DM_2<5% DM_3<10% the progressive collapse does not arise	$DM_{1,2}$<5% DM_3<10% the progressive collapse does not arise	**FAIL** for scenario 1

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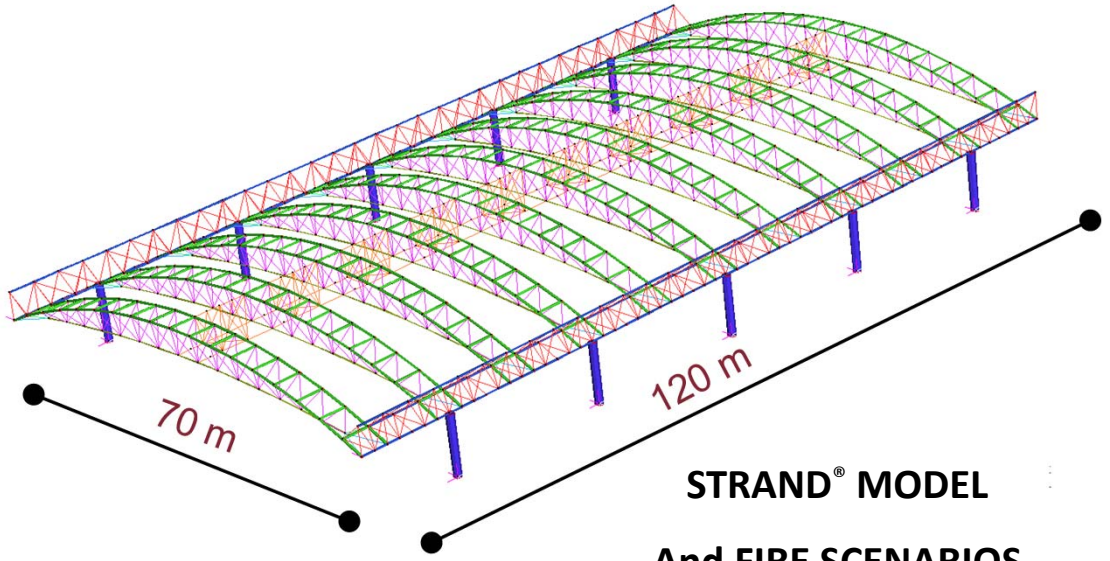
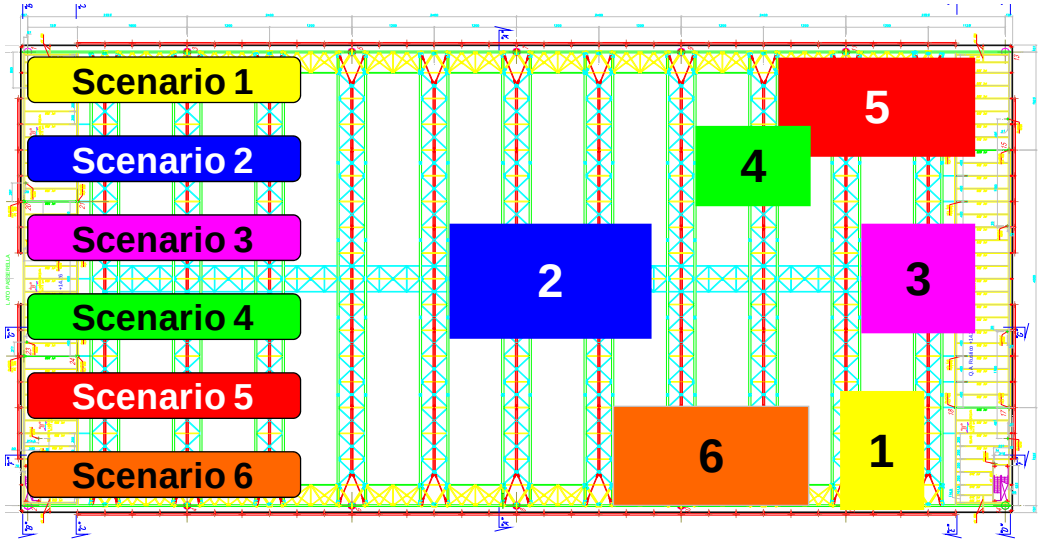
Application 2: a steel exhibition pavilion

REAL STRUCTURE



STRAND® MODEL

And FIRE SCENARIOS



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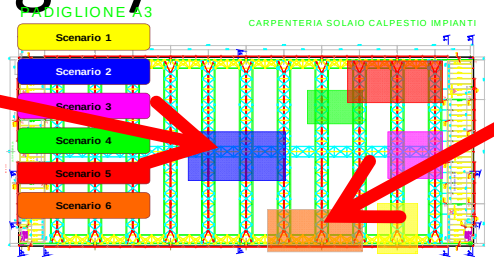
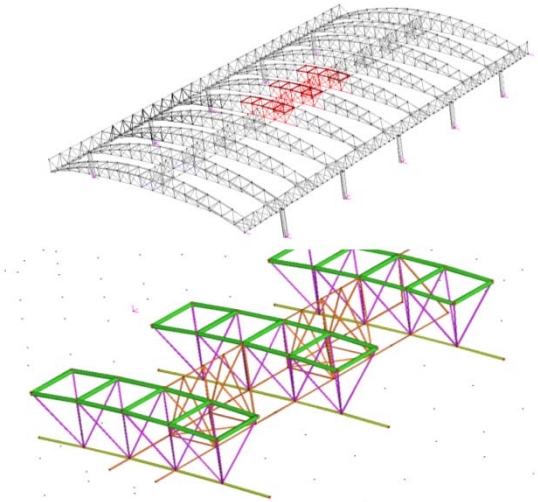
Fire modeling by the ISO 834 curve

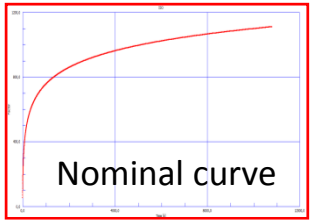
Scenario 2

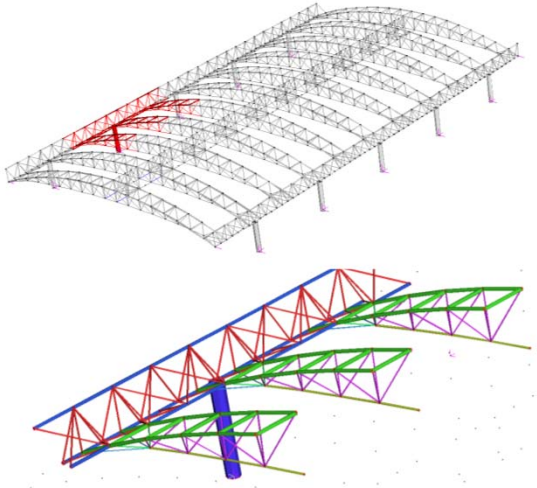


Scenario 6

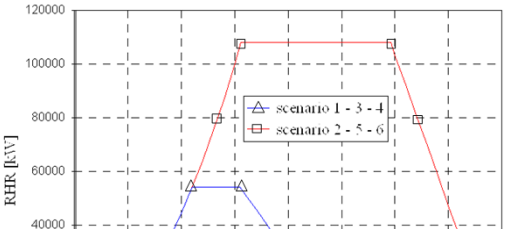


Heated elements are located only inside the tributary area of the scenario

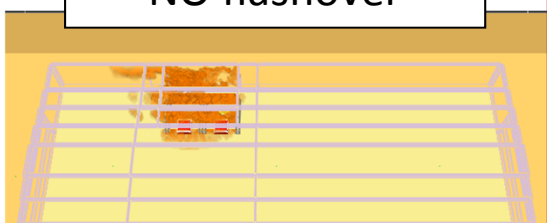




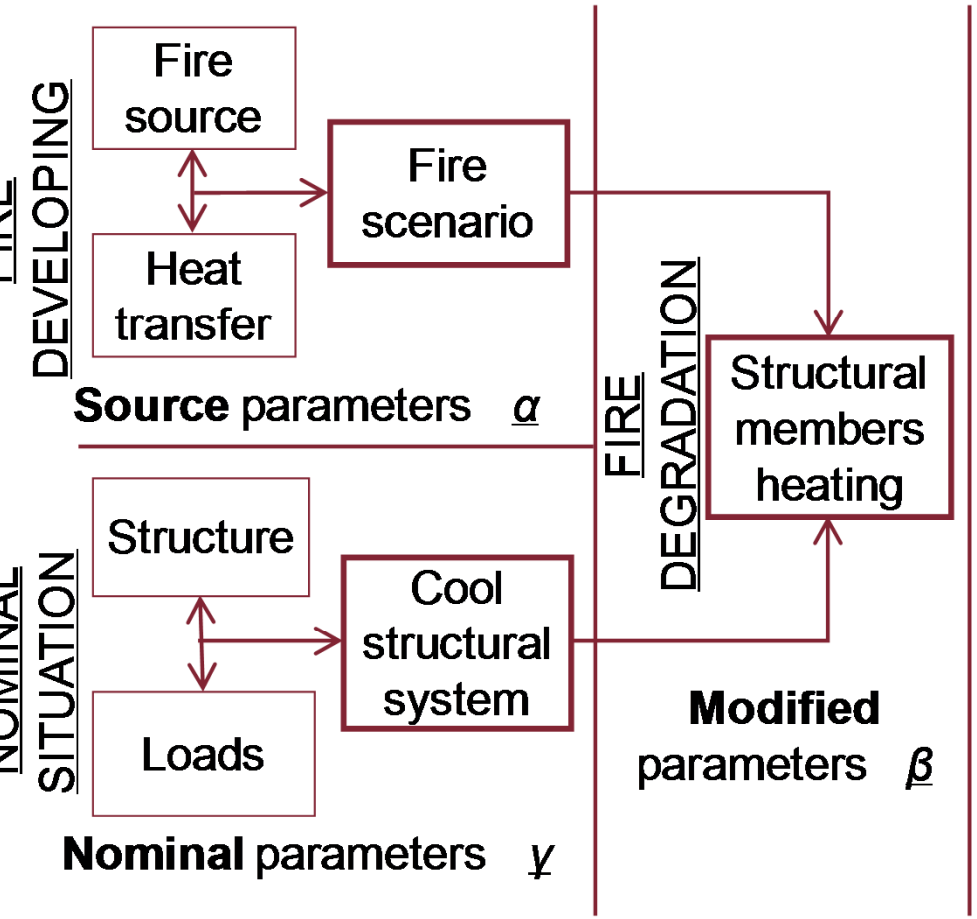
flashover

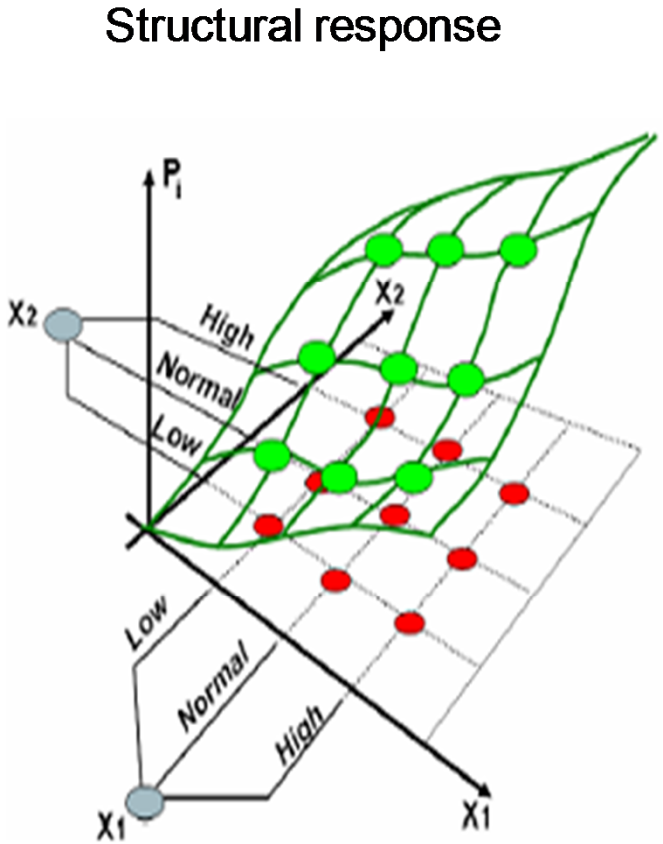


NO flashover

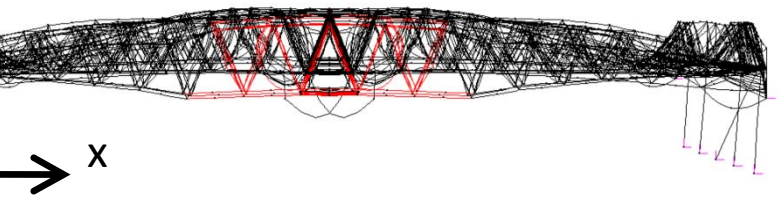


Further developments



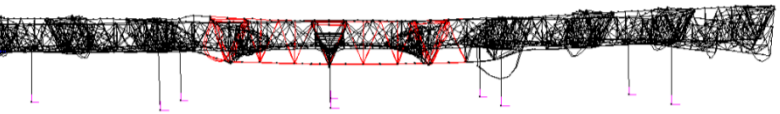


Deformed shape (nominal fire)

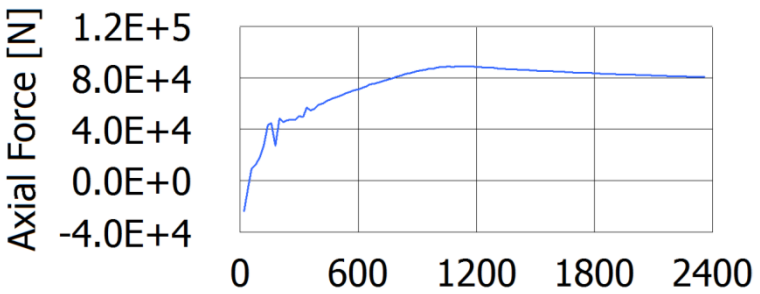


vertical roof displ. Dz= -0.1868 m

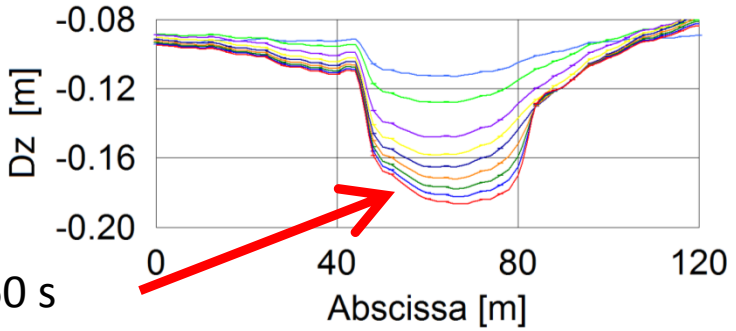
ateral column disp. Dx=-0.1344 m



Axial force of a heated element

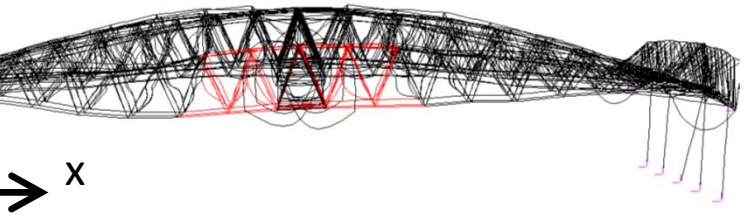


Central alignment vertical displacement



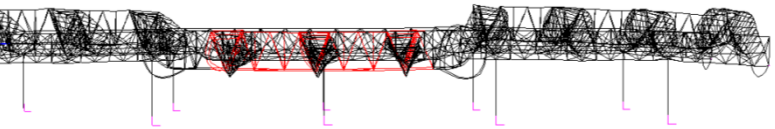
Last curve: 2360 s

Deformed shape (CFD fire)



vertical roof displ. Dz= -0.8243 m

lateral column disp. Dz= -0.6353 m



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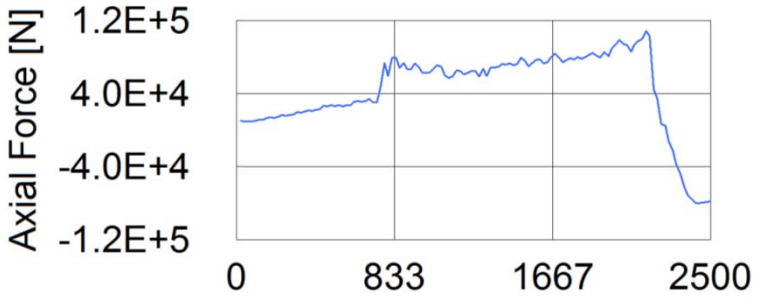
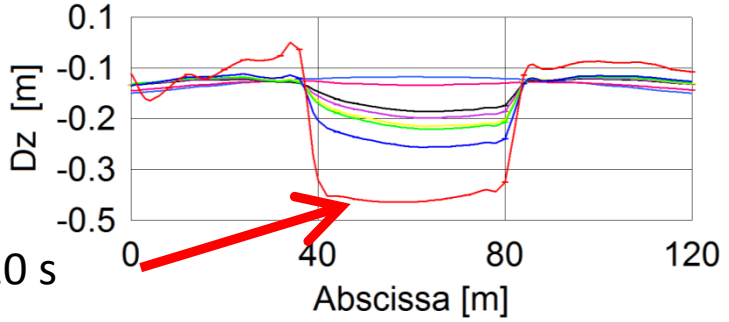


Central alignment vertical displacement



Last curve: 2220 s

Complex structures and LPHC events

	Ordinary structures	Complex structures
Design approach	Prescriptive - PBD	PBD
Minimum check level	Element	Element – Global (for robustness assessment)
Models	Simple-Ordinary	Advanced
Approach for investigations	Probabilistic (Performance = structural risk for a specific limit sate)	Heuristic (Performance = “impact”, as consequence of the hazard)
Fire scenarios	Easily identified and limited in number	Not trivial to define and great in number
Definition of and collapse	Simple-Ordinary	Not trivial (e.g. for high redundant structures)

	Ordinary events	LP-HC events
Approach for		Heuristic (incomplete