SAPIENZA UNIVERSITÀ DI ROMA

International Conference
APPLICATIONS OF STRUCTURAL FIRE ENGINEERING
Prague 29-30 April 2011

Structural analysis of steel structures under fire loading – initial considerations

Introduction

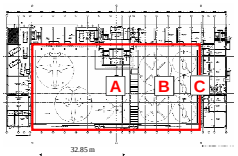
In the recent years with the affirmation of **performance-based** structural codes and standards, replacing more and more the traditional prescriptive ones. Nowadays, structures always bigger and more complex are designed and build, with the use of particularly fire sensitive materials. In modeling such **complex structures**, there are important aspects that need to be taken into account.

This paper focuses on the application of the **performance-based fire design (PBFD) for complex structures**, with the main goal being to outline some specific issues related with this kind of problems.

The structures under inquiry, both in steel, are characterized by a certain degree of complexity related to fire problem, the first one being a facility made of steel for the storage of helicopters, while the second an exhibition pavilion. For the sake of brevity, the main focus is given to the 2nd structure.

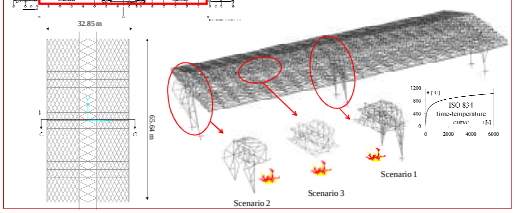
On the basis of the above premises, this paper focuses on the **application of the performance-based fire design (PBFD) for complex structures**, with the main goal being to outline some specific issues related with this kind of problems.

1: a steel structure for Helicopters storage



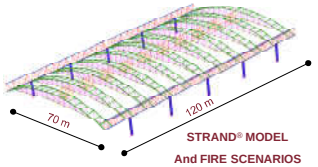
Identification of fire risk prone areas in an industrial facility

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

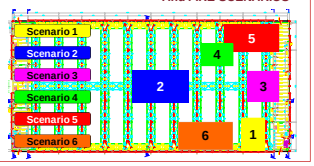


2: a steel exhibition pavilion

REAL STRUCTURE



STRAND® MODEL
And FIRE SCENARIOS

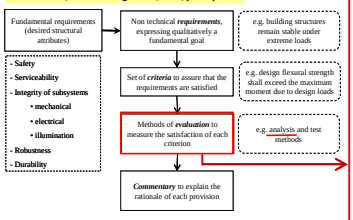


Performance-Based Fire Design of complex structures

Performance based fire design (PBFD)

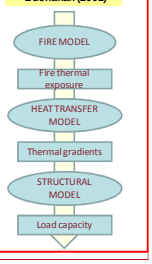
Performance based structural codes

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



Methods of evaluation to measure the satisfaction of each criterion

Buchanan (2001)



Complex structures and LPHC events

Complex structures

High redundant
Complex geometry
Extension
Nonlinear behavior

LPHC
Low Probability High Consequence events

Fire
Malevolent Explosions

	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 investigations	Probabilistic	Heuristic (incomplete statistics)
Models	Ordinary	Advanced

PBFD- 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	

Application 1: a steel structure for Helicopters storage under fire

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

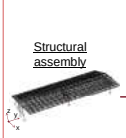
$$DM^{scenario}_{component} = \frac{(n^{\circ}_{collapsed\ elements})^{scenario}}{(total\ n^{\circ}of\ elements)_{component}} \cdot 100$$

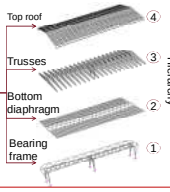
→ irrelevant
→ moderate
→ average
→ significant

DM- Performances connection

Failed Performance (evaluated on DM)

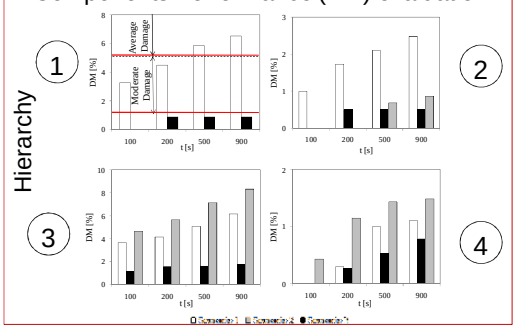
Structural assembly





- Serviceability/ damage
- Serviceability/ local collapse
- Safety/ global collapse
- Robustness/ global collapse

Components Performance (DM) evaluation



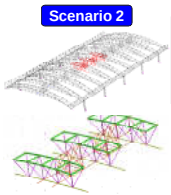
Performance Evaluation

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

Application 2: a steel exhibition pavilion

Fire modeling by the ISO 834 curve

Scenario 2



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

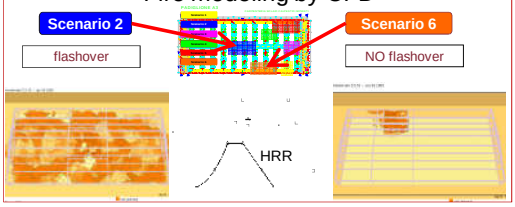
Nominal curve

Scenario 6

Fire modeling by CFD

Scenario 2 — flashover

Scenario 6 — NO flashover



Conclusions and considerations

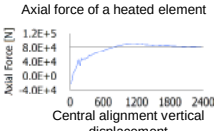
PBD approach is the best way to conceive and assess complex structural systems under fire action. Specific considerations are:

- 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 simplified methods for the fire modeling, using nominal fire curves, apparently conduct to similar results (in terms of the deformed shape under fire), using more advanced methods with CFD, a detailed description of the structural response highlights the great difference of the two methods in obtaining the structural response.

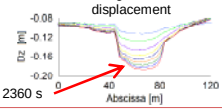
Deformed shape (nominal fire)

Max vertical roof displ. Dz= -0.1868 m
Max lateral column disp. Dx=-0.1344 m

Axial force of a heated element



Central alignment vertical displacement

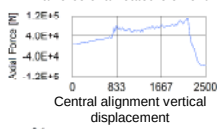


Last curve: 2360 s

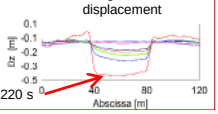
Deformed shape (CFD fire)

Max vertical roof displ. Dz= -0.8243 m
Max lateral column disp. Dz= -0.6353 m

Axial force of a heated element

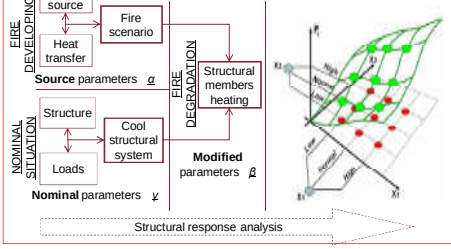


Central alignment vertical displacement



Last curve: 2220 s

Uncertainties



Further developments

COMPUTATIONAL MODELLING FOR PERFORMANCE BASED FIRE ENGINEERING (PBFE)

Francesco Petrini, Konstantinos Gkoumas
Sapienza University of Rome, School of Engineering, Rome, Italy