STRUCTURAL ANALYSIS AND DESIGN IN CASE OF FIRE AFTER EARTHQUAKE

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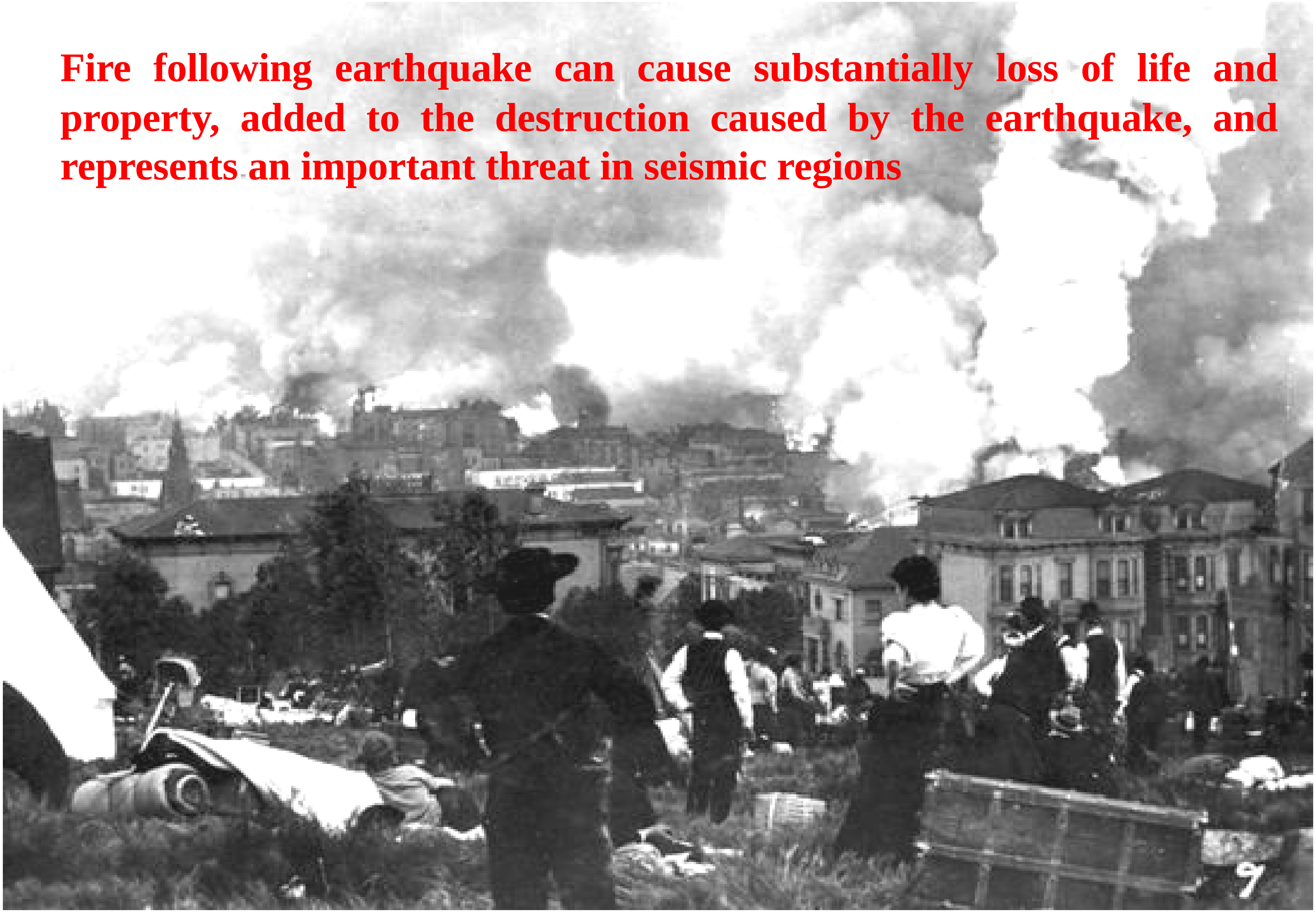
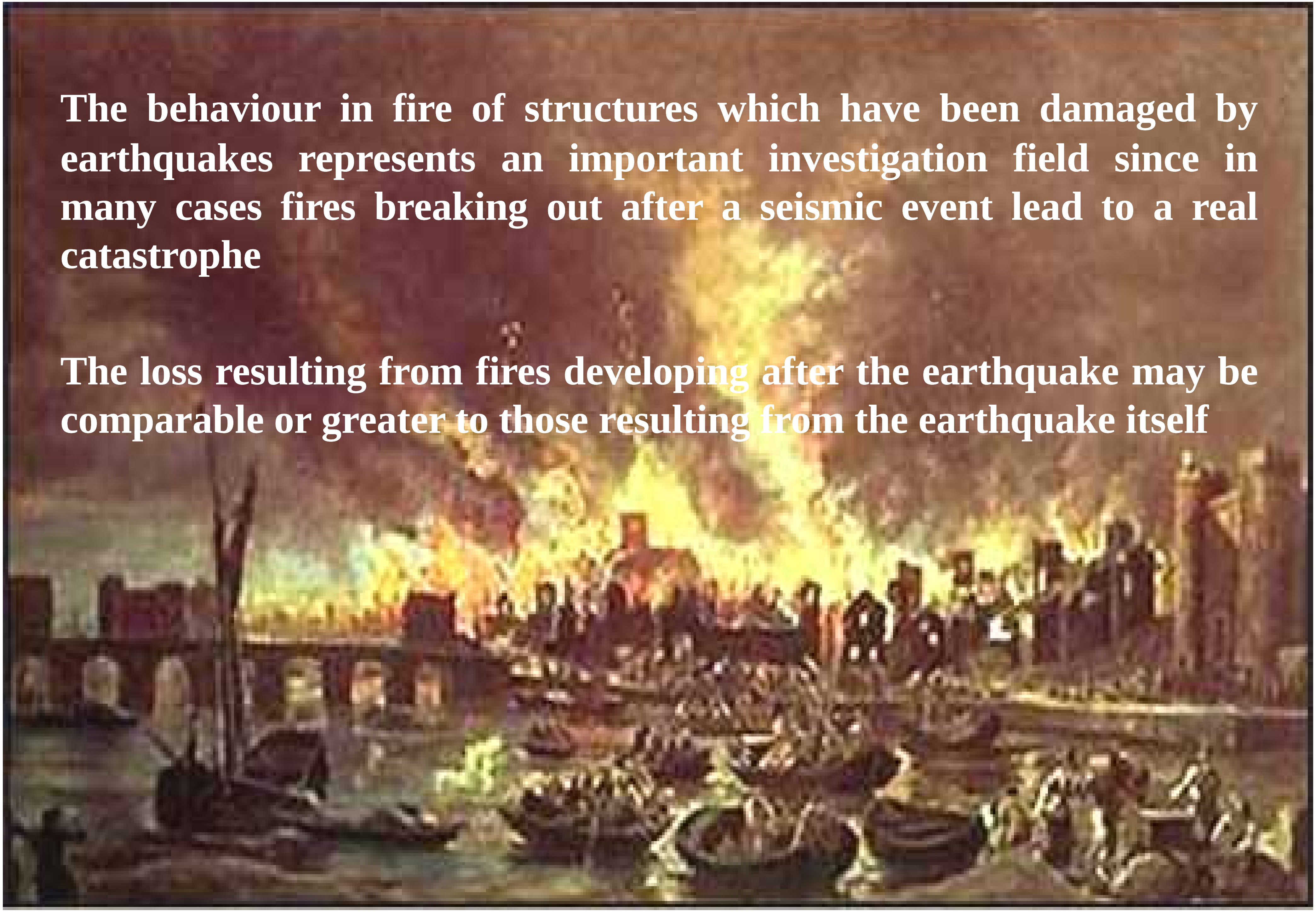
Fire following earthquake can cause substantially loss of life and property, added to the destruction caused by the earthquake, and represents an important threat in seismic regions



The behaviour in fire of structures which have been damaged by earthquakes represents an important investigation field since in many cases fires breaking out after a seismic event lead to a real catastrophe

The loss resulting from fires developing after the earthquake may be comparable or greater to those resulting from the earthquake itself



<u>**Risk Factors related to:**</u>

- *direct earthquake effects:* damage itself, fracturing of gas/ electricity connections;

- *sources of ignition:* boilers, short circuits from structural damage, fallen live wires;

- *establishemnt of fire:* failure of active suppression systems (sprinklers)

- *spread of fire:* wind, damage of passive measures, boundary barriers not designed according to modern fire spread resistance

- *detection/ extinguishment of fire:* panic, uncertainty of fires location, traffic congestion, loss of water supply, brigade response

Even if no fire develops immediately after an earthquake, the possibility of delayed fires affecting the structure must be adequately taken into account, since the earthquake induced damages makes the structure more vulnerable to fire effects than the undamaged one

- **damage of structure**
- **damage to fire protection**
- **damage to non-structural fire protection**

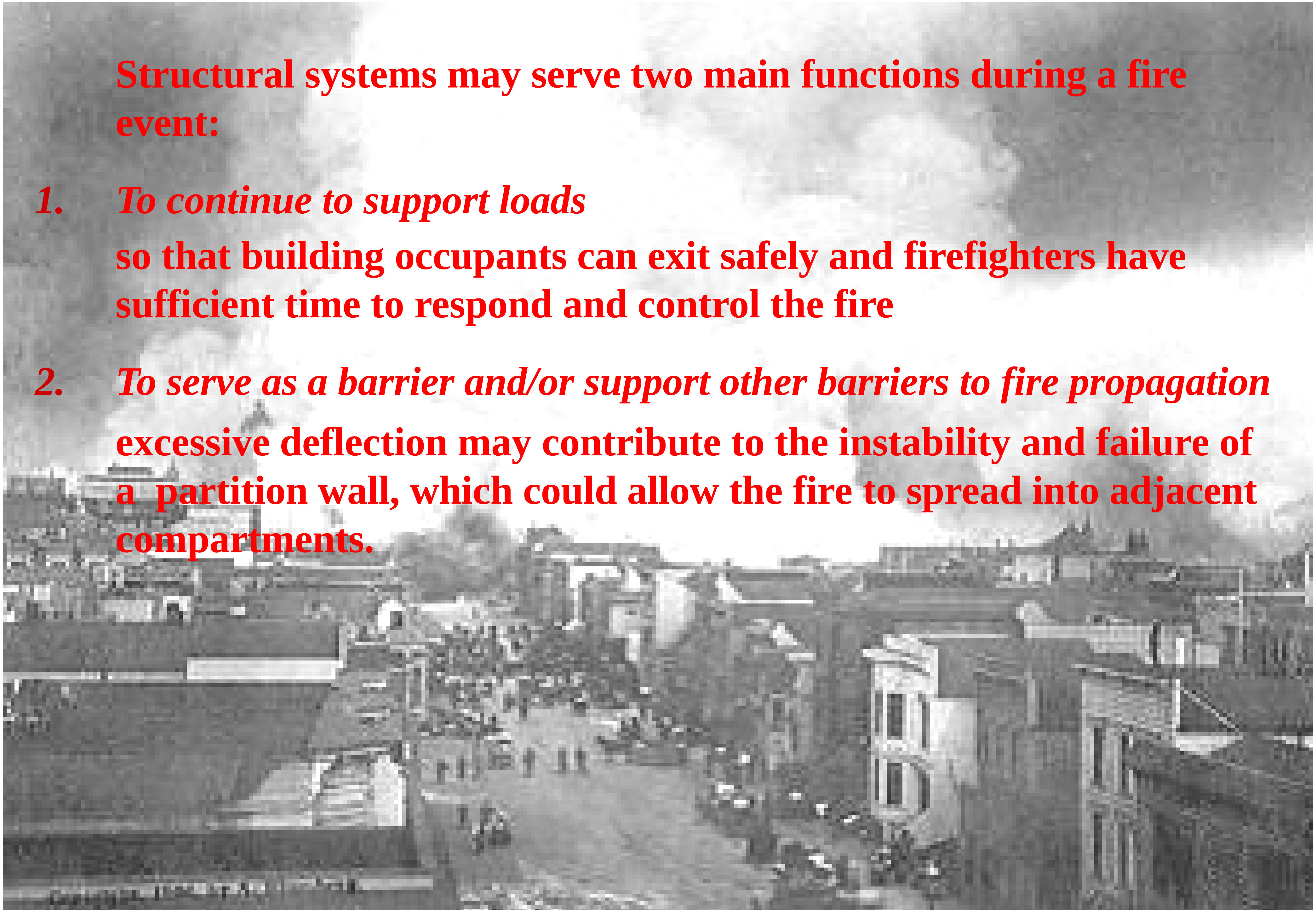
Structural systems may serve two main functions during a fire event:

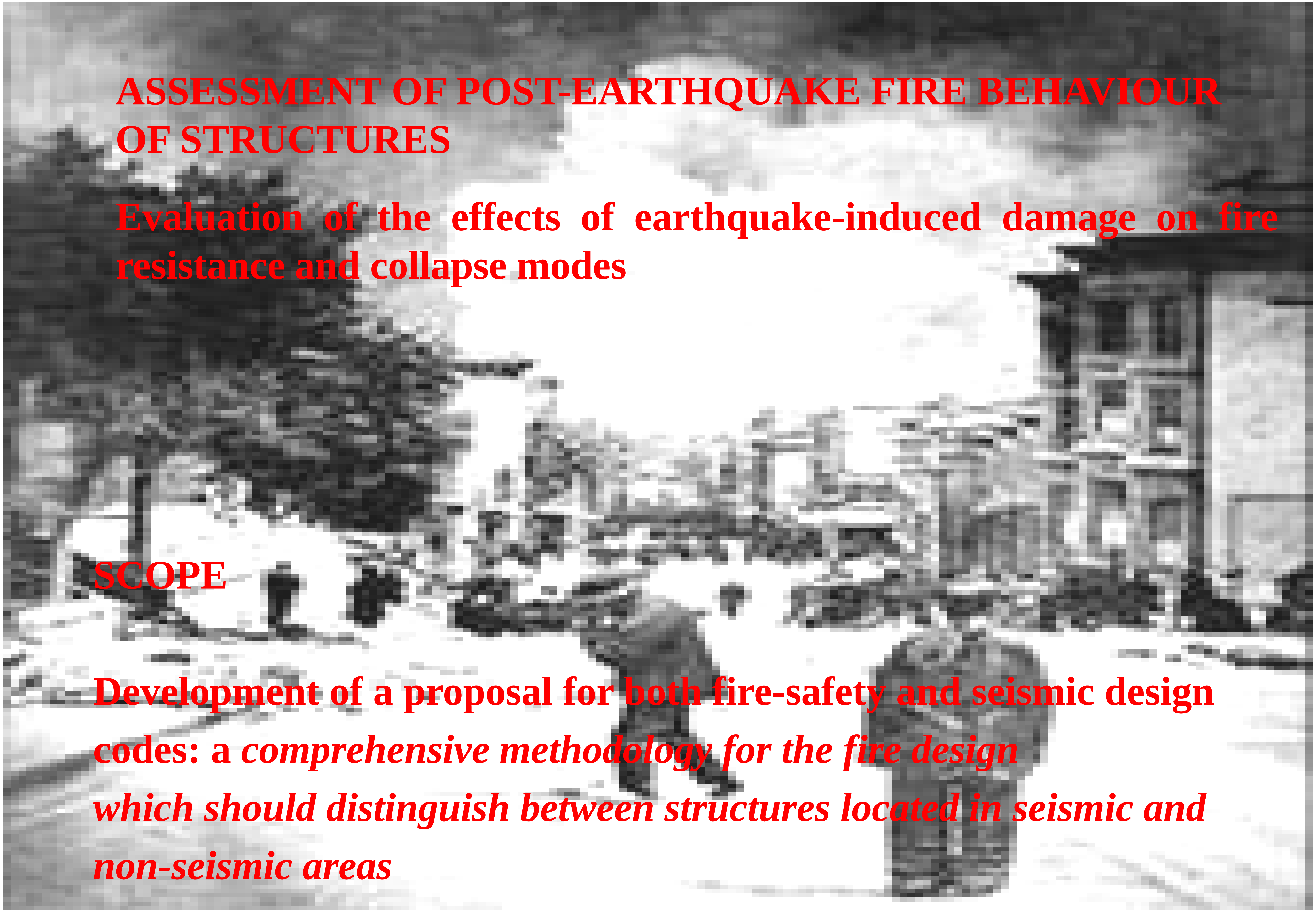
1. ***To continue to support loads***

   so that building occupants can exit safely and firefighters have sufficient time to respond and control the fire

2. ***To serve as a barrier and/or support other barriers to fire propagation***

   excessive deflection may contribute to the instability and failure of a partition wall, which could allow the fire to spread into adjacent compartments.



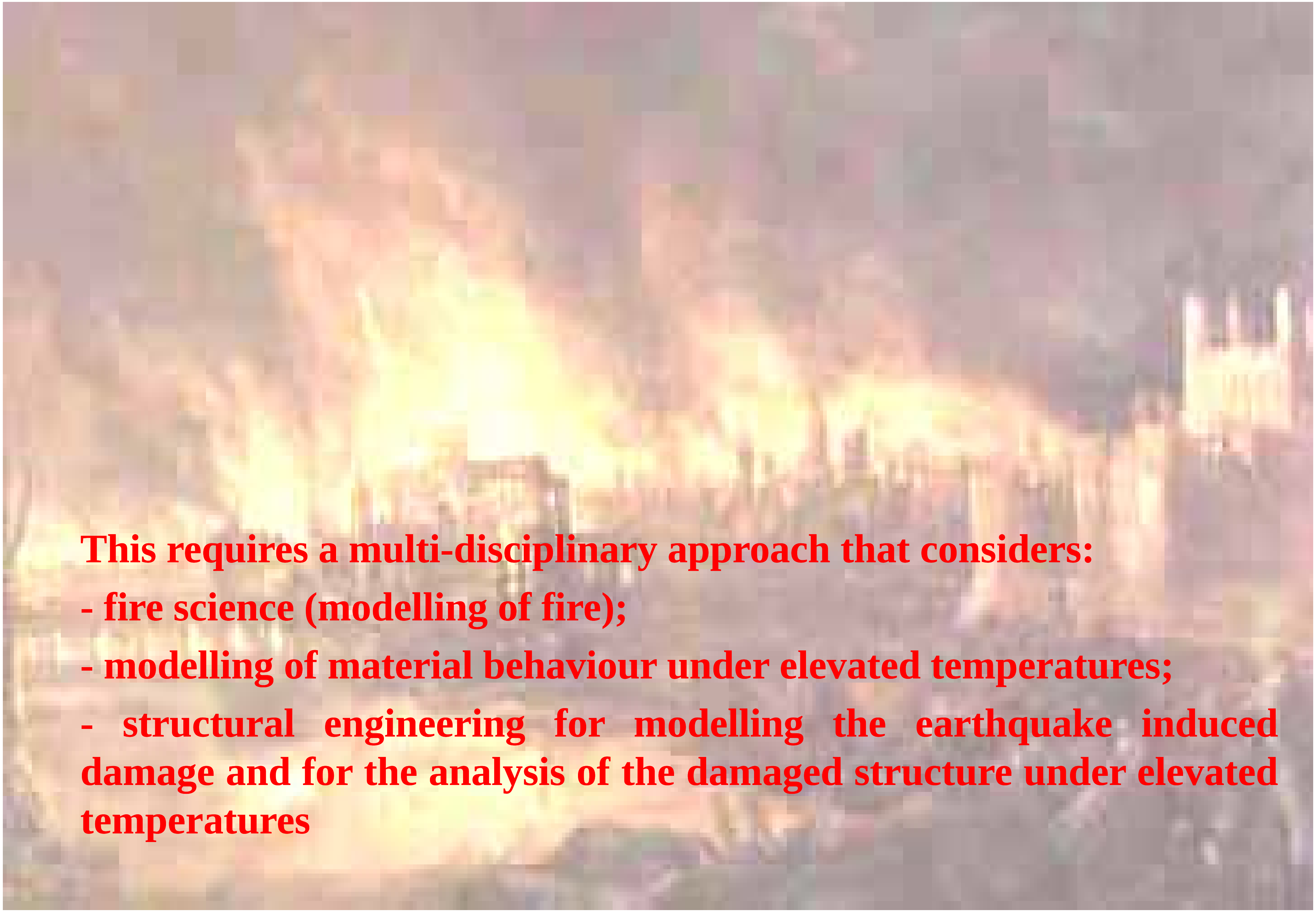


ASSESSMENT OF POST-EARTHQUAKE FIRE BEHAVIOUR OF STRUCTURES

Evaluation of the effects of earthquake-induced damage on fire resistance and collapse modes

SCOPE

Development of a proposal for both fire-safety and seismic design codes: a *comprehensive methodology for the fire design which should distinguish between structures located in seismic and non-seismic areas*



This requires a multi-disciplinary approach that considers:

- fire science (modelling of fire);

- modelling of material behaviour under elevated temperatures;

- structural engineering for modelling the earthquake induced damage and for the analysis of the damaged structure under elevated temperatures

ANALYSIS METHODOLOGY

- Identification of the seismic damage state, according to pre-fixed performance levels, by means of nonlinear pushover analyses or by non linear time-history incremental dynamic analyses

- Analysis under fire of structures already damaged by earthquake, starting from each previously defined performance level

- Correlation between the seismic performance levels and the behaviour of corresponding damaged structures under fire in terms of fire resistance and collapse mode.

- Definition of integrated seismic and fire design criteria

FIRE MODELS (EN1991-1-2)

***Nominal standard ISO 834*: does not take into account any physical parameter and can be far away from reality**

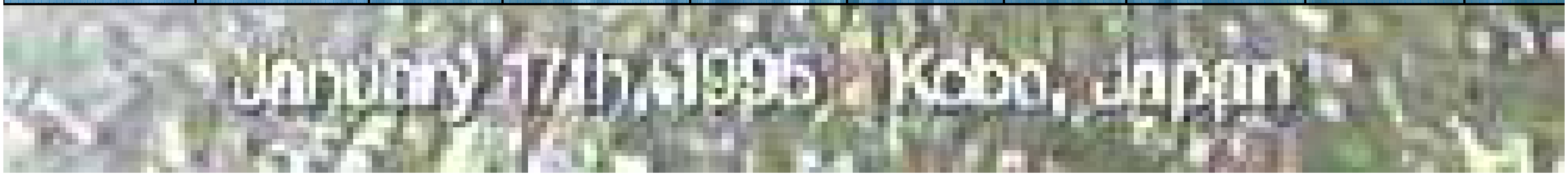
Natural fires:

- ***parametric fire:* considers the fire load density, the openings and the cooling phase**
- ***combined "Two Zone" and "One Zone" model*: considers the fire load density, the openings, the cooling phase and the pre-flashover phase in which the compartment is divided in a hot upper zone and a cold inferior one**

DESIGN FIRE LOAD DENSITY (EN1991-1-2)

$$q_{f,d} = q_{f,k} \cdot m \cdot \delta_{q1} \cdot \delta_{q2} \cdot \delta_{n}$$

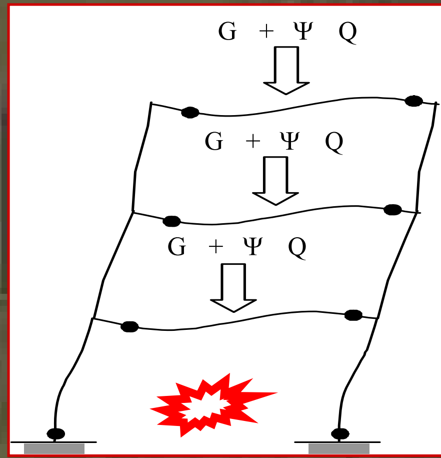
Fire scenario	Sprinklers	Indep. water supply	Auto fire detection	Alarm fire brigade	Off site Fire brigade	Safe Access routes	Fire fighting devices	Smoke exhaust	Total
	δ_1	δ_2	$\delta_{3/4}$	δ_5	$\delta_{6/7}$	δ_8	δ_9	δ_{10}	$\Pi\delta_n$
Before earthquake	**0,61**	**0,87**	**0,73**	**0,87**	**0,78**	**1,0**	**1,0**	**1,0**	**0,26**
After earthquake	**1,0**	**1,0**	**1,0**	**1,0**	**1,0**	**1,5**	**1,5**	**1,5**	**3,38**



EXAMPLES OF APPLICATION

Della Corte, G., Landolfo, R., Mazzolani, F.M., Post-earthquake fire resistance of moment-resisting steel frames
Fire Safety Journal, Elsevier, 2003

Della Corte, G., Faggiano, B., Mazzolani, F.M., On the structural effects of fire following earthquake
COST C12 Final Conference, Innsbruck, Austria, 2005



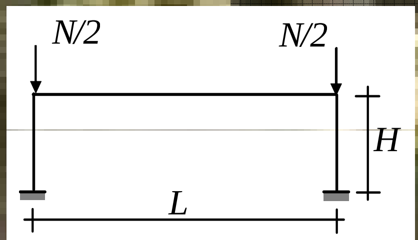
Structural analysis under seismic action: damage distribution and extent

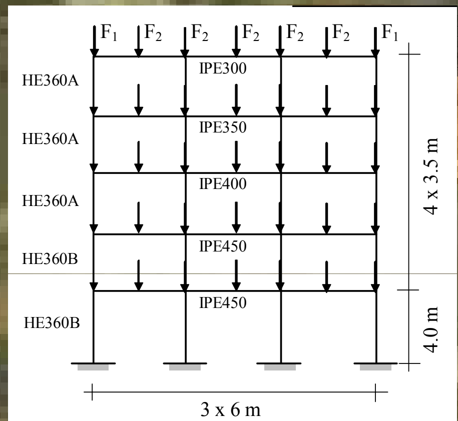
- different acceleration records and multiple levels of earthquake intensities

Structural analysis under fire action:

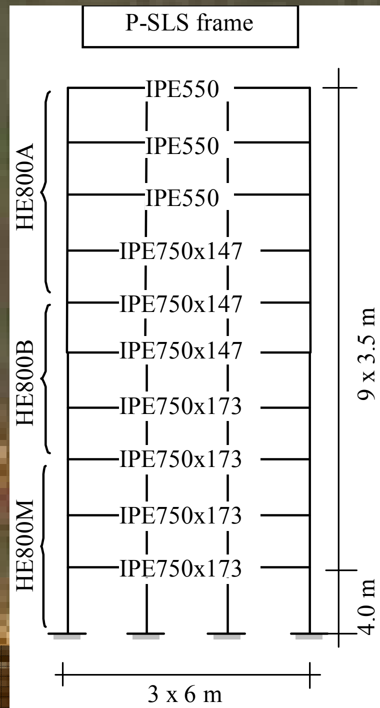
- performed on the frame presenting a deformed geometry due to damage after the earthquake

Portal Frames





5 Story Frames

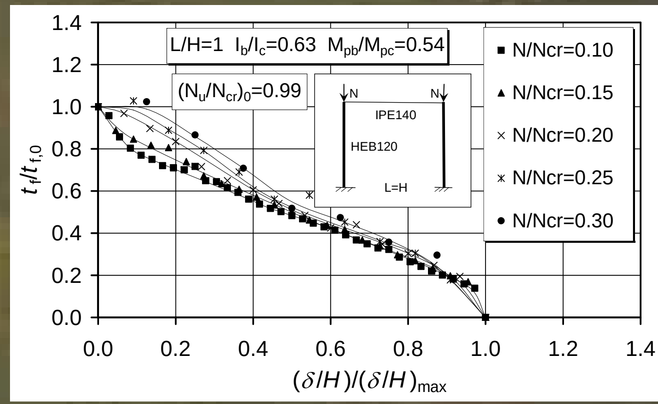


10 Story Frames

Results

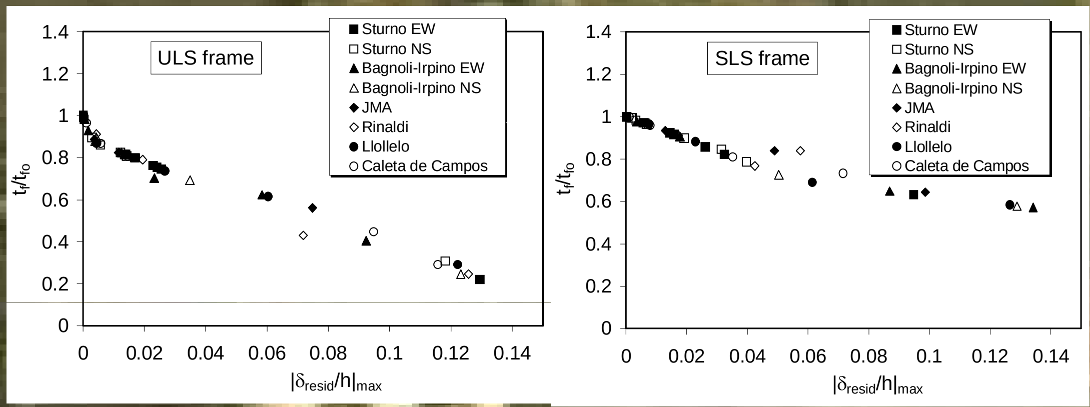
Portal frames:

Fire resistance ratings reduction for steel portal frames subjected to geometrical damage, function of the level of residual storey drift



Multi-storey frames:

Effect of the seismic design option (ULS or SLS)



Normalised fire resistance rating vs. the maximum residual inter-story drift angle for ULS and SLS frame

During the pre-earthquake fires, the undamaged frames collapsed on themselves, without appreciable lateral displacement

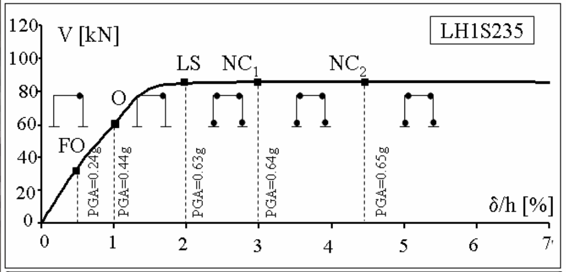
The earthquake-induced damage produces a lateral stability type of collapse mechanism

Faggiano, B., Esposto, M., Mazzolani, F.M., Landolfo, R., Fire analysis on steel portal frames damaged after earthquake according to performance based design
COST C26 Workshop, Prague, Czech Republic, 2007

Pushover analysis of simple steel portal frames under horizontal loads aiming at the damage identification

Definition of the performance levels, which correlate seismic intensity and damage extent

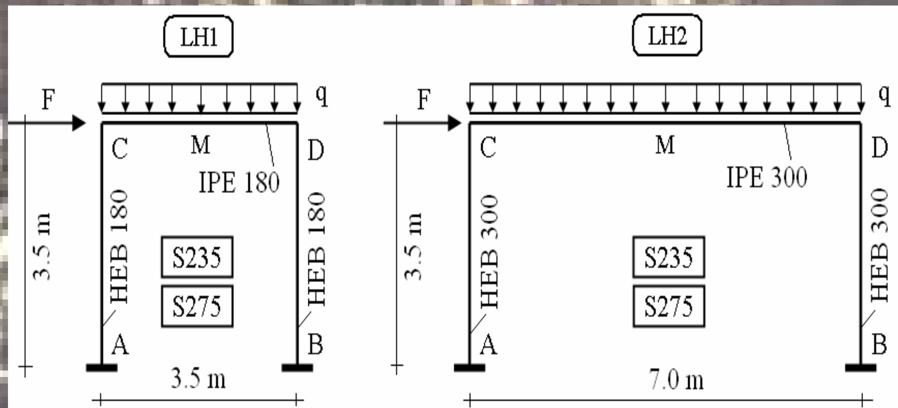
Fire analysis of the damaged structures



δ/h	0.5%	1 %	2 %	3 %	4.4 %
PL	FO	O	LS	NC_1	NC_2
Θ_{plA}	0	0	0.004	0.018	0.031
Θ_{plC}	0	0	0.007	0.020	0.032
Θ_{plD}	0.002	0.014	0.024	0.039	0.050
Θ_{plB}	0	0	0.005	0.019	0.031

SEISMIC PERFORMANCE LEVELS -PL (SEAOC Vision 2000)

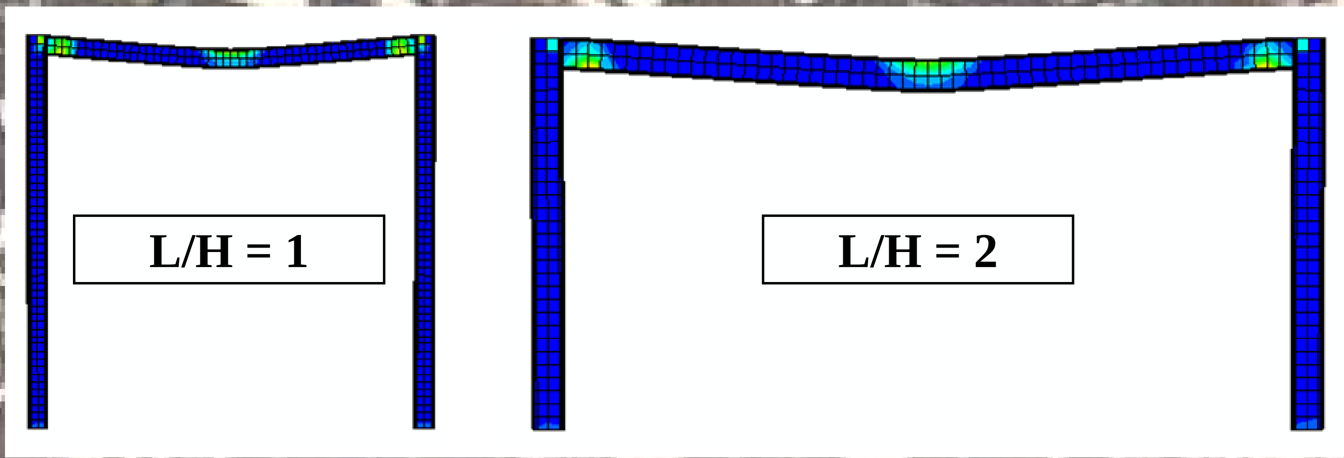
PL	Interstorey drift (δ/h)	Plastic rotations (Θ)
FO	0.002-0.005	0 (elastic range)
O	0.002-0.01	≈ 0 (negligible damage)
LS	0.01-0.02	0.01-0.03
NC	0.02-0.04	0.02-0.05



Results

Fire resistance of the portal frames in relation with the span/ height ratio, the section factor of steel profiles and seismic performance levels

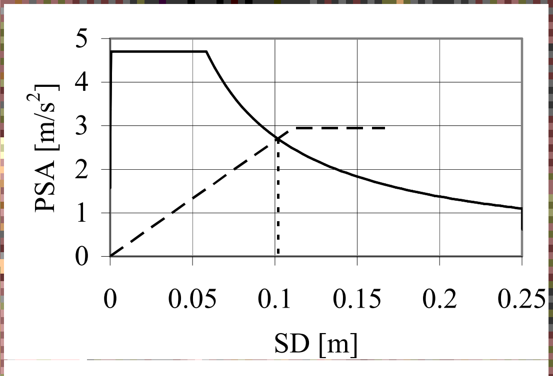
In all cases, the collapse mechanism is a beam mechanism

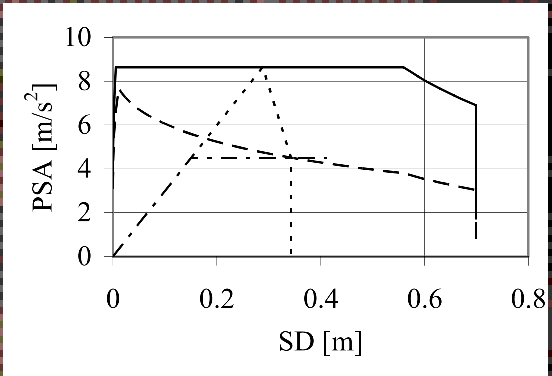


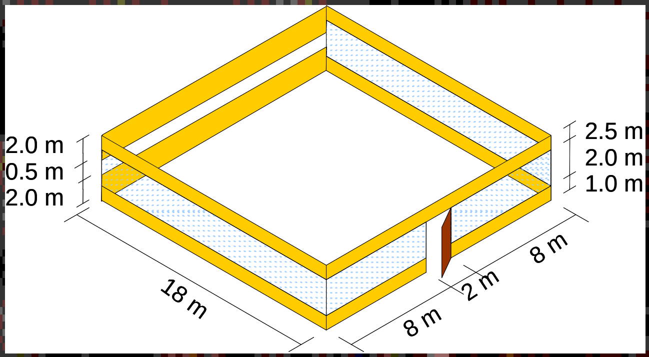
Zaharia, R., Pintea, D., Dubina, D., Fire after earthquake – a natural fire approach, EUROSTEEL 2008, Graz, Austria, 2008

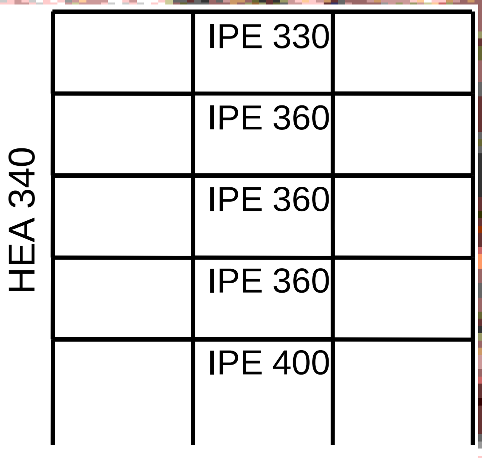
Pintea, D., Zaharia, R., Stratan, A., Dubina, D., V'th Int. Conf. 'Structures in fire', Singapore, 2008

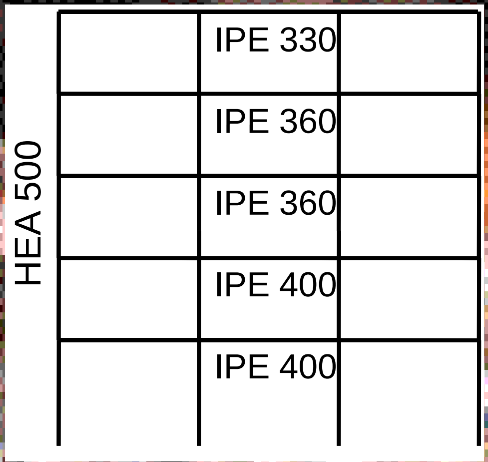
Banat PGA=0.16g Tc=0.7s   Vrancea PGA=0.32g Tc=1.6s

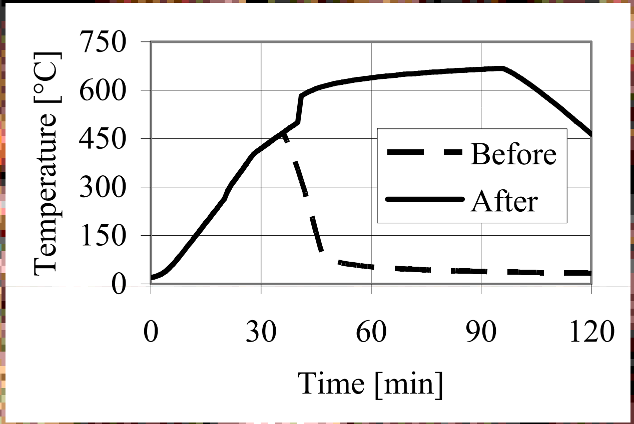












Results

The structure adapted for seismic action has an important reserve of resistance in case of a regular fire situation, but also in case of a fire after an earthquake, considering the corresponding damages for the code earthquake. This conclusion was emphasised considering both standard ISO and natural fire models.

For the scenario with all fire fighting measures available (no flashover) in a fire situation both unprotected steel structures resisted to the fire action.

After earthquake, the structure designed for the stronger earthquake resists at the fully developed fire, even if it is damaged by the seismic action, while the structure designed practically from the fundamental load combinations collapses.

FURTHER DEVELOPMENTS

Parametrical analyses focusing on the influence of some parameters as: span/ height, overstrength, seismic damage

Definition of rules and indications, based on correlatons among site PGA – performance levels – fire design objectives, in a PBD approach, considering different fire scenarios

Fire models: standard fire (for more general results) and natural fires (more realistic information, although reffered to specific cases)


Thank you
for your attention !