COST Action TU0904

IFER Integrated Fire Engineering and Response

Chair: prof. Franticek WALD

CURRENT RESEARCH at the UNIVERSITY OF NAPLES

The Kobe earthquake (Japan, 1995)

www.asiaedu.britannica.com

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FIRE FOLLOWING EARTHQUAKE

dr. Beatrice FAGGIANO

The fire after earthquake risk

Records from historical earthquakes show that sometimes the damage caused by the subsequent fire can be much severer than the damage caused by the ground motion itself

Even in case no fire develops immediately after an earthquake, the possibility of delayed fires affecting the structure must be adequately taken into account

RISK FACTORS

- Building characteristics and density,
- Earthquake-induced impairing to communications, water supply, transportation
- Meteorological conditions,
- Probable multiple simultaneous ignitions

The Great Lisbon Earthquake (Portugal, 1755)

http://nisee.berkeley.edu

The fire after earthquake risk

The risk management activity evidently requires a multi-disciplinary approach, involving:

- fire service,
- local authorities,
- other utility organisations,
- research and hazard informative services,
- insurance industry,
- building owners and/or managers,
- environmental and community,
- the public.

A **response-based approach** was followed in the past: specially trained disaster managers coordinate the relief efforts of both the affected community and the wider aid benefactors.

The recent **risk management approach** aims at identifying problems before they happen, by means of systematic process of analysis of risk and decisions about its acceptability.

The Great Fire in San Francisco Earthquake (California, USA, 1906)

http://contentdm.marinlibrary.org

Two-scale risk management: *Building scale – Regional scale*

BUILDING SCALE

For buildings in seismic zone, both fire and earthquake are important design issues, although they are commonly assumed as independent hazards.

Performance Based Design seems to be the most correct design philosophy for integrating fire safety into the design process for structures.

Already adopted by International Codes (USA, Australia, UK, New Zealand, Sweden, Eurocode system) in the field of structural fire safety,

from meeting the code prescriptive requirements (height and area limits, fire-resistance ratings, egress, separations, etc.) to demonstrating safe performance, which involves design and analysis.

A **multi-disciplinary approach** is required:

- **FIRE SCIENCE**
- **STRUCTURAL ENGINEERING**
- **FIRE SAFETY DESIGN.**

The Great Kanto Earthquake (Japan, 1923)

http://www.eas.slu.edu

Two-scale risk management: *Building scale – Regional scale*

REGIONAL SCALE

Once the earthquake has occurred, the sources of ignitions can range from overturned heat sources, such as candles or lamps, to abraded and shorted electrical wiring, to spilled chemicals having exothermic reactions, to friction of things rubbing together.

At some point, if the fire is not self-extinguished, it could be discovered, however, in the confusion following an earthquake, the discovery may take a very long time.

If it is not possible for discovers to immediately extinguish the fire, intervention of fire department is required, it has to respond to the help request, then to suppress the fire.

If firemen are successful, they move on to the next incident, if not, they continue to attempt to control the fire, until the fuel is exhausted, or the fire comes to a firebreak.

Definitely the following steps of the whole process can be identified:

- Earthquake,
- Ignition,
- Discovery,
- Request,
- Response,
- Suppression.

The Loma Prieta Earthquake (USA, 1989)

www.sfmuseum.org

Two-scale risk management: *Building scale – Regional scale*

REGIONAL SCALE

In a long-term perspective, the emergency management spans

- *routine periods* to facilitate sustainable hazard management practices,
- *emergency periods* to coordinate response and recovery requirements.

Geographic Information Systems (GIS) based approaches for earthquake hazard mitigation may be used.

Such tools provide a decision support for assignment and routing optimization of emergency vehicles after earthquake, considering:

- geographic distribution of ignited fires and injuries,
- locations of emergency response facilities (emergency operation centres, healthcare facilities, fire stations, police station, etc.),
- earthquake damage to the facilities and the transportation system.

The Northridge Earthquake (USA, 1994)

www.lafire.com

Building scale issues related to fire after earthquake

Several categories of structural modifications can occur in case of fire after earthquake:

- damage to passive protection of structural members (insulation, coatings, barriers..)
- changes of structural configuration due to permanent damage to structural members.

They all should be considered in the design process, in order to analyze the structure "as it is".

The evaluation of the effects of earthquake-induced damage on fire resistance and collapse modes is evidently a key issue

the more the structural behavior is degraded after an earthquake, the more time up to collapse due to fire is short and the collapse mode under fire can change as respect to the pre-earthquake one.

The Northridge Earthquake (USA, 1994)

www.cnn.com

A very important role is played by the modeling of

- earthquake-induced damage,
- material behavior at elevated temperature
- fire.

ANALYSIS METHODOLOGY

Reproduction of the actual phases of the phenomena, from the application of vertical service loads and earthquake-induced damage up to the exposure of the structure to fire.

Seismic analysis

The seismic damage state should be identified, according to pre-fixed performance levels, through nonlinear pushover or non linear time-history incremental dynamic analyses.

Fire analysis

Structures already damaged by earthquake, starting from each previously defined seismic performance level, should be analysed under fire.

Fully coupled temperature and displacement analysis is required

Correlation between the seismic performance levels and the behaviour of corresponding damaged structures under fire in terms of fire resistance and collapse mode should be determined

The Chilean earthquake (2010)

allvoices

AIMS

Definition of integrated seismic and fire design criteria, giving rise to guidelines for prevention against fire after a seismic event and related safety rules in earthquake prone countries.

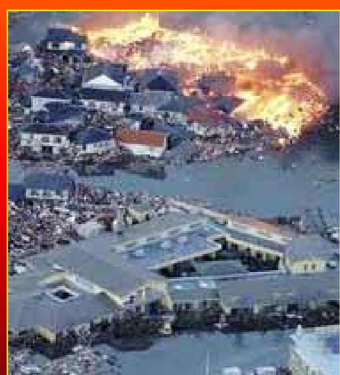
Development of a quantitative proposal for both fire-safety and seismic design codes, aiming at a sound design for guaranteeing fire safety of buildings exposed to post-earthquake fire risk, by fitting fire resistance according to prefixed performance levels.

Design objectives should face the safety in terms of both the structural behaviour in fire and the direct effects of fires on people within the building.

They may include :

- life safety of the occupants;
- non-injury of occupants;
- life safety of fire fighters;
- non-injury of fire fighters;
- prevention of damage to contents;
- avoidance of damage to process;
- prevention of damage to building;
- prevention of collapse of building.

The 2011 Earthquake in Japan



Bestpicblog.com

Future gains

Main issues as developing subjects of the relevant research activity:

1) With regard to the **PBD** approaches for single buildings, the suitable definition of performance criteria and design procedures has to be consolidated;
2) With regard to the **GIS** based regional approaches, the predictions of the earthquake-fire occurrence correlations should be defined.

The 2011 Earthquake in Japan

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spu.esu

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blitzquotidiano.it

The Chilean earthquake (2010)

FIRE AFTER EARTHQUAKE ROBUSTNESS EVALUATION AND DESIGN: Application to steel structures

dr. Beatrice FAGGIANO

Structural and computational aspects related to FFE event

Common numerical programs allow to perform the heat transfer analysis as preliminary step, in order to evaluate the temperature – time law within the structural elements, subsequently, the structural analysis under design loads is carried out, by imposing to the member the temperature variation obtained in the first step:

the heat transfer analysis and the structural one are performed separately (uncoupled analyses).

Some programs, able to carry out the fully coupled temperature and displacement analyses in a unique structural model, are available.

In this case the mechanical and thermal aspects of the problem can be treated simultaneously and the mutual interactions is caught

pisqa.com

The 2011 Earthquake in Japan

piersystem.com

Methodology for the robustness assessment in fire of structures after earthquake

Reproduction of the actual phases of the phenomena, from the application of vertical service loads and earthquake-induced damage up to the exposure of the structure to fire.

The methodology should consist of two main subsequent phases:

1. the identification of the seismic damage state, according to pre-fixed seismic performance levels, in relation to the intensity of the seismic event;

2. the determination of the residual bearing capabilities of the seismic damaged structures subjected to fire, according to pre-fixed fire performance levels, in relation to the fire event.

Correlation between the seismic performance levels and the behaviour of corresponding damaged structures under fire in terms of fire resistance and collapse mode should be determined

Existing structures:
the vulnerability to FFE can be stated and the possible opportune mitigation measures can be identified.

New constructions:
design criteria and procedures against FFE can be defined.

The Northridge Earthquake (USA, 1994)

guerrillalaw.com

Methodology for the robustness assessment in fire of structures after earthquake

The Performance based approach has already been adopted by International Codes (USA, Australia, UK, New Zealand, Sweden, Eurocode system) in the field of structural fire safety.

The novelty to be introduced, in case the former occurrence of the earthquake is a possible scenario, is the degradation of the mechanical behaviour of the structural systems due to permanent damage induced by the seism, as initial state for the event of a fire.

First of all the fire after earthquake hazard should be identified, such as the probability that a fire event of a specific intensity can develop after an earthquake of a specific intensity in a built area.

Then, for every design fire after earthquake scenario a structure should be designed for behaving according to predetermined performance levels, which should integrate both seismic and fire requirements.

FFE scenario and performance levels should be identified for each particular class of buildings, it being ordinary or of strategic or historic-monumental importance

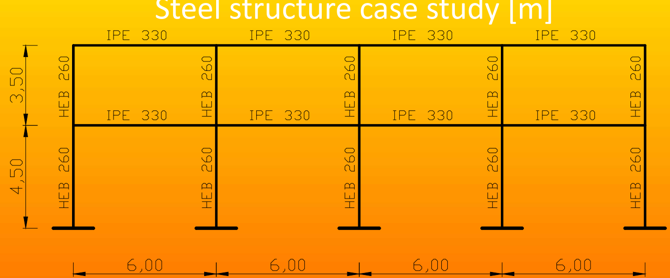
The 2011 Earthquake in Japan

spu.esu

Evaluation of the FFE performance for steel structures

Case study and seismic performance characterization

Steel structure case study [m]



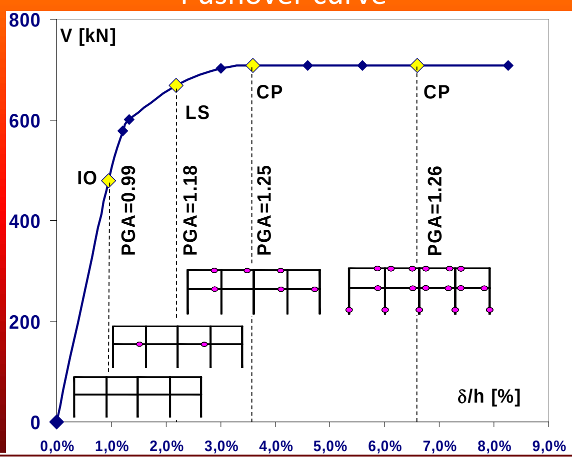
Fire on half structure

Reference seismic performance levels:

Immediate Occupancy (IO)
Life Safe (LS)
Collapse Prevention (CP)

	δ/h [%]	Θ [rad]
IO	0.7	-
LS	2.5	-
CP1	5.0	-
CP2	-	0.05

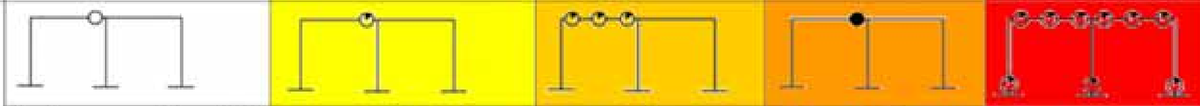
Pushover curve



Evaluation of the FFE performance for steel structures

Fire after earthquake performance for the steel frame

FFE performance levels: simplistic identification for steel structures



	Of	LSf	CLf	CSf	CGf
S	Attainment of the yield stress	Formation of the first plastic hinge	Beam mechanism	Failure of the cross-section	Global mechanism
NS	Negligible damage	Equipments and contents are secure	Extensive damage	Many architectural, mechanical and electrical systems are damaged	θ = θy θ > θy θ = θpl

Operational fire (Of),
Life Safe fire (LSf),
Local Collapse fire (CLf),
Section Collapse fire (CSf),
Global Collapse fire (CGf).

Non structural damage (NS)
Structural damage (S).

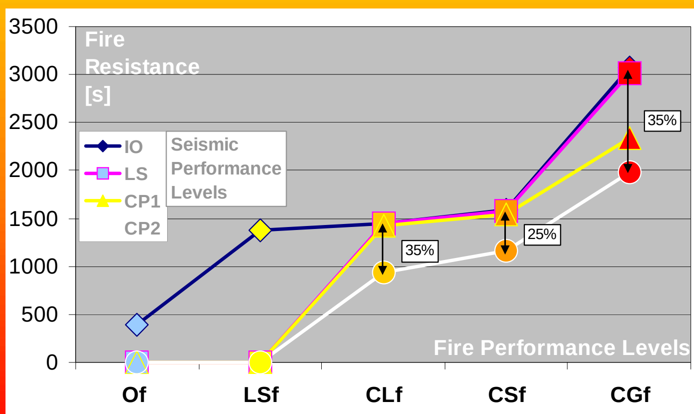
Fire analyses have been performed once the seismic analyses were carried out and the fixed seismic performance levels IO, LS, CP1 and CP2 reached.

Evaluation of the FFE performance for steel structures

Fire after earthquake performance for the steel frame

Fire resistance [s] related to each FFE performance levels

	IO	LS	CP1	CP2
Of	387	-	-	-
LSf	1382	-	-	-
CLf	1451	1446	1418	938
CSf	1587	1574	1544	1168
CGf	3076	3015	2340	1980



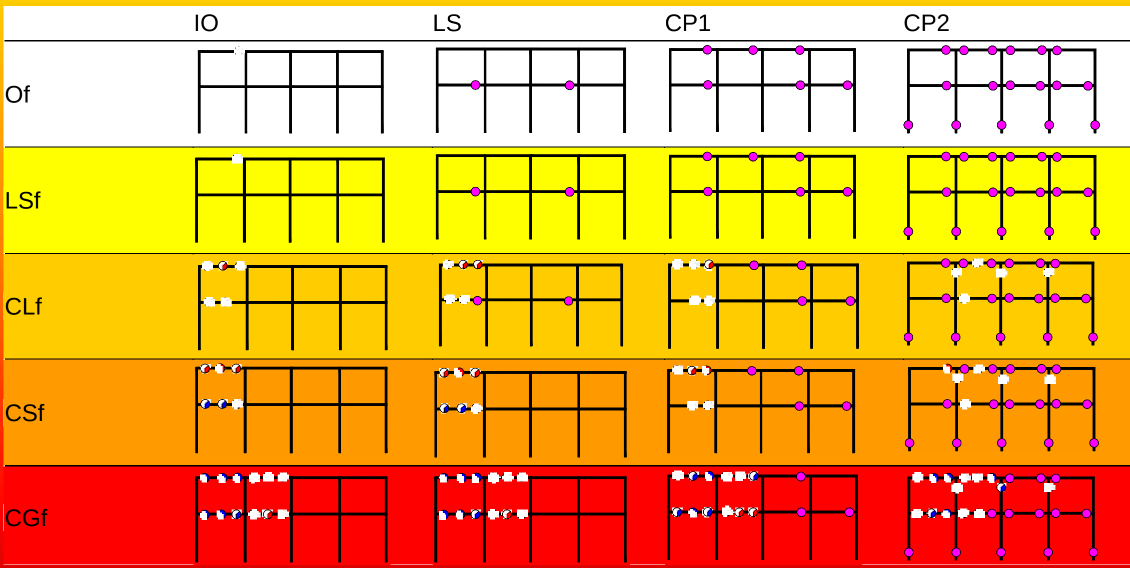
Time (s) necessary to attain the performance fire levels, starting from the predetermined seismic performance levels

As far as the seismic damage is large (from IO to CP2) the fixed fire performance level is reached in shorter time, with a fire resistance reduction up to about 35%

Evaluation of the FFE performance for steel structures

Fire after earthquake performance for the steel frame

Distribution of damage [s] related to each FFE performance levels

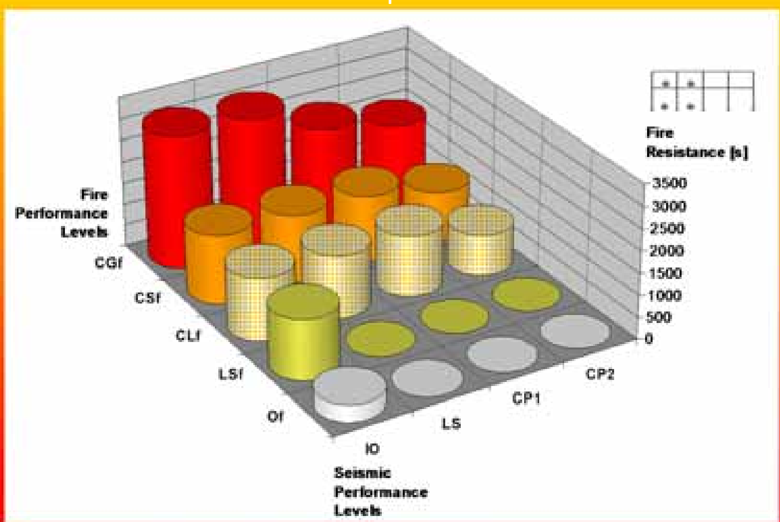


For a fixed required fire resistance rate the damage within the structure is different depending on the preliminary seismic damage extent and therefore for satisfying a fixed fire resistance, members should be designed so that whatever is the level of the preliminary seismic damage they are able to attain the fire performance level

Evaluation of the FFE performance for steel structures

Fire after earthquake performance for the steel frame

FFE performance chart



Useful and powerful representation and tool both for fire after earthquake capability analysis and for fire after earthquake design

for a given structural type, given a fire scenario, once fixed the seismic damage extent corresponding to the design seismic performance level, it is possible either to carry out a fire performance capability analysis with reference to the prefixed fire performance levels, or to design the structure in fire in order that it could reach the fire performance level required at the given acceptable time

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Thank you for your attention....