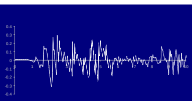
## 2.16 Fire after earthquake (short version)

Lazarov L., Macedonia

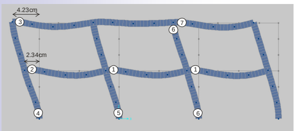
IFER - Integrated Fire Engineering and Response - COST action TU0904

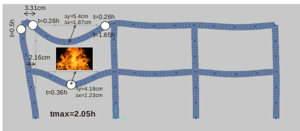
University "Ss. Cyril and Methodius"
Faculty of Civil Engineering, Skopje
Macedonia

# Fire after Earthquake



Lazarov Lj., Todorov K., Cvetkovska M.




COST TU0904 Workshop Barcelona, 5-6 July 2010

1

Calculating structural response to fire after earthquake is a few step process:

1. Modeling the structure including nonlinear analysis options
2. Choice for earthquake analysis scenario
3. Seismic nonlinear analysis: Pushover or Dynamic Time History
4. Fire Hazards Analysis to identify all possible fire scenarios
5. Thermal Analysis to calculate temperature history in each member.
6. Structural Analysis to determine forces, stresses and deformations to estimate whether local or global collapse would occur during any of the fire hazard scenarios.

"Laboratory" or Design Code approach???

2

### Design guidelines and numerical simulation techniques

- Besides satisfying structural design requirements for normal loads, such as dead and live loads including the seismic hazard, buildings should also be designed to withstand the fire following earthquakes for a certain minimum duration as required for a desired level of performance.
- Appropriate analysis and numerical simulation techniques for the evaluation of the structural performance under earthquake-induced fire conditions need to be developed.
- It is necessary to conduct experimental studies to validate such numerical models and refine them.

3

### Structural fire safety design

Typical fire-resistance rating requirements for specific building members are provided in building codes. However, much of this criterion is developed for fire exposure under normal conditions (without an earthquake).

These guidelines may not be fully applicable in the case of PEF events as the structure under fire exposure may experience significant lateral loads from an earthquake prior to the fire.

Earthquake-induced damage to the structure makes it more vulnerable to subsequent fire as both active and passive fireproofing systems may have been damaged and the residual lateral drift in the building frames produces additional stresses from gravity loads due to the P-Δ effect. This may lead to a lower fire resistance of the structural system.

4

### Evaluation of the post-earthquake fire performance of structures

Prior to the occurrence of an earthquake, a building frame is primarily subjected to gravity loads due to dead and live loads.

To evaluate the seismic damage in a structure, first, the seismic hazard level is determined from the seismic hazard spectrum for the given site, followed by the selection of appropriate ground motion records and structural analysis. The seismic excitation induces damage and lateral deformation provoking additional stresses in the frame due to the moment caused by the P-Δ effect. Structural members and joints are also weakened by the cyclic inelastic deformation, causing stiffness and strength degradation.

Once the earthquake-induced damage in the structure is determined, the damaged structure is subjected to a PEF scenario, which involves fire hazard analysis to determine the time history of fire growth and spread and stress and collapse analysis of the structure but also to analyze no-collapse conditions and cooling after fire.

The earthquake and PEF analysis can be performed using either a **coupled structural-thermal-structural analysis** or an **uncoupled thermal and structural analysis.**

5

### Coupled vs. uncoupled analysis

Although the coupled thermal-structural analysis is preferred, it is computationally more time consuming. In each time step, the fire behavior of a structural member is estimated using a complex, coupled heat transfer-strain equilibrium analysis, based on theoretical heat transfer and structural mechanics principles. The analysis is performed in three steps within each time step: namely, calculation of fire temperatures to which the structural members are exposed, calculation of temperatures in the structural members, and calculation of resulting deflections and internal forces including an analysis of the stress and strain distribution.

On the other hand, in an uncoupled analysis, the heat transfer equations are first solved at each time step to determine the time history of the temperature distribution in the structure. The structural response is then calculated separately, where the temperature time history as determined from the thermal analysis is fed to the structural model to perform stress analysis.

Inelastic deformation and temperature dependent material properties are used in the structural analysis in both schemes (coupled and uncoupled) of analyses.

6

## Analysis and simulation tools

Currently, there are a few research- and commercial-level software tools available for the analysis of fire hazard, loss estimation, and structural response. Modeling the temperature-dependent material properties including creep and strain-rate effects is one of the key challenges to the development of analytical and computer tools for the analysis of structures subjected to elevated temperature. The structural fire-safety analysis by itself is a complex task for which the existing modeling tools are inadequate. A PEF further complicates the modeling process and the current analysis tools and mathematical models are not capable of capturing all aspects of the structural behavior and related physical processes involved in such events. Whereas software packages such as SAFIR (Franssen et al. 2000) and VULCAN (SUEL 2006) are capable of performing a structural fire safety analysis to a certain degree of accuracy, they cannot be used for simulating the combined effects of earthquake and fire scenarios. Some commercial packages, such as ANSYS and ABAQUS, are more sophisticated in terms of structural analysis subjected to fire and earthquakes, separately. However, the combined analysis, including seismic hazard and structural damage evaluation, subsequent fire hazard, and corresponding thermo-structural analysis is not directly available in any of the software systems currently available. Moreover, the finite-element-based models for this analysis may require a large number of elements that will produce complex models that are often computationally very extensive to solve. Simplified, yet realistic, macro-models are needed for regular use to carry out performance-based design, evaluation, and retrofit. Clearly, there is a need for the development of robust mathematical models for material and joint behavior. There is a strong need for comprehensive and sophisticated analysis tools on the one hand and simplified tools on the other, for simulating realistic fire and PEF scenarios, modeling the behavior of various materials and structural joints at high temperature and **at the cooling phase**, and performing nonlinear thermal--structural analysis.



## Research needs

There is very limited research data from experimental, analytical, and field studies available with respect to the aspect of structural fire safety, on which a particular statistical level of performance could be established.

There is limited data on the mechanical behavior of materials under cyclic loads followed by elevated temperature coupled with high strain rate deformation, effect of lateral loads on fire safety, and data on the levels of structural damage under a PEF scenario that can be deemed acceptable.

This type of data is needed for the development of advanced structural models and software tools for performing simulation and parametric studies that are essential for formulating PEF design guidelines.