Fire Engineering Research – Key Issues for the Future II
6th - 9th June 2013, Naples, Italy

The Fire–after–Earthquake event in a Library Building Simulation of the Natural Fire

Kalliopi Zografopoulou, MSc Candidate
Daphne Pantousa, Doctoral Candidate, MSc.
and Euripidis Mistakidis, Professor

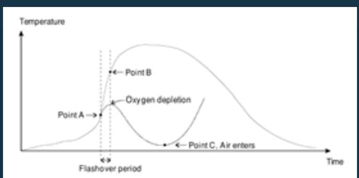
Laboratory of Structural Analysis and Design
Dept. of Civil Engineering - University of Thessaly
Volos, Greece, web page: http://lsad.civ.uth.gr

Post-earthquake, non-structural damage can alter significantly the fire behaviour of a building which, if not taken under consideration, could downgrade the structural safety and pose a threat for the fire fighting and rescue crews.

The target of this paper is to examine the impact of the damage of the non-structural members on the development of natural fire in a library building.

Several fire scenarios that correspond to different levels of damage are simulated and the gas temperatures arising in the vicinity of the steel structural members are discussed

Natural Fire inside an Enclosure



- the Pre-flashover period
- the Post-flashover period
- the Decay period

Factors affecting the fire development
- Ignition source
- Fuel
- Geometry of the enclosure
- Compartment openings
- Enclosure boundaries.

Thermal Actions – Eurocode 1, part 1-2

- Parametric temperature-time curves
  - Compartments < 500 m^2
  - No roof openings
  - Compartment height < 4 m
- One/Two-zone models
  - Post flashover conditions
  - Homogenous temperature, density, internal energy and pressure of gas within the compartment
- Computational Fluid Dynamic models (CFD)
  - Numerical solution of partial differential equations of the thermo-dynamic and aero-dynamic variables
  - application/results in all points of the compartment

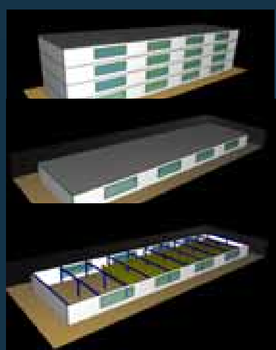
Computational Fluid Dynamics Analysis

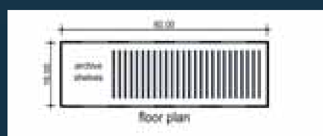
- Detailed geometry
- Custom-defined burn behaviour of the combustible materials
- Time-history temperature results at any position of the model

Fire Dynamics Simulator (FDS) of *N.I.S.T.*
A large-eddy simulation (LES) code for low-speed thermally driven flows, with an emphasis on smoke and heat transport from fires.

Smokeview (SMV) of *N.I.S.T.*
A visualization program used to display the output of FDS simulations

Model





- 4-storey library building
- Dimensions 60 x 16 x 14m
- Books and paper materials on
- 2.5m high shelving units
- Structural system: 11 double-span steel frames

Model

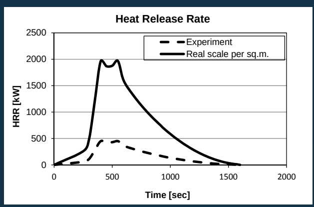
Input parameters

- Construction materials: *steel, concrete, typical insulation panels*
- Mesh: *220.320* cells of dimensions *0.33 x 0.33 x 0.33m*
- Simulation time: *1 hour*
- Simulation time step: *<0.1 sec*

Combustible materials

Combustion described by a Heat Release Rate curve
(G. Rein et al. 2007, the Dalmarnock fire tests)

26 HRR sections
Temperature activation at 250 °C



The Fire–after–Earthquake event in a Library Building - Simulation of the Natural Fire

Parametric Fire Scenarios

Variables – Damage

- Number of damaged windows
- Position of damaged windows
- Water sprinkler malfunction

Output Results

Gas temperature time-histories in 52 points on every frame (total 572 time histories)

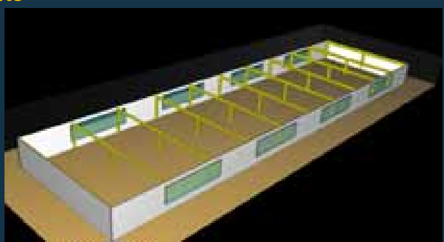
#	Scenario name	% of damaged openings	% of damaged openings / wall area	% of operational water sprinkler system
1	SC - 00	0 %	0 %	0 %
2	SC - 12	12.5 %	2.7 %	0 %
3	SC - 25A	25 %	5.5 %	0 %
4	SC - 25B	14 %	5.5 %	0 %
5	SC - 50A	50 %	11.0 %	0 %
6	SC - 50B	50 %	11.0 %	0 %
7	SC - 50C	50 %	11.0 %	0 %
8	SC - 75	75 %	16.5 %	0 %
9	SC - 100	100 %	22.0 %	0 %
10	SC - SP100	50 %	11.0 %	100 %
11	SC - SP40	50 %	11.0 %	40 %
12	SC - SP20	50 %	11.0 %	20 %

Fire scenario description — broken opening

Kalliopi Zografopoulou, - Fire Engineering Research – Key Issues for the Future II , 6th - 9th June 2013, Naples, Italy

The Fire–after–Earthquake event in a Library Building - Simulation of the Natural Fire

Results



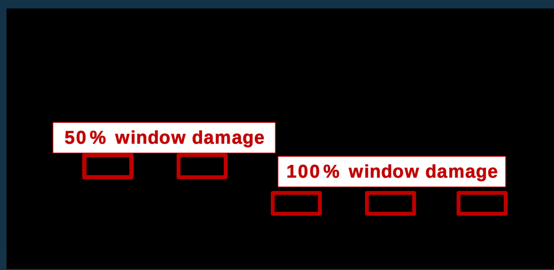
- For every time history the duration (minutes) of temperatures over the levels of 600°C, 700°C, 800°C, 900°C, 1000°C is calculated.
- For every temperature level the longest durations are obtained for every sub-frame.
- For every temperature level the average duration and st. deviation of all sub-frames depict the thermal severity of the fire scenario.

Kalliopi Zografopoulou, - Fire Engineering Research – Key Issues for the Future II , 6th - 9th June 2013, Naples, Italy

The Fire–after–Earthquake event in a Library Building - Simulation of the Natural Fire

Results

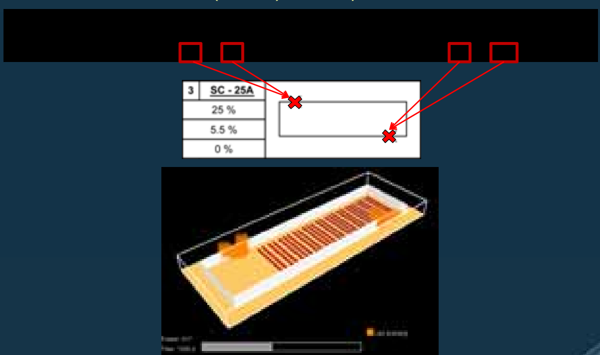
Average durations (minutes) over temperature levels



Kalliopi Zografopoulou, - Fire Engineering Research – Key Issues for the Future II , 6th - 9th June 2013, Naples, Italy

Results

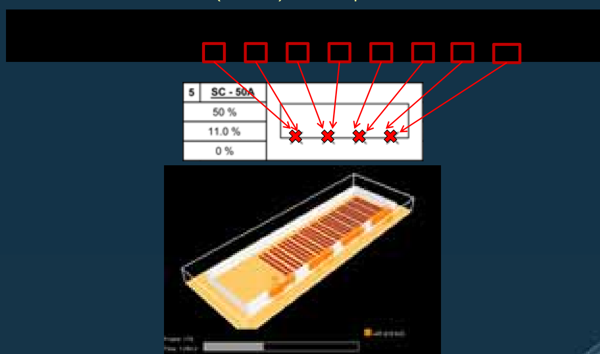
Durations (minutes) over temperature levels



The Fire–after–Earthquake event in a Library Building - Simulation of the Natural Fire

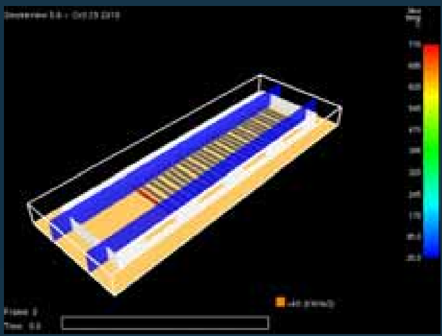
Results

Durations (minutes) over temperature levels



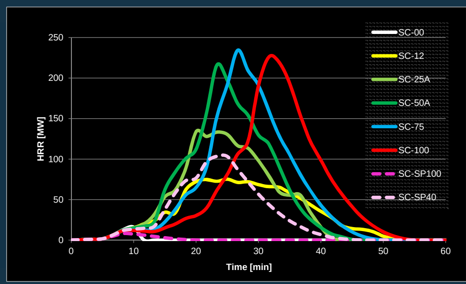
Kalliopi Zografopoulou, - Fire Engineering Research – Key Issues for the Future II , 6th - 9th June 2013, Naples, Italy

Fire Scenario SC-50A



Results

Total Heat Release Rate



More ventilation from the beginning of the fire ⇨ higher temperatures though delay in fire growth ⇨ Better chance of manual fire suppression

Conclusions

Non-structural damage can influence greatly the development of natural fire

The most influential damage is the malfunction of the active fire suppression systems

Window damage changes ventilation and could result in temperatures different than the ones expected during the fire design

Conclusions - Suggestions

- Design of sprinkler systems to withstand seismic displacements.
- Consider non-structural damage during the fire design.
- Vicinity to openings influences greatly the heat exposure of the structural members
- CFD analysis is a useful tool for fire design, though it should be used with caution.

Modelling of the seismic and the fire hazard

The fire action is represented through time-history temperature curves

Note: The structural members are not included in the numerical model used for the CFD analyses in order to overcome the difficulties that arise from the fully-coupled analysis

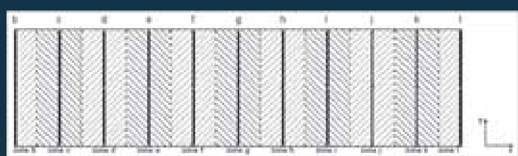
- ✓ the dimensions of the structural elements are small compared to the dimensions of the fire-compartment
- ✓ the structural system does not significantly affect the air-flow and the temperature distribution in the fire compartment

Thus, the thermal analysis of the structure is disconnected from the temperature development in the fire-compartment

Modelling of the seismic and the fire hazard

Interface between the CFD and the FE structural analysis

- ✓ The fire two-zone model is adopted.
- ✓ Special layer zoning devices are included in FDS.
- ✓ Devices are placed every one meter along the x and y axes on the model plan.
- ✓ The fire-compartment is separated into 10 different virtual zones, each corresponding to the effective area for each frame.

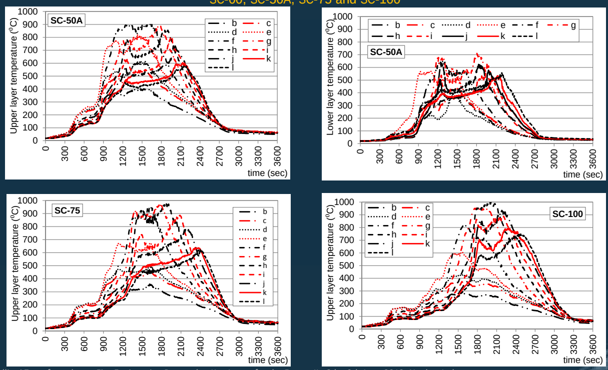


The evolution of gas-temperature with time for the upper and the lower zones is obtained for each frame, taking into account the corresponding effective area

Results of CFD analysis

FAE scenarios concerning the breakage of the windows:

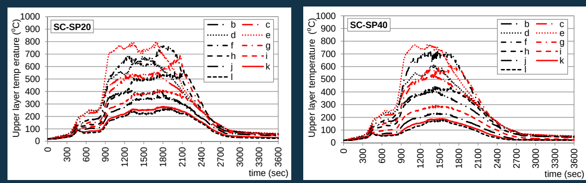
SC-00, SC-50A, SC-75 and SC-100



Results of CFD analysis

FAE scenarios concernign the malfunction of the fire-extinguishing system:

SC-SP20 and SC-SP40

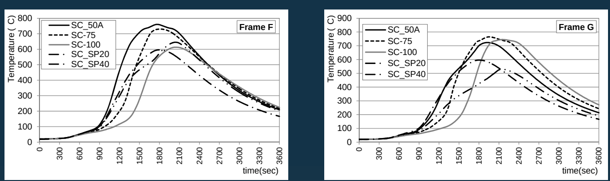


- ✓ In reference scenario SC-00 the fire is not fully-developed due to the lack of oxygen and the temperature of the fire compartment does not exceed the level of 300°C.
- ✓ The same holds for the reference scenario SC-SP100, due to the fully-active sprinkler system.

Results of thermal analysis

Thermal analysis is based in the guidelines of Eurocode 3

the temperature evolution with time for beams 1a and 1b, which are located in frames F and G, for different fire scenarios



Issues

- Finding accurate HRR of burning paper stack
- Simulation of fire spread from one shelving unit to another
- Temperature interface between gas temperature and steel surface temperature
- Choice of a representative temperature time history for every fire scenario

Thank you for your attention

Laboratory of Structural Analysis and Design
Dept. of Civil Engineering - University of Thessaly
Volos, Greece, web page: http://lsad.civ.uth.gr

Contact:
kazograf@gmail.com
emistaki@uth.gr