COST ACTION TU0904 – IFER
Integrated Fire Engineering and Response
Workshop in Naples, 6-9 June 2013

Numerical approach to the effect of fire extinction processes on the spalling risk of high strength concrete

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Introduction

• During heating of concrete, there are observed several complex, interacting physical, chemical and mechanical phenomena resulting in significant changes of the material inner structure and properties. A significant phenomenon is the **Thermal Spalling**.

• This phenomena is still not fully understood due to inherent technical difficulties associated with testing of concrete elements at high temperature → Computer Simulations.

• It has been reported that water cooling caused more severe decrease in strength compared to natural cooling, but it has mainly been dealt from an experimental point of view. No references were found about the effect of the cooling regimes on the spalling risk.

• A scarcely studied point is the analysis of the effect of the fire fighting strategies on the structural state of the High-Rise Buildings during natural fires.

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Objectives

• The analysis of the effect of a spectrum of cooling processes on the hygro-thermo-chemo-mechanical state of a structural element, manufactured with High-Strength concrete, during the development of a natural fire.

- **Spalling Index Evolution** — To Assess it → **Is4**: Consider both effects of pore pressure build-up and the accumulated strain energy, together with material degradation and cracking.
- **Damage Evolution** — To Assess it → Following the scalar isotropic model by Mazars (1989) .

(For the present work, the model chosen is the one presented by D. Gawin, F. Pesavento and B.A. Schrefler (2003) –HITECOSP)

• The development of a heuristic analysis of the effect of cooling processes of a square column, manufactured with High-Strength concrete, during the development of a natural fire in a High-Rise Building.

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3. TEMPERATURE PROFILES

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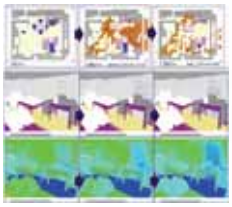
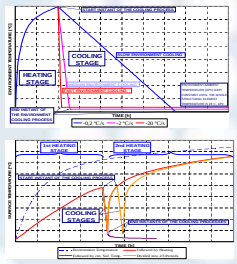
Temperature Profiles

• The adopted **Heating profiles** have been obtained, from the time-temperature parametric curves defined in the Eurocode 1, Part 1-2.

• In order to ensure a practical usefulness of the results, the definition of the **Cooling profiles** has been developed in sight of their Physical Background and from the development of several FDS simulations of natural fires in an office. Temperature evolution of the surface of structural elements where a water jet/spray is directly applied was recorded.





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4. DEFINITION OF THE ANALYSIS CASE

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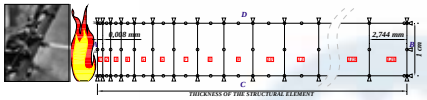
Definition of the analysis case

• Structural element selected (*one-dimensional fluxes of both heat and mass*):



• A total amount of twenty nine simulations resulting from the combination of different ranging parameters, start of cooling and cooling types and subtypes, have been analized.

- Cooling Start Time
  - Environmental Cooling
    - Slow Cooling
    - Medium Cooling
    - Fast Cooling
  - Surface Cooling
    - Heat
    - Keep
    - Repeat
- No cooling

Ranging Parameters:

- Initial Saturation Degree
- Permeability
- Thickness
- Heating Profile
- Material Strength

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5. SPALLING INDEX AND DAMAGE EVOLUTION

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Spalling Index and Damage Evolution

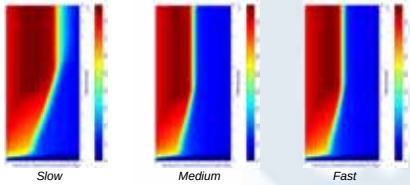
• To assess spalling risk ⟶ Spalling Index Is4

• Considering all the different cooling types and subtypes, none of them have resulted increasing values of the Spalling Index *Is4* during the cooling stages.

Not increasing, therefore, the Thermal Spalling risk during cooling stages.

• ***Comparison of the subtypes of Environmental cooling on Damage Evolution***

The final state of the structural element after a Slow environmental cooling have shown higher levels of cracking both in value and, what it is equally unfavourable due to the loss of resistant surface, in its extent towards inner layers.



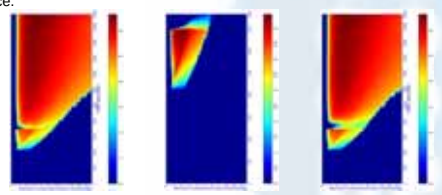
Slow *Medium* *Fast*

Spalling Index and Damage Evolution

• ***Comparison of the subtypes of Surface cooling on Damage Evolution***

The number of sweeps done by the Fire-Fighter applying the water jet on the surface of the structural element (among one and three cycles/sweeps) – does not appear to lead to significant differences after 3 hours from the start of the natural fire.

When the water jet is kept applied to the surface of the wall over a longer period. The higher cracking rates appear in a narrow layer close to the heated/cooled surface.



One Sweep *Keep* *Three Sweeps*

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LES

ANALYSIS C

VOLUTION

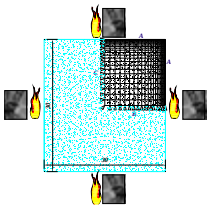
6. HEURISTIC ANALYSIS OF SQUARE COLUMNS

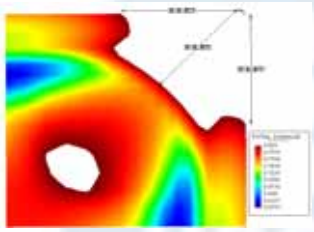
Heuristic Analysis of Square Columns

• Introductory extension of the analyses already presented in the previous sections to cases with bidimensional fluxes.

Corner Thermal Spalling is often the most dangerous type

• Arrow-shaped damage distribution, representative of the corner spalling





Total Damage distribution at the end of the fast environmental cooling stage , having removed the zones where D>0,825 (i.e. zones almost completely destroyed).

Issues

• Most of the experimental data available dealing with the effect of water cooling to the residual properties of the concrete do not specify the cooling rate they are applying → Difficulties to validate the model

• Difficulties to validate many of the parameters we obtained through the simulations: Humidity infiltration, vapor pressure inside the pore,..

Thanks for your attention

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