The Assessment and Response of Concrete Structures Subject to Fire

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INTRODUCTION
Over the last 20-30 years, much of the research in structural fire engineering has been on the behaviour of steel. The performance of concrete has remained relatively unexamined. The work in this project analyses the behaviour of concrete structures to develop new techniques for structural modelling and design. Specifically, this work aims to:

- Understand how concrete material behaviour and the way it is modelled can affect structural response;
- Develop a method for assessing structural capacity during and after a fire;
- Develop a methodology for assessing whole building behaviour aspects during and after a fire;
- Understand whether, and how, different design fires can affect a concrete structure.

This poster summarizes each of the main areas of work that have been completed as part of this project.

SECTIONAL ANALYSIS
Develop a method for assessing structural capacity during and after a fire.

Sectional analysis allows designers to quickly determine the amount of reinforcement required to resist certain moments and axial forces. In ambient conditions they are simple to create because a maximum allowable strain is defined to prevent crushing. When high temperatures are introduced, the crushing strain of the concrete increases. Consequently, interaction diagrams become much more difficult to define and a large number of trial points are required.

A new technique was created which allows the huge number of calculations usually required to generate an interaction surface to be circumvented. It used the properties of the determinant of the tangent stiffness matrix to find the ultimate capacity of the section.

LOAD INDUCED THERMAL STRAIN
Understand material behaviour and how it affects structural response.

Transient strain, or load induced thermal strain (LITS) occurs in concrete as it is heated under some degree of pre-stress. It is well characterized at a material level, but little understood in terms of its structural impact.

Current methods for modelling LITS were reviewed, and a new way of including LITS in finite-element models was introduced. It was found that current design methods underestimate the development of plastic strain (fig 2), and that these effects become critical on cooling.

TRAVELLING FIRES
How different design fires can affect a concrete structure.

A series of experimental and accidental case studies have shown that fires do not burn in a uniform fashion. In small compartments, temperature variations can be extreme and, in large areas, fires can move around the floorplate gradually.

To account for this, a design methodology was developed to represent the temperatures which a travelling fire might expose a structure to as it moved across the floorplate (fig 3). The methodology, developed by Stern-Gottfried et al., split the floorplate into a hot area near to the fire (the near-field), and a cooler area further away from the fire (the far-field).

WHOLE FRAME ANALYSIS
Methodology for assessing whole frame behaviour aspects.

The events at Broadgate and Cardington highlighted the importance of whole frame behaviour when a building is subjected to fire. However, despite this understanding, the measures that are often used to characterize structural failure have remained relatively basic, and often arbitrary.

A new approach for characterizing a structure’s response to a fire was created to provide a more comprehensive assessment of behaviour. A finite-element model of a generic concrete structure was subjected to a series of fires and the changes in member loading that these induced were calculated.

The modified member loadings were combined with estimations of bending, axial and shear capacity to allow utilization factors (load ratios) to be calculated for each section. This allowed the loading ratios for every part of the structure to be automatically calculated.

The methodology enables standardized reports to be prepared for the whole structure (fig 5). Thus, it is possible to compare the effects of different fires in a quantitative manner. The overall trends due to a number of fires can also be analysed, and design modifications can be made based on the results. Thus, it is possible to achieve a relatively uniform degree of safety across the structure.

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