The Assessment and Response of Concrete Structures Subject to Fire

Angus Law[a], Martin Gillie[a]

[a] University of Edinburgh, BRE Centre for Fire Safety Engineering, Edinburgh, Scotland, UK

BRE Centre *for* Fire Safety Engineering

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.

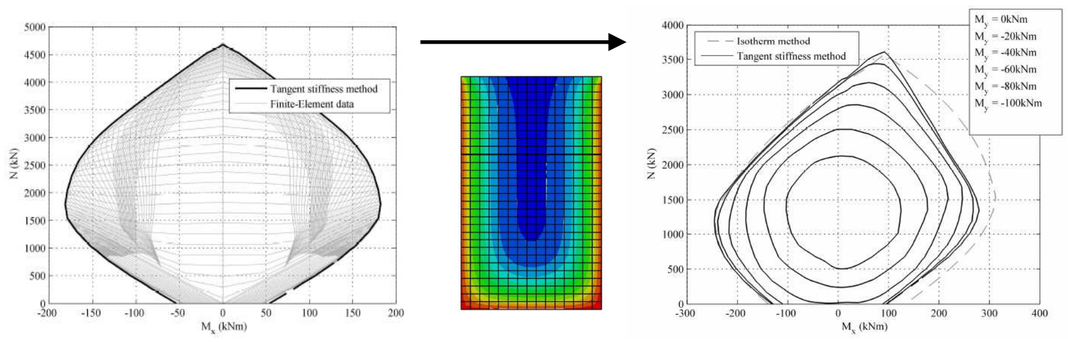

Figure 1: Sectional analysis before and during exposure to fire

The new method was applied to find biaxial interaction diagrams for concrete sections subject to various fires (fig 1). It was found that the 500°C isotherm method was **unconservative**.

The origins of the unconservatism in the isotherm method were traced to the **assumption of ambient temperature** in active concrete and the inaccuracies inherent in the stress block method.

It was found that modification of the various safety factors in the stress block method did not result in a conservative sectional analysis and that explicit consideration of the **changing strain-at-peak-stress** is required for representative interaction diagrams.

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.

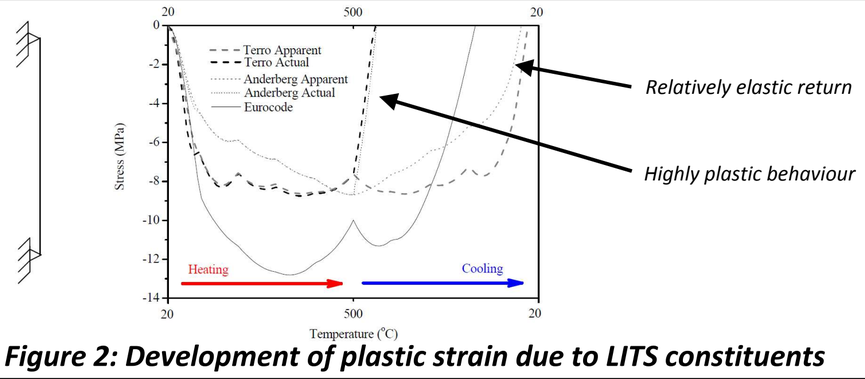

Figure 2: Development of plastic strain due to LITS constituents

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).

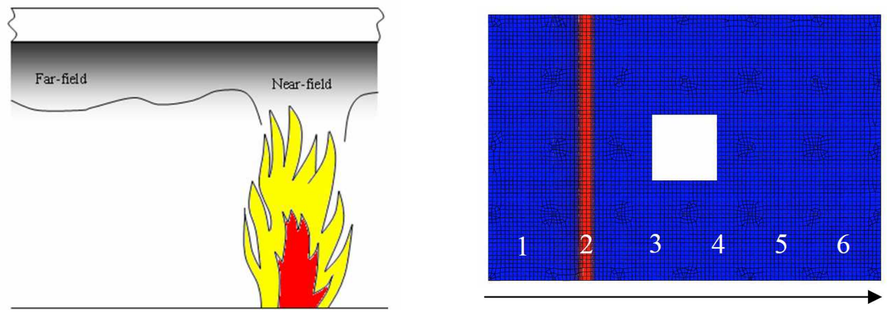

Figure 3: A fire in a large enclosed area and a fire travelling across a floorplate

The effect of **different sizes** and shapes of travelling fire were analysed with reference to a generic concrete structure. The response of the structure was measured using accepted measures of structural performance such as defection, rebar temperature and rebar strain.

It was universally found that fires that engulfed 10-25% of the floorplate at any one time induced the **most extreme** structural response (fig 4). It was also found that in many cases, the travelling fires induced a more extreme structural response than conventional codified fires.

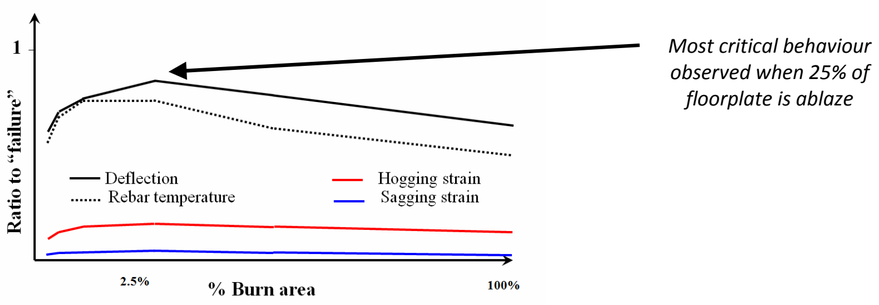

Figure 4: Behaviour measures as a function of fire size

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

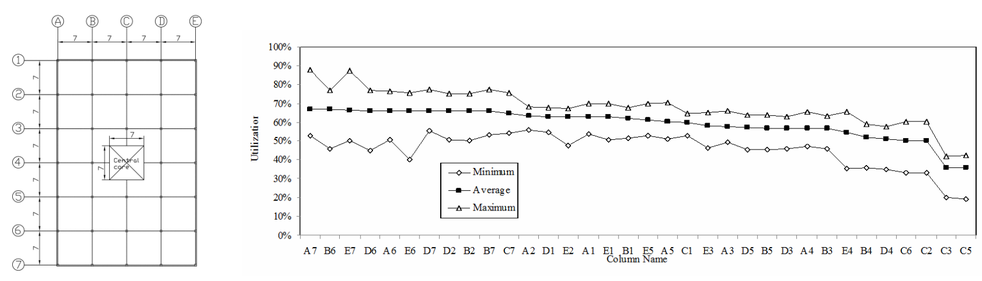

Figure 5: Generic frame, and percentage assessment of each column

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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