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Structural behaviour in fire compartment under different heating regimes — Part 1 (slab thermal gradients)

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Abstract

Modelling the full-scale Fire Tests at Cardington has led to new understanding of the behaviour of structures under fire conditions. Much of this understanding has come from parametric explorations using models verified against the tests. The structural phenomena observed in highly redundant, composite structures, during a compartment fire are dominated by restrained thermal expansion. The large deflections experienced in the structural elements in the region of the fire are almost entirely attributable to thermally induced strains. The mechanisms responsible for producing these large deflections are restrained thermal expansion and thermal bowing. Material degradation and loading are secondary influences. A clear understanding of the response of the structure to an average temperature increase and through depth temperature gradients is essential. This paper discusses the structural response when subjected to different heating regimes obtained by changing the mean temperature and temperature gradient applied in the concrete slab of the composite floor slab system to a computer model of the British Steel restrained beam test. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Restrained composite beam; Finite element modelling; Thermal bowing

1. Introduction

This paper is the first part of a series of papers reporting the main findings of the numerical investigations performed on the full-scale fire tests at the BRE LBTF in

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Cardington [1]. Extensive investigations of these fire tests have been carried out by collaborating research groups at Edinburgh University, Corus at Swinden Technology Centre and Imperial College. This work was funded by DETR under the PiT scheme. These investigations have produced a new picture of composite frame structure behaviour in fire. There are numerous aspects to this complex picture and it will require considerable effort devoted to recording and writing down all the important features, a task which is currently ongoing. These messages are vitally important to the design and construction of composite steel-framed structures for fire. It is however in the interest of steel construction community that the messages illustrating some of the most important pieces of information are reported as soon as possible. From all the investigations carried out by the different groups involved in the PiT project (using different numerical models) a consensus of opinion has emerged which identifies the evolution of the thermal regime in the structure as the most dominant factor which determines structural behaviour in fire. The significance of the temperature fields and the way it influenced behaviour of the structure was never realised to its full extent previously.

There are two main effects of heating in a structural member, thermal expansion caused by an average rise in temperature, and thermal bowing caused by a non-uniform distribution of temperature over the depth of the member. Both of these actions impose thermal strains (longitudinal extension in case of expansion and curvature as a result of thermal bowing). However, if these thermal strains are restrained, the result is the development of mechanical strains in the opposite sense of the thermal strains thus reducing the total strains (and therefore displacements), giving rise to large forces (most commonly axial compressions and hogging moments, however, if the gradients are large enough axial tensions can also develop). The purpose of this paper is to describe the effects of different slab heating regimes on the structural behaviour (in the British Steel restrained beam test) using a detailed analyses of the internal forces developed in each structural member subjected to the fire.

The finite element models, using the commercial package ABAQUS [2], developed to simulate the behaviour of the structure in Cardington fire tests [3,4] reproduce all the phenomena occurring during a fire and have the advantage of providing a description of the complex behaviour in a relatively simplified context by virtue of representing the slab using a *grillage*-type model. The paper is divided into two parts because of the volume of results to be presented. The first part sets the context and provides brief details of the model used before presenting the results and their interpretation for the case of applying different thermal gradients to the concrete slab while maintaining the average temperature increase over the slab depth equal to a fixed reference value. The second part presents the results and interpretations of applying different average temperature increases and maintaining the gradients at reference value.

2. Description of the fire compartment

In 1995 an 8-storey composite frame building was erected at the BRE test facilities in Cardington. The full-scale building was designed to be typical of modern