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Fire Safety Journal 35 (2000) 165–188
FIRE SAFETY JOURNAL
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Composite beams in large buildings under fire — numerical modelling and structural behaviour

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Received 17 February 2000; received in revised form 14 March 2000; accepted 13 June 2000

Abstract

A good engineering assessment of the fire safety of a building structure should be based on a sound understanding of the mechanics of its behaviour under fire. Existing standards and methods of design for fire assume that the structural behaviour is effectively the same as that at ambient temperature, allowing for the reduced material properties. This simple assumption is valid for statically determinate structures, but is in serious error for highly redundant structures, and may be unconservative in certain cases. In particular, the effect of thermal expansion is generally ignored, even though it may swamp the effects of all other phenomena in a large highly redundant building under a local fire. This paper presents some of the results of an extensive investigation (Usmani et al., DETR-PIT project, final report (draft), March 2000) in which the structural action in a two-way slab and composite beam structure subjected to a compartment fire has been explored. These results show that thermal expansion dominates the response of highly redundant structures under local fires, and that local yielding and large deflections can be beneficial in reducing damage to the complete structure. However, it is now clear that explicit cognisance should be taken of thermal expansions in design calculations, but this can only be done when a thorough understanding of the behaviour, appropriately generalised, is in place. This is the main motivation behind the results presented in this paper. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Restrained beams; Structural behaviour in fire; FE modelling

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PII: S0379-7112(00)00034-5

1. Introduction

Following the Broadgate fire [1], it was clear that the behaviour of real buildings in fire is significantly different from that assumed in current design practice. The full-scale fire tests on the BRE multi-storey composite frame at Cardington confirmed this. The Cardington structure was a typical example of current UK steel construction with a concrete profiled deck floor slab acting compositely with hot-rolled steel beams, which were mostly left unprotected. The tests showed that very high temperatures could be sustained [2]. However, the test results on their own are insufficient to provide a full explanation of the mechanics that governs the response of such structures to fire. Interactions between thermal expansion, large deformation effects, material degradation and three-dimensional effects in the building lead to complicated behaviour that can only be understood if high-quality numerical and analytical models are developed and interrogated. When the effects have been understood, it should be possible to exploit them in design against fire. This paper describes a simple model of the Restrained Beam test to investigate the behaviour of an unprotected restrained composite beam during fire.

When a compartment in a large building is exposed to a severe fire, the behaviour of the heated zone is strongly affected by surrounding parts of the structure (outside the compartment) that remain cold, stiff and strong. The interactions between the heated zone, which is expanding and losing strength, and the surrounding cool structure produce several different effects that are difficult to present in the conventional manner, where each member is proportioned as if it were isolated, but subject to stress resultants found from a global analysis. Thus, current practice, based on the behaviour of an isolated element in a test furnace, seriously misrepresents the behaviour of elements of the complete redundant floor system.

Finite element calculations are described that match the experimental observations quite well. These are used to obtain information about quantities that cannot be measured, such as internal forces and moments in a structural element. If the calculation matches the measured responses on those items, which can be measured, then it is reasonable to infer that other parts of the prediction are also realistic components of the complete behaviour. Thus, the calculation of the structure during fire can be used to deduce many features of the response that cannot be deduced in any other way.

Over the last decade many papers have discussed the effect of fire on steel frame structures. One of the first models of the Cardington test frame was by Wang et al. [3], which was a 2D model that produced useful conclusions on the critical role of columns. A further theoretical study by Wang [4] indicated the importance of tensile membrane action in maintaining the robustness of composite slabs. Rose et al. [5,6] published one of the first 3D models of the Cardington tests, which showed a good match between predicted and test deflections for the Restrained Beam test and the Plane Frame test [7] and the BRE Corner test. However, none of the computational models of the Cardington tests to date have been used to provide a detailed description of the behaviour of the structure, and that is the purpose of this paper.