

The influence of the thermal expansion of beams on the structural behaviour of columns in steel-framed structures during a fire

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Abstract

In the UK, new design guidance is currently being developed for the behaviour of steel-framed buildings when subjected to fire. This is primarily based on recent research that considers the structural behaviour of all horizontal members, without applied fire protection, acting as a complete entity within the building. This guidance assumes that columns designed to current design procedures will always be adequate when used within this new design philosophy. For bare steel columns these existing design methods usually consist of applying some form of passive fire protection.

Presented in this paper is an analytical investigation of the structural behaviour of columns when subjected to various structural and fire scenarios. The results from this study do not endorse the view that current fire design methods for columns are adequate. These design methods will require revision if instability of columns during a fire is to be avoided. In most cases this will result in the need for additional passive fire protection to be applied to the steel columns. © 2000 Published by Elsevier Science Ltd. All rights reserved.

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1. Introduction

Recent research [1–4] into the behaviour of steel-framed buildings during a fire has begun to consider the structural response of the building in its entirety instead of considering structural members in isolation. In the UK the nucleus of this research [1] is the recently completed fire tests, conducted on a full-scale eight-storey steel-framed building constructed at the Building Research Establishment (BRE) Laboratory in Cardington, Bedford.

A total of six compartment fire tests were carried out [3], two by BRE and four by British Steel. The major aim of the tests was to provide quality data to validate and develop computer models, which will enable different structural and fire scenarios to be investigated. Before the Cardington tests, it was felt that existing design guidance on horizontal spanning structural members was too conservative, since it is based on the behav-

our of isolated members. Results from the tests supported this theory, and together with supplementary computer modelling design guidance is now being developed based on whole building performance during a fire.

The major aims of fire design, once ignition occurs, is to contain the fire within the compartment of origin and to limit structural damage so that overall collapse is avoided. Before the Cardington fire tests were conducted it was generally agreed, by the Research Organisations [1] involved, that to meet these criteria the bare steel columns would need to be designed to current practice [5–8] (i.e., treated as isolated members). This involved applying passive fire protection to the columns. This effectively resulted in only the horizontal members being tested. Since the limit in terms of load-carrying capacity of these members in fire was unknown, it was decided to protect the columns to a higher standard than that given by current design methods, to ensure that the columns did not fail first. This is based on the assumption that columns designed to current UK practice will perform adequately in a fire, and therefore do not need to be tested to their limit in the full-scale fire tests.

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The design guidance, which is currently being developed, based on the Cardington test results, is effectively a hybrid design philosophy. The design of the beams (which could possibly be unprotected) and slabs is based on the behaviour of the structure as a whole, whereas the columns are based on current design practice by treating them as a series of isolated members. This paper investigates the validity of this approach and raises questions about its safety in relation to the overall stability of the structure.

2. Review of the full-scale fire tests conducted on the Cardington frame

The full-scale eight-storey steel-framed test building [9] was designed and constructed to resemble a typical modern UK city centre eight-storey office development. On plan (Fig. 1), the building covers an area of 21 m × 45 m with an overall height of 33 m. There are five equally spaced bays along the length of the building. Across the width there are three bays spaced 6 m, 9 m and 6 m. Placed centrally, on the footprint of the building, is a 9 m × 2.5 m lift core with two 4.5 m × 4.5 m stairwells placed at each end. The structure is designed as a braced frame with lateral restraint provided by cross-bracing around the three vertical access shafts. The beams are designed as simply supported acting compositely (via shear studs) with the supported floor slab. The composite floor slab is 130 mm deep and consists of a steel trapezoidal deck, with lightweight concrete and anti-crack mesh.

Six compartment fire tests were conducted on the frame at various locations throughout the building. In all the tests the columns were protected using ceramic fibre,

with the steel beams and underside of the steel trapezoidal deck unprotected. To highlight the behaviour of the columns the results from two of the tests are briefly presented, one conducted by BRE, the other by British Steel. The locations of these tests are shown in Fig. 1 and are situated in the corner bays of the frame. The following description of the tests concentrates on the behaviour of the columns. A more detailed description of the overall structural behaviour is presented elsewhere [1,2].

2.1. BRE corner fire test

In the BRE corner fire test, situated between second and third floor levels, the columns were extensively instrumented, which allowed their behaviour during the test to be investigated. Figs. 2 and 3 show the maximum recorded test moments (calculated from the strain gauges) about the minor and major axes at various positions along the length of the columns, between the first and fourth floors. In the figures the notation '(?)' represents strain gauges that failed during the test. However, it was possible in most cases to identify the 'trend' of the moments from the strain gauges at these locations, which allowed the sign of the moment to be identified and the full column moment pattern estimated.

From the test results it can be seen that the columns are subjected to significant moments about both axes during the fire test. The pattern of the recorded moments suggests that the columns are displaced laterally at third floor level in the minor axis direction and, for perimeter columns (depending on their orientation), in the major axis direction. This was caused by the thermal expansion of the connected heated beams and has been proved by

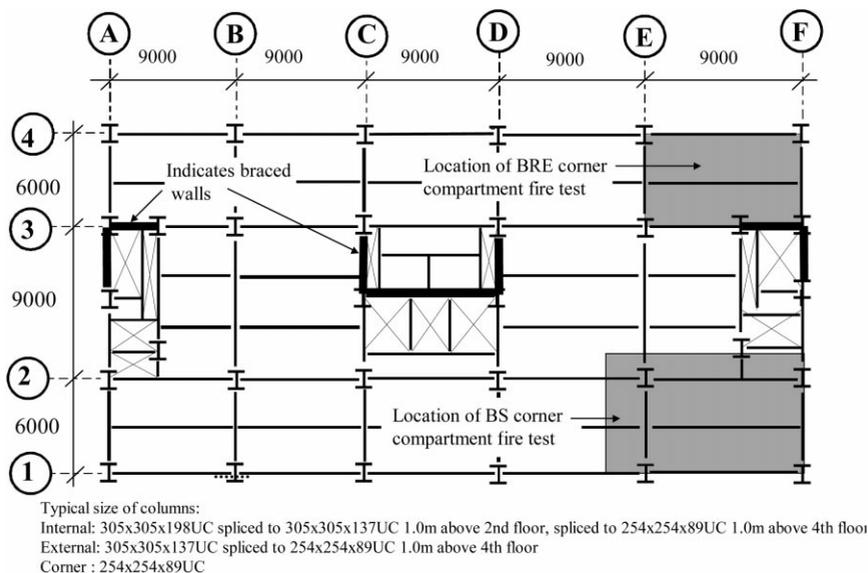


Fig. 1. Location of corner compartment fire tests.

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