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Fire Safety Journal 35 (2000) 117–130

FIRE SAFETY JOURNAL

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Structural behaviour in fire compartment under different heating regimes — part 2: (slab mean temperatures)

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Received 14 March 2000; received in revised form 1 May 2000; accepted 8 May 2000

Abstract

The effect of varying the thermal regime in a highly restrained composite beam in a steel frame structure is studied using a finite element model. The variation of through depth thermal gradients in both directions of the orthotropic slab was studied in the first part of this paper. In this part the effect of varying the mean temperature increase in the slab is investigated using the same model of the British Steel restrained beam test. © 2000 Elsevier Science Ltd. All rights reserved.

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

1. Introduction

In this second part of the paper we concentrate on interpreting the results obtained from the finite element grillage model [1] of the British Steel restrained beam test from varying the mean temperature rise in the slab in both directions (parallel and perpendicular to the composite beam) while maintaining the thermal gradients to the reference values. The joist maximum temperature is also kept unchanged as in the reference case (represented by the test measurement) and is equal to 850°C. The information about the model and all other relevant background information is given in Part 1. The focus of this study is the effect of an average temperature rise in the slab,

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PII: S0379-7112(00)00025-4

this is studied at first in the context of a simple restrained beam to establish the main principles of behaviour. The results of applying varying levels of mean temperature on the model of the British steel restrained beam test will then be discussed on the basis of these principles.

2. Effect of varying the uniform mean temperature

To illustrate the effect of restrained thermal expansion in the context of a composite framed structure a few simple scenarios are considered. At first, consider a beam with ends free to rotate and free to translate laterally with a uniform mean temperature (ΔT) applied along its entire length. This will cause the section to expand and there will simply be a simple increase in length (equal to $\alpha \Delta T l$) moving the beam ends further apart. As all the thermal expansion strain ($\varepsilon_{\mathrm{T}} = \alpha \Delta T$) goes towards producing displacements, there are no mechanical strains in the beam and therefore no forces. If now the ends of this beam are restrained laterally but free to rotate a uniform compressive stress ($\sigma = E\alpha\Delta T$) will develop across the whole length of the beam because the ends are no longer free to move further apart and accommodate the increase in length due to thermal expansion. In this case the total strains are equal to zero because the thermal expansion is cancelled out by the equal and opposite contraction caused by the restraining force. The magnitude of the compressive force associated with restrained thermal expansion is

$$P = EA\alpha\Delta T, \tag{1}$$

where EA is the beam axial stiffness. If the heating applied to the beam is allowed to continue indefinitely, there are two distinct phases in the response to restrained thermal expansion depending on the slenderness of the section. If the slenderness is low (stocky section) the thermal expansion is absorbed in elastic straining and no displacement is produced. During this phase the thermal and mechanical strains are equal. If the beam is sufficiently stocky, the axial stress will sooner or later reach the yield stress of the material and if the material has an elastic–plastic stress–strain relationship the beam will continue to yield without any further increase in stress but with increasing plastic strains.

If the beam section is slender then compressive stresses are generated until the beam reaches its Euler buckling stress limit at a critical temperature (ΔT_{cr}). The critical Euler buckling load is

$$P_{\mathrm{cr}} = \frac{\pi^2 EI}{l^2}, \tag{2}$$

where l is the "effective length" (this depends upon the rotational restraint available at the beam ends, so for no rotational restraint the effective length is the same as the length of the beam and for full rotational restraint it is equal to half the beam length). Equating this to the restraining force P in Eq. (1) leads to a critical buckling