PIT Project

Behaviour of steel framed structures under fire conditions

STUDIES USING NUMERICAL MODELS : EFFECT OF INCREASING LIVE LOADS IN BRITISH STEEL TEST1

Research Report

Report R00-SM1

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1 GENERAL NOTES

In the description of the numerical model below the following terms are used :
"The plane" to define the plane of the floor.
"Joist" means a steel beam, and the test Joist means the heated Joist during the fire test.
"Vertical" means vertical to the slab plane.
"In plane" means in the plane of the Long. slab.
"Joist longitudinal direction" or "longitudinal direction" to mean parallel to the Joist length coordinate.
"Transverse direction" to mean at right angle to the Joist longitudinal direction (i.e. in the direction of the longitudinal axis of the ribs Figure 1.
"Reference vertical co-ordinate" is the interface between the Long. slab and Joist .

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A) General layout

The following set of figures describes the evolution against time of deflections, axial forces and moment in different structural member :

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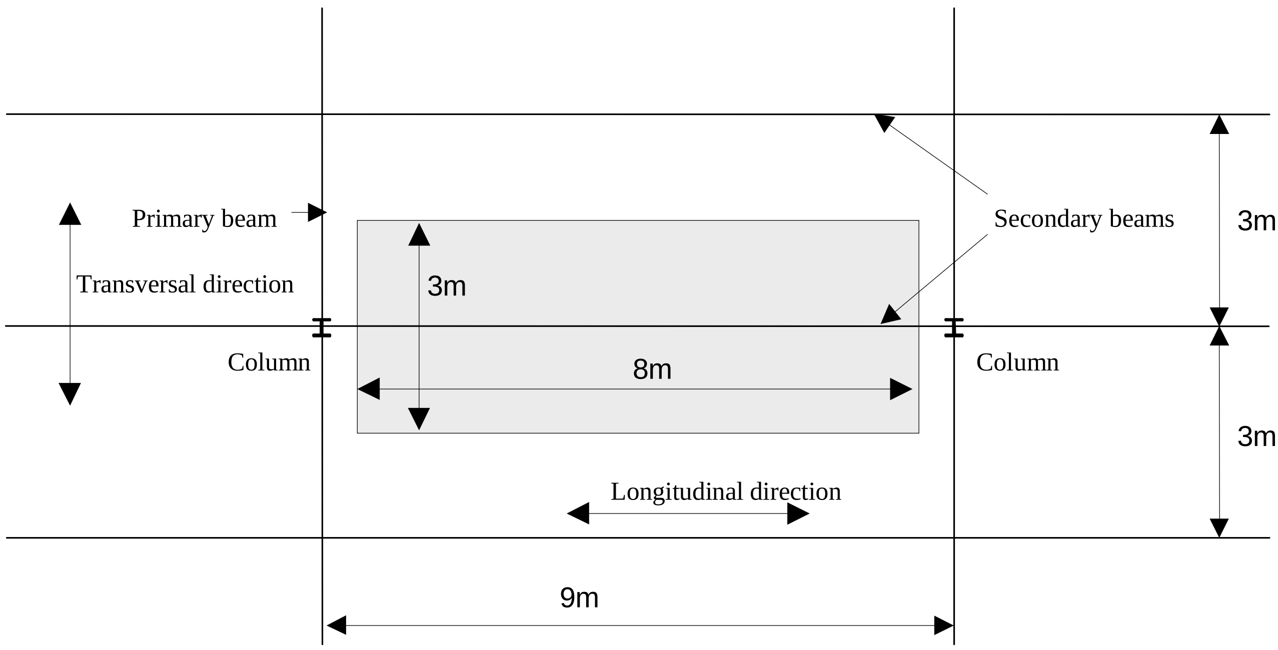
3 ABSTRACT

Modelling the British Steel Fire Tests has led to new understanding of the behaviour of structures under fire conditions. Much of this understanding has come from parametric analysis of the models. The structural phenomena observed in highly redundant, composite structures, during a compartment fire are due to the huge impact of restrained thermal expansion. The large deflections experienced in the structural elements in the region of the fire are almost solely due to restrained thermal expansion. Thermal gradients play a supporting role but material degradation and loading are secondary influences. A clear understanding of the response of the structure to temperature and temperature gradients is essential. This paper discusses the response of the grillage model of test 1 to changes in the mean temperature and temperature gradient applied to the slab.

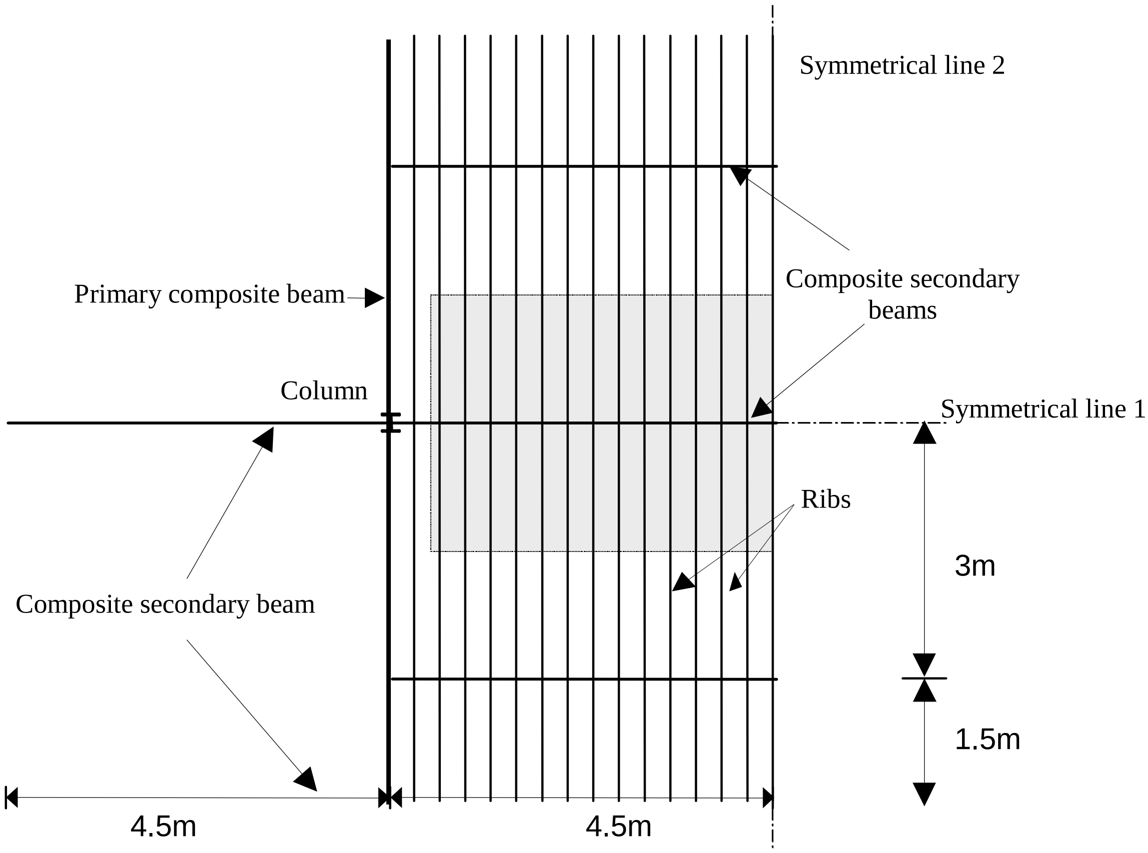
4 INTRODUCTION

The effect of live load imposed on the structure is a principal question that needs to be answered in order to develop any design guidance concerning the structures under fire. The finite element models, using the commercial package ABAQUS[1], developed to simulate the behaviour of the structure in Cardington fire tests (Sanad 1999)[6] has the capacity of producing the phenomena occurring during a fire under different loading conditions. It also has 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 report presents the results obtained from the numerical model when applying twice the reference live load imposed during the real test. It then compares these results with the reference case (Sanad 1999) to clarify the effect of applying different loads to the concrete slab when subjected for a fire.



Layout of the Cardington Fire tests

Figure 1



Layout of the finite element model
Figure 2

The analysis of internal generalised stresses in the structure are necessary here in order to give the full description of the local and global behaviour. A description of the structural behaviour according to the calculations undertaken is given below. To clarify the location of each discussed member the geometry of the fire compartment is given in Figure 1 and the layout of the finite element model is given in Figure 2.

5 FLOOR DEFLECTION

The main characteristic of the behaviour of the floor is the homogeneous deflection obtained over the full heated area. The maximum deflection is obtained at mid-span as shown in Figure 3. The deflection-temperature relationship is very close to a straight line with local perturbation due to the localised variation in the temperature-time heating regime. The value obtained for the deflection of the floor system is very similar to the reference case (Sanad 1999)[7].

6 AXIAL BEHAVIOUR OF THE HEATED BEAM

The behaviour of the each structural element is self-explanatory and can be observed from the set of figures included in this report. This section discusses the behaviour of each structural element separately and is followed by a more general discussion based on the global equilibrium of the floor system and the contribution of each element to the equilibrium state and compared with the reference case.

The axial forces in the joist and the longitudinal slab during the fire are plotted against the reference temperature at different location of the joist (x/l=0, 0.1, 0.2, 0.3, 0.4, 0.5). This axial forces are shown in Figure 4 to Figure 9.

Figure 6 to Figure 9 show similarly the evolution of the axial force in the joist and the slab during the fire at x/l=0.2,0.3,0.4 and 0.5, at these section the initial forces confirm the bending behaviour of the composite, where at mid-span (Figure 9) for example, the beam is in tension and the slab in compression indicating a sagging moment acting on the beam at this section. However from the beginning of the fire all axial forces in the joist and the slab are dominated by the huge effect of restraint thermal expansion and both section go into higher compression regime.

In Figure 10 the axial forces acting on the composite beam is represented by two curves for the section at the column and at mid-span. The two curves are very close to each other, showing that each section across the beam is subjected to the same compressive normal force (Figure 25). The axial force diagram over the composite beam is also given in detail at different instants during the fire (Figure 26 to Figure 35) showing the individual contribution of the joist and the Long. slab to the composite axial force.

7 BENDING BEHAVIOUR OF THE HEATED BEAM

7.1 P-D moment during fire

Similar to the reference case, the increasing thrust developed in the composite beam during the fire combined with its deflection produces a second order moment which is called P-Δ. Under increasing temperature the magnitude of the P-Δ moment increases as both P increase and Δ increases however it does not exceed the initial moment due to the ambient live load as shown in Figure 11).

Under the new added *thermal* loads, the composite beam behaves accordingly to satisfy the equilibrium conditions and to carry both (*thermal* and *ambient*) loads. Figure 12 to Figure 17 show the moment acting on the joist and the slab separately at different section (x/l=0.1 to x/l=0.5).

7.2 Composite moment along the beam

For bending moment diagrams over the composite beam is given in detail at different instants during the fire (Figure 36). The individual contribution of the joist and the Long. slab to the composite moment are given on the Figure 37 to Figure 46. Figure 18 shows the moment acting on two critical sections at support and mid-span. The curves show that initially the end section is under hogging moment and the mid-span is subjected to sagging which is a classic figure of a fixed end beam subjected to a distributed load.

Figure 19 shows the composite moment acting over the previous two sections. The same figure shows as part of the total composite moment the moment due to the thrusts in joist and Long. slab. As can be see from the curve and contrary to the reference case, a small part of the composite moment developed in over the beam are due to the difference in thrust between the two individual members. The different of moment between the end and mid-span can represent the total moment carried by the beam, this is represented by the first curve on Figure 20.

8 BEHAVIOUR OF SLAB IN TRANSVERSE DIRECTION

Figure 21 shows the axial forces developed in the slab ribs in transverse direction at different location above the heated beam (x/l=0.1 to x/l=0.5). At ambient temperature this membrane forces are negligible. From 20°C to 200°C all the ribs are subjected to and increasing compressive forces as they expand against the cold surrounding slab. The magnitude of the compressive force developed in each rib depends on it location as can be seen from the figure. The axial force developed in each rib depends on the rib's location, the ribs near to the primary beam are subject to higher compression as they deflect less. The ribs at mid-span will be subjected to lower axial forces as they deflect more. From 150°C the axial forces developed reduces in all ribs with the ribs at mid-span (x/l=0.4 and x/L=0.5) going into tension from 500°C onward. This shows clearly that tensile membrane forces are developed in the transverse direction of the slab at the later stages of the fire. This tensile membrane action is mobilised by compatibility of deflection in the longitudinal and transverse directions to carry the loads at later stage of the fire. The magnitude of the tensile forces developed in the transverse slab are far from the tensile capacity of the slab used.

Figure 22 shows the moment developed in the ribs over the joist at the above locations. At ambient temperature all ribs are under hogging bending moment showing that the ribs are supported by the test beam at ambient temperature. Figure 23 and Figure 24 show also that at ambient temperature the ribs a subjected to a hogging moment over the parallel non-heated joists while the far end of the ribs, located at mid-span between two beams, is subject to a sagging moment. In this configuration the ribs are acting as continuous beam running over intermediate support and subjected to a distributed load. During the fire this configuration changes as can be seen from the figures. The ribs near the primary beams reach some yield line, over the heated joist, from nearly 200°C until the end of fire. For the ribs near the mid-span (x/l=0.4 and x/l=0.5), the hogging moment over the heated joist reduces with temperature increase, showing that less support is given by the heated joist during the fire and goes into sagging moment at the later stage of fire. Over the next non heated secondary beams the hogging moment increase in all ribs with a larger effect for the ribs at x/l=0.5. which shows that the support coming from the non-heated beams increase during fire to compensate for the loss of support from the heated one.

9 CONCLUSIONS

1. Increasing the live load applied on the slab by 100% in the numerical model doesn't change the deflections during the fire, however it produces a significant variation in the internal forces generated in the structural element.
2. Significant reduction in the composite beam axial force in the longitudinal was observed when applying a large live loads on the slab.
3. The effect of P-D moment applied on the composite beam reduces for large live loads.
4. The load carrying mechanisms within the structure changes for under the effect of large live loads, however no unsuitability of loss of integrity are generated in the structures
5. The total composite moment acting at mid-span and the support doesn't vary significantly for different live loads, however the moment obtained from the differences in the axial thrusts (between the joist and the Long. slab) decreases for larger live load.

6. Changing the temperature gradient applied in the longitudinal direction has an insignificant effect on the structural response.
7. Changing the temperature gradient applied to the ribs has a significant effect on the ribs moment over the joist and the axial force in the ribs.
8. The thermal bowing action of the ribs due to the increase in thermal gradient absorbs some of the compressive strains caused by restrained thermal expansion.

10 REFERENCES

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