PIT Project

Behaviour of steel framed structures under fire conditions

STUDIES USING NUMERICAL MODELS : EFFECT OF STEEL SECTION IN BRITISH STEEL TEST1

Research Report

Report R00-SM2

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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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2.1 First case : twice the steel area for secondary steel joists

General layout

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

Heated joist

Slab in the transverse direction (Ribs)

The next set of figures describes the space distribution of axial forces, and moment in different structural member during the fire :

Heated joist

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

Heated joist

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Figure 61 : Moment in Long. slab and joist at x/l =0.5

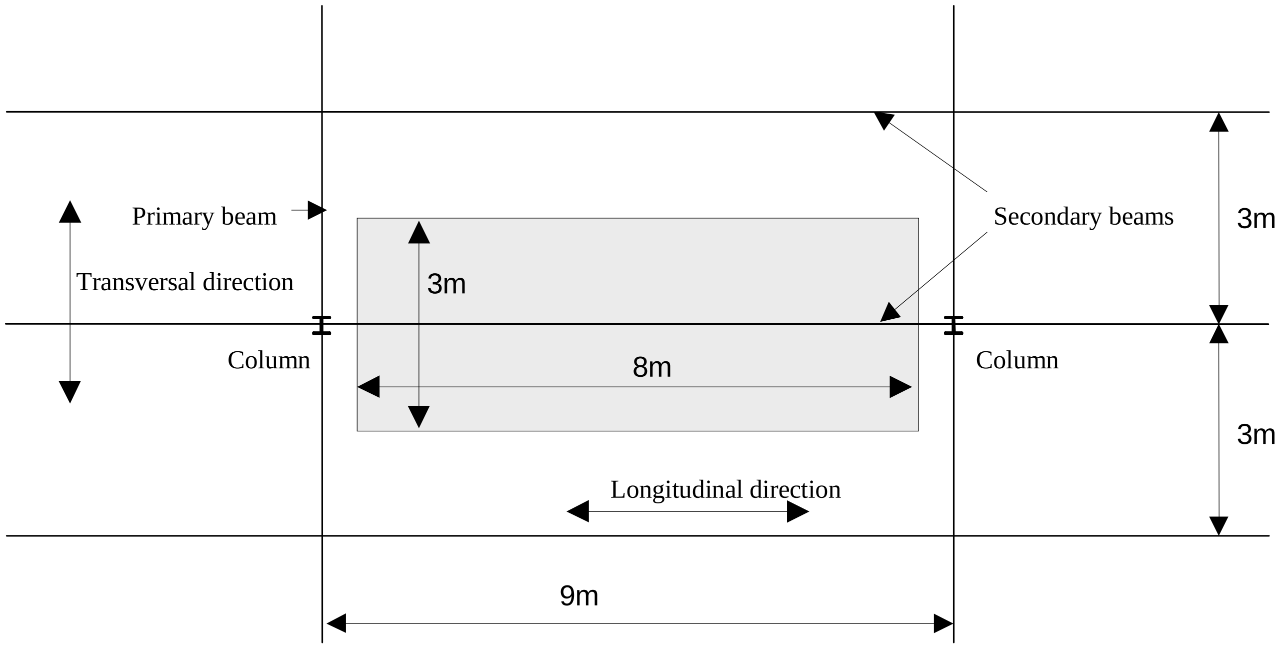
Slab in the transverse direction (Ribs)

The next set of figures describes the space distribution of axial forces, and moment in different structural member during the fire :

Heated joist

3 INTRODUCTION

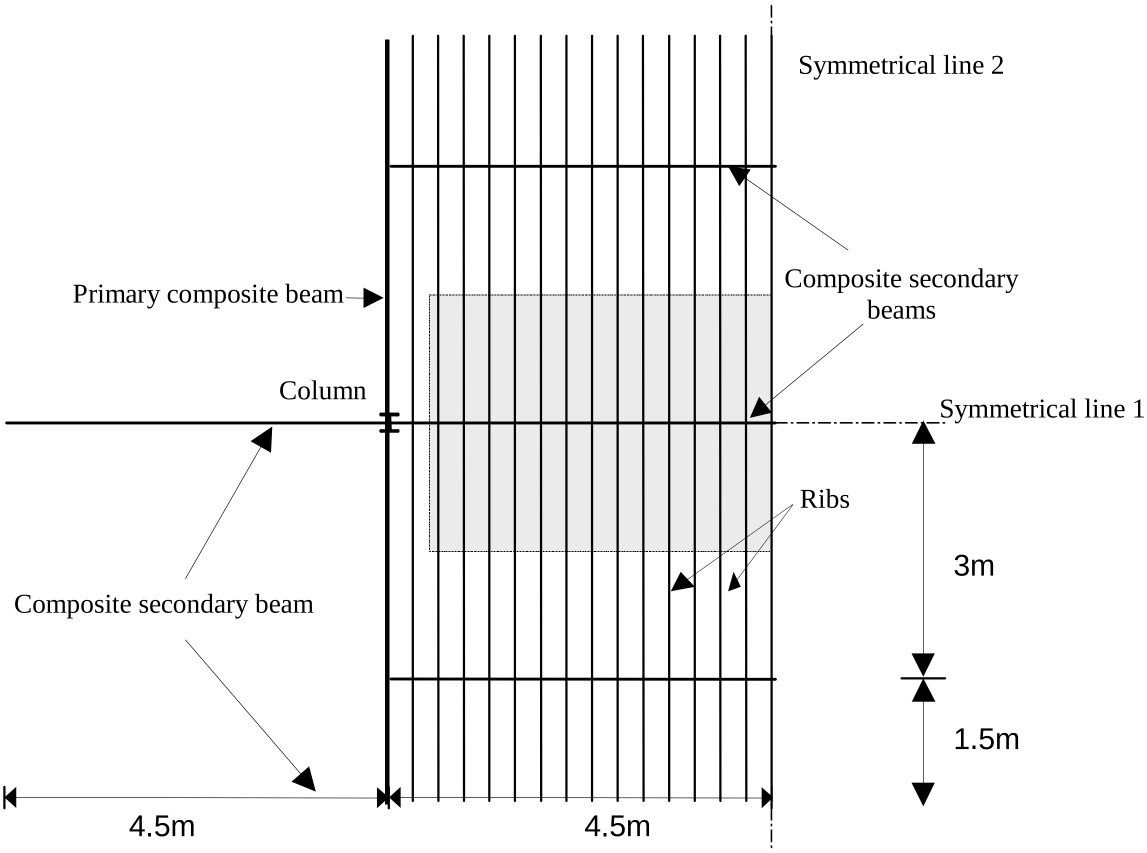
The effect of the joist cross section on the structure is a principal question that needs to be answered in order to develop any design guidance concerning the structures under fire. The finite element models, using the commercial package ABAQUS[1], developed to simulate the behaviour of the structure 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 using different steel cross section for the secondary joists. It should contain a comparison between different cases (using half to 50% increase to the reference area of secondary joists. In this study two major studies were carried out, the first when using 50% increase the area (width) of all secondary joists and the second when using half the width of the steel cross section for the same joists.



Layout of the Cardington Fire tests

Figure 1

The analysis of internal generalised stresses in the structure are given below to describe the local and global behaviour of the structure under fire. 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.



Layout of the finite element model
Figure 2

4 FIRST CASE : 50% INCREASE IN THE STEEL AREA FOR ALL SECONDARY JOISTS

4.1 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 value obtained for the deflection of the floor system is very similar to the reference case (Sanad 1999)[7].

4.2 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 near the column. 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.

4.3 Bending behaviour of the heated beam

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).

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.

4.4 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.

5 SECOND CASE : HALF THE STEEL AREA FOR ALL SECONDARY JOISTS

5.1 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 Figure49. The value obtained for the deflection of the floor system is very similar to the reference case (Sanad 1999)[7].

5.2 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 Figure50 to Figure55. The initial forces confirm the bending behaviour of the composite, where at mid-span (Figure55) 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 Figure56 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 (Figure71). The axial force diagram over the composite beam is also given in detail at different instants during the fire (Figure72 to Figure81) showing the individual contribution of the joist and the Long. slab to the composite axial force.

5.3 Bending behaviour of the heated beam

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 Figure57).

Under the new added *thermal* loads, the composite beam behaves accordingly to satisfy the equilibrium conditions and to carry both (*thermal* and *ambient*) loads. Figure58 to Figure63 show the moment acting on the joist and the slab separately at different section (x/l=0.1 to x/l=0.5).

Composite moment along the beam

For bending moment diagrams over the composite beam is given in detail at different instants during the fire (Figure82). The individual contribution of the joist and the Long. slab to the composite moment are given on the Figure83 to Figure92. Figure64 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.

Figure65 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 Figure66.

5.4 Behaviour of slab in transverse direction

Figure65 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.

Figure66 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. Figure67 and Figure68 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.

6 CONCLUSIONS

1. Increasing the secondary joist's steel area (50% increase of width) in the numerical model doesn't change the deflections during the fire, and reduction of the area by 50% tend to increase the deflection but within a very limited range (about 10%).
2. Changing the steel section, changes significantly the internal forces in the structural members, larger steel section generate large internal compressive forces due to the restraint of thermal expansion.
3. The effect of P-D moment applied on the composite beam increases for larger steel sections.
4. The load carrying capacity of the composite member is larger for larger steel joist and consequently, the composite beam is able to carry the self implied P-D moment.
5. The tensile membrane action developed in the slab at mid-span are developed at high temperature, without any major influence related to the steel joist area.
6. From the above the area of the secondary steel joists does not seem to play any major effect on deflections or the global stability of the structure under fire conditions.

7 REFERENCES

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