# THE INFLUENCE OF ADJACENT COOL STRUCTURE ON THE BEHAVIOUR OF COMPOSITE FLOORS IN FIRE

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**Abstract:** In structural behaviour observed from real large-scale fire tests it has been seen that adjacent cool structure can be an important influence on the structural behaviour within the fire compartment, and should be investigated in more detail. In this paper a large generic composite steel framed building is designed, and a series of analyses are carried out based on different extents and locations of fire compartments, in order to develop a better understanding of the interactions between cool and hot zones of the composite flooring system. The modelled behaviour is compared against fire engineering design calculations according to the new Eurocode 4, showing that this is very conservative.

## 1. INTRODUCTION

In 1995-96 six large-scale fire tests were carried out on a full-scale composite building at the BRE Fire Research Laboratory at Cardington UK. One of these tests, known as the "Restrained Beam Test", was subject to very high restraint from surrounding cool structure, while at the opposite end of the range the "BRE Large Compartment Test" was subject to virtually no restraint at all. The cost of such full-scale fire testing, and of fire tests in general, is very high. It is therefore becoming increasingly important to have available analytical methods which can predict the behaviour of structures when subjected to fire conditions. One such computer program VULCAN [1, 2] has been progressively developed in recent years at the University of Sheffield to carry out three-dimensional modelling of the global behaviour of composite buildings in fire, and this is beginning to make such studies practicable.

In this paper a large generic composite steel framed building, which has a footprint of 18m by 54m is designed (see Fig. 1). Along the length there are 6 bays, each of 9m width, and across the depth there are 3 bays of 6m width. The construction of the building is similar to that of the Cardington test frame [3] but with a higher uniform floor loading of 8.86kN/m$^2$ in the fire limit state. All primary and secondary beams have been standardised, respectively using 305x165x40UB and 356x171x51UB sections. The load ratio of all internal secondary beams is 0.7 according to EC4 [4]. The floor slab is identical to that used in the Cardington frame. It comprises a profiled metal decking acting compositely with a 130mm total depth (including profile) reinforced concrete slab and an A142 anti-cracking mesh is used. A series of analyses are carried out based on fire compartments of different extents and locations. A number of different fire scenarios, using both the ISO834 [5] Standard fire curve and typical natural fires, are applied. The results are compared with fire resistance calculations according to EC4 [4].

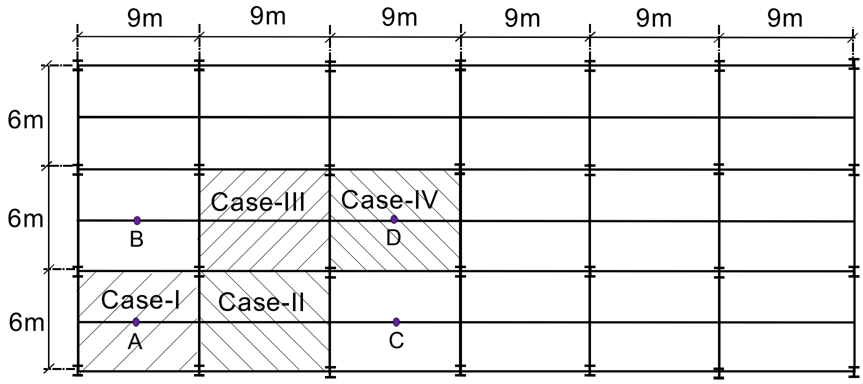


Fig. 1. A large generic composite steel framed building with different fire compartment positions marked.

## 2. INFLUENCE OF SURROUNDING COOL STRUCTURE

In this analysis fire compartments in four different locations are modelled (see Fig. 1). As a representative natural fire, temperature records from the Cardington "British Steel Corner Fire Test" [3] are used. The maximum temperatures of the bottom flange, web and top flange of unprotected secondary beam within the fire compartment are respectively 1000°C, 960°C, and 890°C. All edge beams of the compartment were fire-protected; they all have the same maximum temperature distributions with the bottom flange, web and top flange at 280°C, 200°C, and 120°C respectively at this point. The cross-sections of all protected columns have uniform temperature distribution, with a maximum temperature of 160°C. The average test temperature distribution through the thickness of the concrete slab is used, with the maximum temperatures of bottom and top layers at 400°C and 75°C respectively. In the following text the key temperature quoted in all figures refers to the temperature of the bottom flange of the hottest beams.

Fig. 2 shows the mid-span deflection of the secondary beam within the fire compartment against the temperature for the four different cases, of which Case-I and Case-IV are the extremes. The influence of surrounding cool structures on the behaviour of the fire compartment is clearly significant, especially when temperatures are high. The restraint from the cool structure and continuous floor slabs provide some benefits in increasing the fire resistance of the fire compartment. For a given deflection level, say *span*/30, the key temperature in Case-IV is about 150°C higher than Case-I. To demonstrate the influence of the surrounding edge beams Cases I and IV are analysed once more with all edge beams unprotected, so that the temperatures of all beams are identical. The results are shown in Fig. 3. It can be seen that the effect of edge beams is significant. It is interesting to see that when temperatures are less than 500°C there is little difference between the two situations, but when temperature are over 600°C a huge difference between the two cases can be seen.

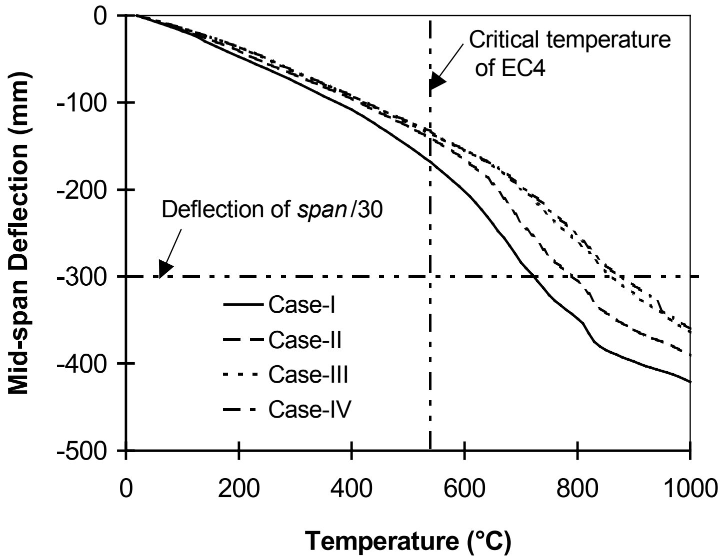


Fig. 2. Comparison of predicted deflections; different fire compartment positions.

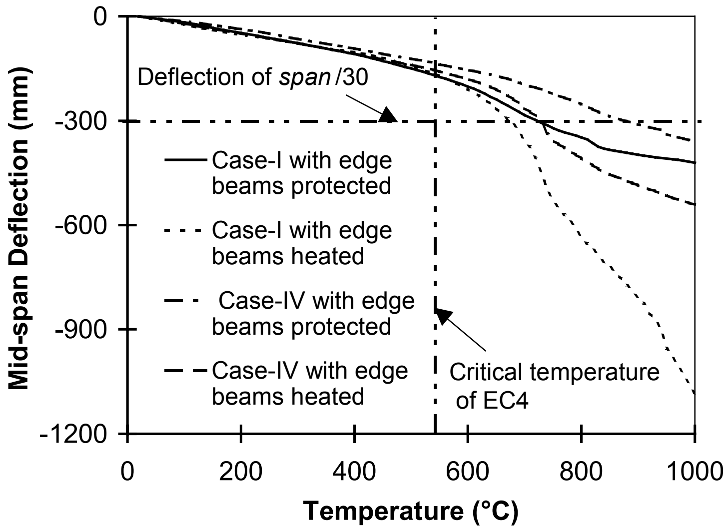


Fig.3. Comparison of predicted deflections; edge beams protected or heated.

Finally a demonstration modelling is carried out in which the whole storey floor is heated. Because of the inherent symmetry only a quarter of the area is modelled. Fig. 4 shows the deflections of some key points (see Fig. 1) within the structure analysed. When temperatures are higher than 700°C a run-away failure is happening, which implies an overall structural failure. Fig. 5 shows the deformed structure at 765°C.

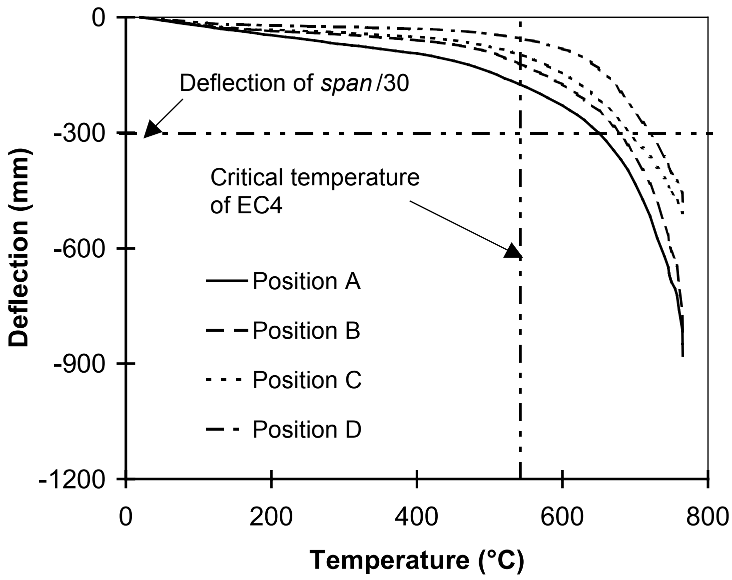


Fig.4. Deflections at four key positions (whole storey heated).

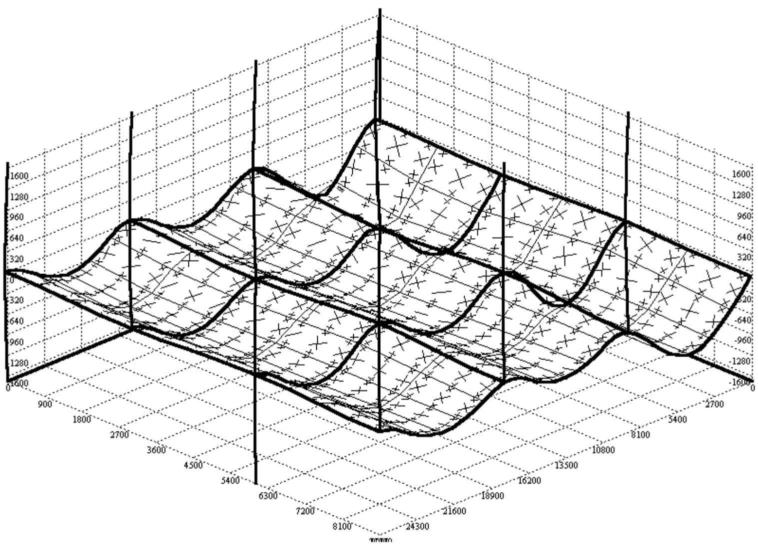

Fig. 5 Deformation of one quarter of the structure at 765°C (whole storey heated).

## 3. MODELLING USING ISO834 FIRE

It is almost impossible to use the ISO834 fire in full-scale tests on buildings, so the temperatures of exposed steel beams and slabs are assumed to follow those taken from standard fire tests on simply supported composite beams [5] and composite decking slabs [6]. The temperatures of the bottom flange and web, and the top flange of a heated beam are 1010°C and 980°C respectively at 120 minutes. All protected columns have uniform temperature distributions equal to 18% of the hottest beam temperature. The average test temperature distribution through the thickness of the concrete slab is used, with the temperatures of the bottom and top layers at 1010°C and 285°C respectively at 120 minutes. All edge beams of the fire compartment are heated. Fig. 6 shows the predicted deflections at mid-span of the secondary beam for Cases I and IV, together with the results using the natural fire. It can be seen that the standard fire is more severe than natural fire test. This is because the temperatures in the concrete slabs are much higher than in natural fires, and at high beam temperature the slabs dominate the behaviour. Fig. 7 shows the deflection of some key positions against the time of heating. It is seen that the deflection of "A" reached *span*/30 at about 25 minutes.

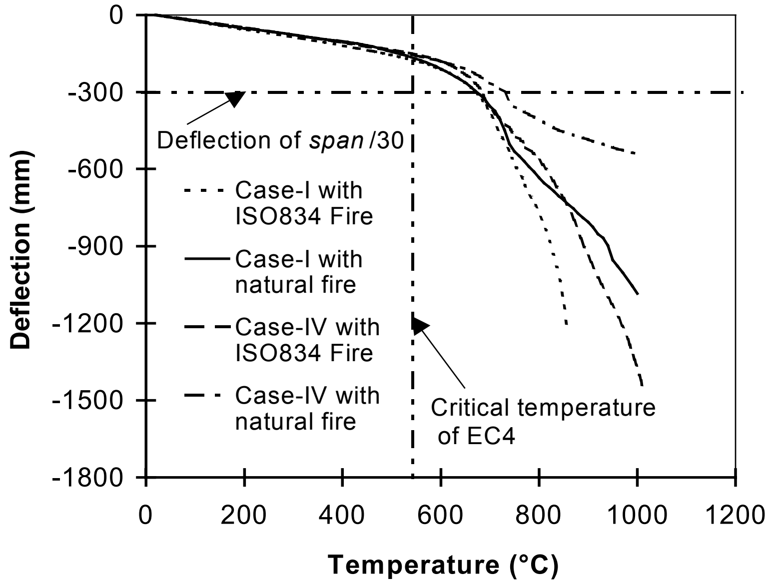


Fig.6 Comparison of deflections for an ISO834 fire and natural fire (Cases I and IV).

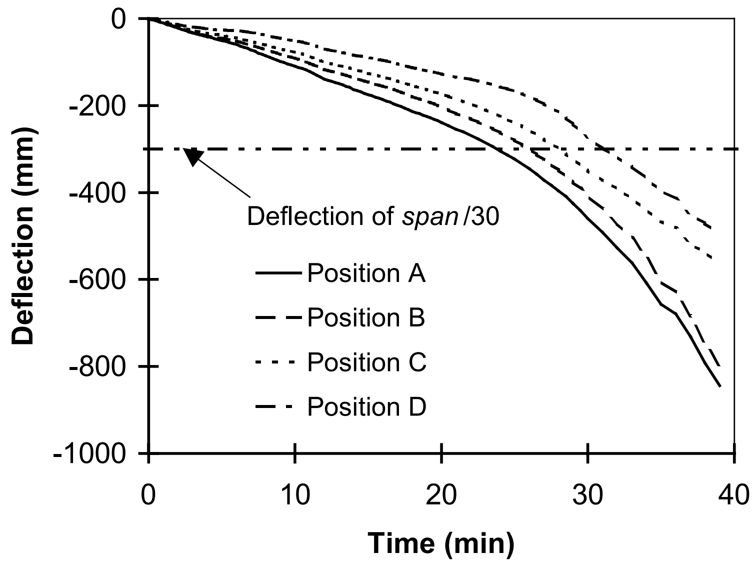


Fig. 7 Deflections at four key positions with whole storey heated by ISO834 Fire.

## 4. COMPARISON WITH EUROCODE 4 CALCULATION

Eurocode 4 Part 1.1 [4] deals with fire resistance of composite structures and members. The heated secondary beam within the fire compartment is now idealised in the usual design fashion, as a simply supported composite beam with an effective-width concrete flange. In EC4 terms the load level is $\eta^*=0.7$ and the adaptation factor $\kappa=0.855$, giving a critical temperature of 555°C. This critical temperature is marked on the figures, together with the *span/30* deflection level which is the lower limit used in standard furnace testing. It can be seen that in all situations the temperatures of the bottom flange of the beam at deflection of *span/30* are higher than the EC4 critical temperature. It is interesting that in Fig. 4, in which the whole storey is heated using a natural fire, the temperatures at predicted deflection of *span/30* for key Position A are always within 17% of the EC4 critical temperature, and always conservative. This gives an indication of the limitations of current fire engineering design codes, because of their emphasis on representation of simply supported members in the furnace test environment.

## 5. CONCLUSIONS

It is clear from the studies presented here that restraint from surrounding cool structure is indeed a significant influence on the behaviour of composite steel-framed buildings in fire. More comprehensive studies are needed, using tools such as VULCAN to develop a more detailed understanding of the behaviour. It is now time to raise serious questions about the validity of structural fire design codes which base their fire resistance calculations on standard furnace tests of isolated members. Clearly future developments of fire design codes should allow a more representative modelling of real behaviour to be used by designers who wish to optimise fire resistance strategies.

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