

Is Fire Protection Necessary?

Jef Robinson

Abstract

Large-scale fire tests conducted in Australia and UK have shown that there are large reserves of fire resistance in modern steel framed buildings and that the standard fire test, ISO 834, is not a satisfactory indicator of performance.

Natural fire tests on the 8-storey building at BRE Cardington indicate that stability in modern composite steel framed buildings can be maintained by continuity and beam/slab interaction even when the temperature of unprotected beams exceeds 1000°C. Unprotected steel beams in such structures appear to have fire resistance equivalent to a rating of around 90 minutes. It is important to understand the mechanisms that underlie this behaviour and to develop ways of achieving “Fire Performance “ in real buildings rather than “Fire Resistance” in standard fire tests. This paper presents some initial proposals.

Significant saving of cost and construction time can be achieved without impairing life safety by improving design procedures to eliminate unnecessary fire protection. The first practical step in this direction is embodied in a recent publication by the UK steel Construction Institute – “ Fire Safe Design – A new approach to multi-storey buildings”.

Keywords

Fire, fire protection, fire resistance, Cardington, performance based.

Author Details

Jef Robinson is Market Development Manager, Sections at British Steel SP&CS and Honorary Professor at the Civil & Structural Engineering Dept at Sheffield University.

1. INTRODUCTION

Fire protection - currently seen by most control authorities as a necessary part of the construction process and by most designers as the principal restriction to the greater use of steel - is an issue that has caught the attention of the steel construction industry throughout the world.

A reassessment of the role of fire protection is long overdue bearing in mind the enormous changes that have taken place in construction in the last half-century. Design philosophies have evolved from elastic through plastic to the limit state approach. Simple construction has advanced to composite construction. The properties of the materials that we use are being improved continually and even the furnishings in buildings are now rarely from natural sources but more often from man made fibres and foams. All of these changes will influence a structure's behaviour in a fire, yet the very idea of "fire resistance" - being the measured or calculated survival time of a single beam or column in a laboratory furnace - is a concept that remains rooted in a pre 1940's era.

The standard fire test has been very useful as a grading method for protection materials but it is important to recognise its limitations as a means of representing reality. We must be careful not to take the results of such tests too literally or extend them too far from simple comparative assessment into the broader realm of engineering. There are just too many other influences and interactions at work in a real structure to expect such a simple unrepresentative test to provide the answers that a designer needs in order to work most effectively in the interests of both his client and the wider community.



Figure 1: Fire test of an office in the 8-storey Cardington building. The temperature reached over 1200°C and large volumes of dense smoke were generated.

The only justifiable approach in the 21st century will be to shift the basis of fire design away from the behaviour of individual members in the laboratory and towards the performance of whole buildings in real fires. A number of recent large-scale fire tests are throwing new light on the differences between the two approaches.

2. TRADITIONAL FIRE RESISTANCE

As we normally express it in the UK and Europe today, the fire resistance of a beam is the period of time that it can maintain a deflection less than span/30 under standard ISO 834 fire conditions in a laboratory furnace. Individual beams are tested in isolation, in a simply supported condition without restraint, without continuity or any other interaction. If tested without protection the fire resistance of steel beams is typically between 15 and 25 minutes and the limiting test deflection of span/30 is normally reached when the beam temperature is between 550 and 700°C depending on the applied load. This has given rise to the commonly held assumption that steel members will fail at a “critical temperature” of 550°C – an assumption that we now know to be wrong.

3. REAL BUILDING BEHAVIOUR

For many years it has been known that steelwork in a structural frame is much more fire resistant than are single simply supported members in the standard test. Since the 1970's there have been a number of natural fire tests and real building fires in which steel beams have demonstrated enhanced behaviour, among them: -

- Liverpool Hospital UK - 1978
A natural fire simulation conducted by BRE using a 42m² fire compartment inside a 300m² test rig. The fire load of 95kg/m² generated a heat output of 15MW and an atmosphere temperature of 1100°C. Unprotected steel beams, which reached 950°C, survived.
- Broadgate UK - 1990
A real fire incident in a 14-storey building under construction in London which occurred before some of the steel work in the fire zone had been fire protected. Unprotected columns weakened and deformed but transfer of loads between members allowed structural stability to be maintained
- Australia, William St. tests – 1991
A natural fire simulation conducted by BHP in a 144m² test rig using real furniture equivalent to 65kg of wood /m². Atmosphere temperature peaked at 1228°C and unprotected steel beams, above a non-fire rated suspended ceiling, survived at 632°C with deflection of only 120mm in a 12m span (span/100).

These observations indicated that it is possible for steel framed buildings to survive fires without protection of all the structural members and the Cardington Project was undertaken to obtain detailed data from which to quantify and predict whole frame behaviour.

4. THE CARDINGTON 8 STOREY FRAME PROJECT

In 1995/6 a series of natural fire tests was carried out in the BRE Large Scale Test Facility at Cardington UK. The test building was 33 metres high and constructed as a modern steel framed office with composite metal deck floors and comprised eight levels, each almost 1000m² in area. In total six fire tests, funded by ECSC and DETR, were conducted in the structure, increasing in severity from a single heated beam to a fully fitted office. Although analysis of the data from the tests is still in progress and few detailed conclusions can be drawn at this stage, preliminary results based on simple observation raise a number of fundamental questions with regard to the standard fire test.

4.1 Single beam behaviour

One of the first tests in the project was carried out on a single unprotected beam and it is thus possible to compare beam behaviour in the building frame with that of single beams in the standard fire test which are well documented.

During the 1980's a programme of standard fire tests was carried out by British Steel and BRE Fire Research Station at the Warrington Fire Research Centre to establish the response in the ISO 834 fire of single unprotected steel beams subject to different load levels. This work was used to define the limiting temperature tables in BS 5950 part 8 and Eurocode 3 part 1.2. One of the beams tested at that time was similar in size (356x165x46) to that in the first test in the Cardington frame (356x165x40). A comparison of the behaviour of the two beams is striking (Figure 2).

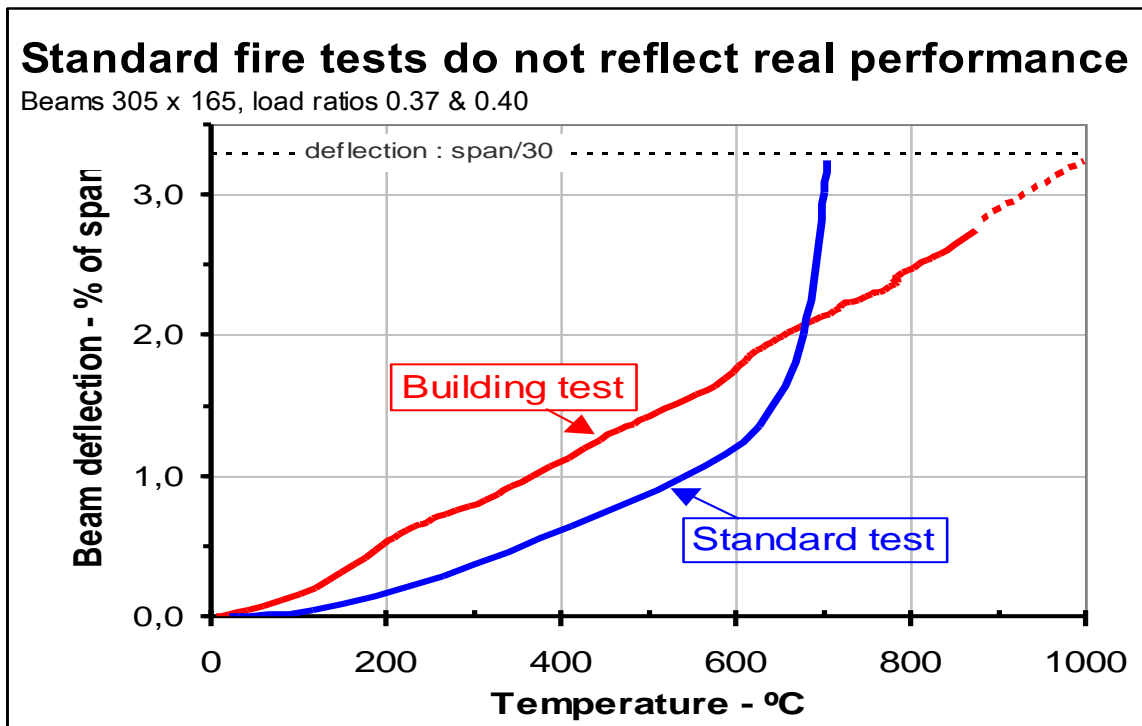


Figure 2: Comparison of the deflection behaviour of a beam under standard test and frame test conditions.

In the standard ISO test the beam had been subject to a load ratio of 0.37 and tested as a 4.5m span in the usual simply supported condition without restraint. It's behaviour was as we have come to expect from such tests, deflection beginning slowly as the temperature rises then progressively accelerating up to the termination point of span/30, in this case at 705°C and a time of 22 minutes.

By contrast the unprotected 9m beam in the frame with a similar load ratio of 0.4 was subject to considerable restraint and continuity effects from composite action with the floor slab and from the beam/column connections. As a result, its deflection behaviour was entirely different. The deflection rate was virtually constant throughout and showed no sign of accelerating even when the beam temperature was 875°C, at which point the test was terminated because of electrical breakdown in the deflection measuring instrumentation. If we assume that deflection would have continued at the same rate, a temperature of over 1000°C would have been needed to achieve the standard test criterion of span/30 deflection and that would be equivalent to a rating of over 90 minutes without protection.

This difference in behaviour raises the obvious question "How relevant is the standard test for structural design purposes?"

4.2 3 Dimensional beam / floor behaviour

The last and most severe test conducted in the building was a simulation of a fire in a modern office using real furniture with a fire load equivalent to 46kg/m² (20% of which was plastic material) in a compartment of 135 m². The columns were protected but the beams were left exposed. The fire generated atmosphere temperatures of over 1200°C, which resulted in beam temperatures up to 1100°C. The building survived without collapse of any structural element even though the beams suffered considerable deformation (see figure 3). However, fire is an ultimate limit state that requires only resistance to collapse and there is no limit to deformation provided that integrity is maintained.

It is clear that true fire resistance is not about the properties of individual members but about the behaviour of whole structures, and to assess it realistically we must take account of interaction of members and of load transfer between them. It is also clear that if structures could be designed to survive fires without incurring the expense of protecting the beams, then sprinklers could be used to provide all of the required fire resistance in the knowledge that the risk to loss of life and property would be reduced dramatically. Only in the extremely small minority of cases when the sprinklers failed to operate might any structural deformation occur, but even then the Building Regulation's structural stability criterion would be fulfilled.



Figure 3: Deformed but stable structure after a fire in the Cardington eight storey building. No collapse occurred even though unprotected beams reached temperatures up to 1100°C

The fact that unprotected beams survived the severe fire conditions experienced in the Cardington project raises a number of fundamental issues against which we should reassess our approach to structural fire resistance.

5. IMPLICATIONS FOR MODERN STEEL FRAMED COMPOSITE FLOOR CONSTRUCTION

5.1 *Column behaviour*

Columns are critical elements and must resist deformation in order to confine damage to the fire compartment. **Fire protection of columns will normally be required** to achieve this.

5.2 *Beam behaviour*

Beam deformation is not critical provided that integrity of the fire compartment is maintained. In normal service at ambient temperature the building is designed so that the beams support the floors in a way that satisfies the serviceability Limit State. At 1100°C the beams have virtually no fire resistance (Eurocode 3 indicates that only 3% of their design strength remains at that temperature) and act only as catenary members in tension. It is clear that **in fire the floors provide support to the beams and protection of beams may be unnecessary** when they are designed to act compositely with the floor slab.

5.3 *Implications for the concept of "Fire Resistance".*

The tests have shown that fire **resistance is not a property inherent in a member - but of the structure that surrounds it** and with which it interacts. Indeed, it is not possible to define fire performance realistically without reference to structural interactions and load transfer. A laboratory test on an isolated member is unable to provide a realistic indication of performance.

5.4 *Implications for the standard fire test*

The standard fire test is not a precise method of measurement; it simply enables us to compare the insulation and adhesive characteristics of one protection material with another. It is now clear that **ISO 834 tells us nothing about structural behaviour** for design purposes. We should not waste time and resources trying to give the test a validity and a precision that it can not support but seek a better approach based on improved understanding of what actually happens in practice.

5.5 *Implications for building codes and regulations*

In an era of performance-based codes we should seek performance-based solutions. We have to find ways of achieving "Fire Performance" in real buildings rather than "Fire Resistance" in prescriptive tests. Only then will the potential of this opportunity to improve both life safety and construction economics be fully realised. The challenge is to make certain that the new methods are as accessible to the Building Control Officer, who is charged with ensuring public safety, as they are to the Fire Safety Engineering experts, who are generating new knowledge.

6. TOWARDS PERFORMANCE BASED SOLUTIONS

The ability of the beams and floors in the eight-storey Cardington building to withstand temperatures up to 1100°C without fire protection shows that there are large reserves of fire resistance in modern steel deck composite buildings. Although much analytical work remains to be done before a comprehensive understanding and full practical realisation of the results of the project can be achieved, there are, nonetheless some simple yet conservative proposals that can be made based simply on the observations of the tests.

6.1 *Two storey buildings*

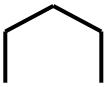

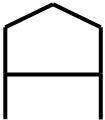
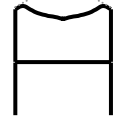
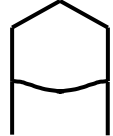
Approved Document B currently recommends that, in general, fire resistance for structural members is applicable only up to the floor of the uppermost storey. Thus, in a two-storey building only the load bearing members of the ground floor level are considered to represent a life risk in fire and fire resistance periods of 30 and 60 minutes are quoted.

The extensive testing of steel deck composite construction at Cardington has shown that: -

- Floors provide support to beams in fire conditions and structure stability can be maintained at very high temperatures.
- Levels of safety at least equivalent to those implied by Approved Document B for two storey buildings can be achieved without fire protection to beams.
- Floors retain their integrity and the steel deck soffit prevents spalled concrete from falling and causing injury to fire fighters.
- Deformation, if it occurs, does not happen suddenly or unexpectedly but proceeds by slow, visible and audible ductile movement.

In single-storey buildings rapid evacuation is normally assumed and structural fire resistance is deemed unnecessary since all escape routes are at ground level. It seems logical that the ground floor level of a two-storey building, which is subject to exactly the same life risk, should be assessed in the same way (as shown in table 1), and fire resistance requirements for two storey buildings should be no higher than for single storey buildings of the same purpose group.

Table 1
Single & two-storey building risk comparison

Single storey buildings		Approved Document B Structure Fire resistance	Risk Factors	Fire Resistance Recommendation
As built 	After fire 	None normally required (except for wall stability to inhibit external fire spread in boundary condition)	Life risk: Very low – we accept that structure deformation incurs minimal risk Means of escape: Simple - all exits lead to a place of safety	No change
Two storey buildings				
As built 	Fire in upper storey 	None normally required	Life risk: Very low – we accept that structure deformation incurs minimal risk Means of escape: Easy - only one storey height to a place of safety	No change
	Fire in lower storey 	30 or 60 minutes depending on building category	Life risk : Very low - structure deformation incurs minimal risk Means of escape: Simple - all exits lead to a place of safety	Columns – no change Beams : Protection Unnecessary - There is sufficient stability and equivalent life safety without protection
Conclusion	<i>The risk to life in the ground floor of a two-storey building is the same as in single storey building; thus the same fire resistance provisions should apply.</i>			

As far as property loss is concerned the cost of damage to fixtures, fittings, contents and consequential losses normally far outweigh the cost of structural damage, especially in low rise buildings. Unlike a high rise structure, if a two-storey building has been subjected to a fire severe enough to deform unprotected beams it will have been suffused with smoke and

the loss of contents will be high in relation to the value of the building. It is unlikely to be repaired. It will almost certainly be quicker and easier to demolish and replace rather than clean and reinstate.

If limitation of structural damage is important then sprinklers should be installed. They are by far the most effective means of damage limitation, not only to the structure but also to the building contents and function, and they attract insurance premium discounts.

6.2 Taller Buildings

The purpose of stability requirements in fire is twofold. Internally, to maintain the viability of escape routes for a sufficient period to allow safe evacuation and search and rescue; and externally, to prevent toppling of the building which would endanger people in the vicinity. The stability requirements to ensure safe egress are independent of storey level but the external risk from overbalancing of the building depends both on the height of the structure and the level on which the fire occurs. There is less risk of overturning from fires on upper levels than on lower levels (see figure 4) and fire resistance provisions for columns should logically increase progressively down the building from top to bottom, as is the case in Japan.

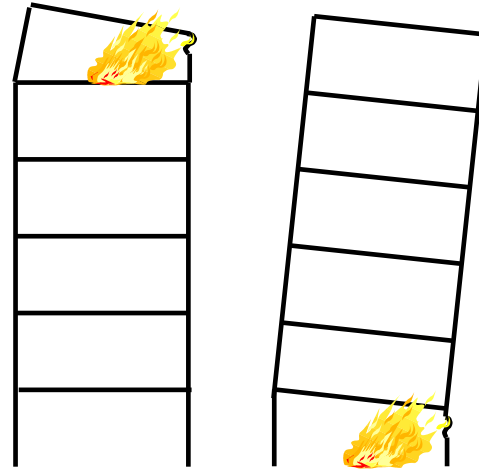


Figure 4: Stability of upper storeys is less critical than lower storeys

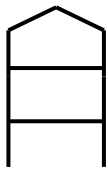
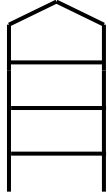
Beams are less critical, in overall stability terms, than columns and their fire resistance requirement should normally be dependent only on the expected fire load or occupancy category and not on the storey level.

Although we always seek to minimise risk we can never be absolutely certain that unforeseen circumstances will not occur and that one or more structural members might fail. We therefore need to consider a failsafe condition such that if collapse occurs it will be inward and not outward. This implies a “strong column / weak beam” philosophy similar to that used in seismic design. Survival of structures in earthquakes is dependent on columns maintaining their integrity. This is achieved by ensuring that the kinetic energy of the seismic movement is transferred from the columns and absorbed by plastic deformation of beams. After the event beams are distorted but the columns maintain their function and the maximum number of buildings and people survive.

There is no reason why exactly the same approach should not be adopted for fire. The failsafe condition of inward collapse might be achieved by ensuring that beams deform at high temperature and enhance stability by absorbing expansion forces before the columns are damaged. This implies that beams should be less fire resistant than columns.

As a first, conservative, step towards a performance based structural solution the recommendations of table 2 are proposed for composite steel framed buildings.

Table 2
Composite steel framed buildings of 3-storeys or more

		Approved Document B Structure Fire resistance	Fire Resistance Recommendation	
			Columns	Beams
3-Storeys 	Top storey	None normally required	None	} None } (as in table 1)
	Mid storey	} 60 or 90 minutes } depending on building } category	30 or 60 min (as in table 1)	
	Bottom storey		No change	30 minutes
4-Storeys 	Top storey	None normally required	None	} None } (as in table 1)
	Upper storey	} 60 or 90 minutes } depending on building } category	30 or 60 min (as in table 1)	
	Lower storey		No change	30 minutes
	Bottom storey		No change	No change

7. INITIAL RECOMMENDATIONS

- The fire resistance requirements for columns should remain unchanged - except for the single case that columns in the top two storeys of buildings of 3-storeys or more would be rated as for 2-storey structures.
- The high performance of beams observed in the Cardington tests shows that equivalent levels of safety could be maintained with reduced beam ratings (as determined by the standard fire test) for the uppermost three storeys.
- Below the top three storeys no changes are proposed at this time.

8. ACKNOWLEDGEMENT

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