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Structural Fire Safety:

A Handbook for Architects and Engineers

S J Ham Dipl Arch, RIBA, AIFireE
G M Newman BSc(Eng), MIStructE, AIFireE
C I Smith BSc, MSc, PhD, MIM, AIFE, CEng, AIFireE
L C Newman T Arch, MNFPA

Published by:

The Steel Construction Institute
Silwood Park
Ascot
Berkshire SL5 7QN

Tel: 01344 623345
Fax: 01344 622944

stability will be maintained for a reasonable period. Structural fire precautions however make a contribution to all sections of Part B of the Regulations except for B2 Internal Fire Spread Linings.

Demonstration of compliance with the functional requirement may be achieved in one of two ways:

- by compliance with the guidance in Approved Document B[4] or
- by meeting defined objectives set out in a Fire Safety Engineering strategy.

3.1.1 Approved Document B

In order to assist the designer, practical guidance on how the requirements of the Regulations may be satisfied is presented in the supporting Approved Document B. As explained at the start of that document: *There is no obligation to adopt any particular solution contained in an Approved Document if you prefer to meet the relevant requirement in some other way. However, should a contravention of a requirement be alleged then, if you have followed the guidance in the relevant Approved Documents, that will be evidence tending to show that you have complied with the regulations. If you have not followed the guidance then that will be evidence tending to show that you have not complied. It will then be for you to demonstrate by other means that you have satisfied the requirement.*

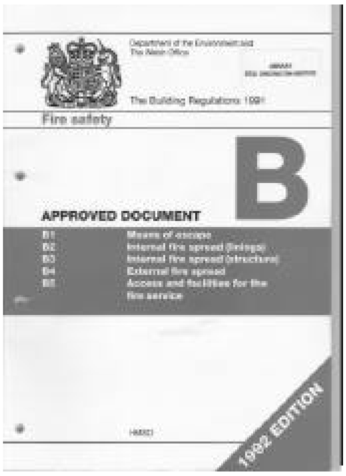


Figure 3.1 *Cover of Approved Document B*

Approved Document B offers some general guidance at the start of each section as to how, in the view of the Secretary of State, the various functional requirements may be satisfied. This can only be a view, as the final arbiters on matters of law are the courts and not the Secretary of State.

Where there is a dispute between a developer and a Building Control Authority as to whether plans for proposed work satisfy the functional requirements of the Building Regulations, the Secretary of State does have the power to determine such matters, but will charge a fee for doing so. It should be understood that the Secretary of State can only determine the proposals prior to the works being completed. Such a determination, once made, can only be challenged through the courts.

3.1.2 Fire safety engineering

A fire safety engineering approach that takes into account the total fire safety package can provide a more fundamental and economical solution than the prescriptive approaches to fire safety. Compliance with the Regulations can, as an alternative to the use of the Approved Document, be demonstrated by use of "fire safety engineering". Indeed, the Approved Document states that, fire safety engineering ……. may be the only viable way to achieve a satisfactory standard of fire safety in some large or complex buildings". However, the Approved Document offers no more than a very general outline of the principles as to how this can be achieved.

The Approved Document indicates that it may also be appropriate to vary the provisions in the document in existing buildings and some guidance on this is included in paragraphs 0.12 to 0.15 of that document).

Structural fire precautions can form part of a fire safety engineering design solution. More guidance on fire safety engineering approaches is included in Section 9.

3.2 Property protection

It is important to recognise that structural fire safety measures can make a contribution to the protection of property and, as a consequence, premium reductions may be derived from insurers if advice offered by their surveyors is followed. Guidance on standards that may be applied by insurers is available in a document published by the Loss Prevention Council (LPC), *Design guide for the fire protection of buildings*[5]. The LPC was set up by the Association of British Insurers and Lloyd's as a leading authority in the field of loss prevention and control.

Part 2 of the LPC guide addresses general principles of fire protection. The guidance generally follows that of Approved Document B, but suggests that in the case of offices, shops, commercial premises, industrial and storage buildings that are not protected by a sprinkler system, and with a height (see Figure 5.1) of more than 20 and up to 30 m, "consideration may be given by insurers to increased fire resistance in place of sprinkler protection [see Section 5.4]. Assessment of risk should be carried out in consultation with the insurer."

Figure 3.2 *Cover of LPC Design Guide*

3.3 Other legislation

Other legislation that may stipulate the need for structural fire resistance, explicitly or implicitly includes:

The Fire Precautions Act 1971

Although the Act contains no specific requirements in respect of structural performance, the general requirements for certification of premises may be dependent on the performance of the structure in fire.

Safety of Sports Grounds Act 1975

Fire Safety and the Safety of Places of Sport Act 1987

Both statutory instruments are concerned with sports facilities and assume, in the case of new buildings, that they have been constructed in accordance with the Building Regulations but the latter contains amendments to other general fire safety legislation.

Fire Certificates (Special Premises) Regulations 1976

Although the Act contains no specific requirements in respect of structural performance the general requirements for certification of premises may be dependent on the performance in fire of the structure.

The Fire Precautions (Workplace) Regulations 1997

This legislation implements the European Workplace Directive requiring the owners and or occupiers of most premises in which work takes place to carry out a risk assessment of all aspects of their premises.

Local Acts (Various)

There are a number of Local Acts, including the London Building Acts, that have requirements that apply in particular circumstances and that vary from those in Building Regulations.

London Building Acts (Amendment) Act 1939 - Section 20

This empowers a Local Authority in Inner London after consulting the London Fire and Civil Defence Authority to impose conditions for the provision and maintenance of: (a) fire alarms; (b) automatic fire detection systems; (c) fire extinguishing appliances and installations; (d) effective means of removing smoke in case of fire; and (e) adequate means of access to the interior, exterior and site of the building for fire brigade personnel and appliances.

In addition, the Local Authority may impose further conditions in respect of any special fire risk area to reduce the danger from a fire in the building. An area of special fire risk includes a garage, vehicle park, loading bay or loading dock, located in a basement, or at ground level or above, which is not adequately ventilated.

4 WHEN IS FIRE RESISTANCE NECESSARY?

Structures are not required to have fire resistance. Only members that are classed as an "element of structure" of the building may be required to have fire resistance. Approved Document B lists fire resistance requirements for elements of structure.

There are circumstances where the guidance in Approved Document B or other authoritative publications indicates that structural members may not need to have any fire resistance.

4.1 Members not required to have fire resistance

There is often confusion as to whether a member requires to have fire resistance. Some of the situations where confusion may arise are now discussed.

There are situations where a member is not considered to be an element of structure, and therefore it is excluded from the need to have fire resistance. Clause 7.4 of Approved Document B excludes the following:

a. *structure that only supports a roof, unless:*

  i. *the roof performs the function of a floor, such as for parking vehicles, or as a means of escape, or*

  ii. *the structure is essential for the stability of an external wall which needs to have fire resistance.*

b. *the lowest floor of the building; and*

c. *a platform floor.*

Roof structure

A roof may be left "unprotected" unless it is used as a floor or a means of escape. The roof becomes a floor when, for example, it is used for parking cars or as a roof garden.

The part of a roof structure supporting a means of escape across a roof requires a minimum of 30 minutes fire resistance.

Platform floor

A platform floor, sometimes referred to as a 'raised floor' or 'computer floor', is defined in Appendix E of Approved Document B as:

*"**Platform floor (access or raised floor)** A floor supported by a structural floor, but with an intervening concealed space which is intended to house services."*

Platform floors are not required to have fire resistance. The cavities formed between the platform floor and the main structural floor can constitute a concealed void and, as such, may be required to have cavity barriers installed within them.

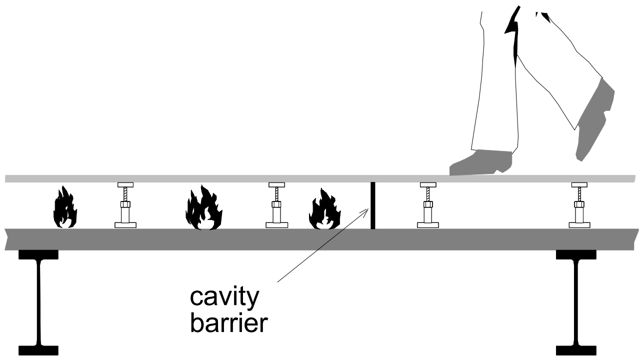


Figure 4.1 *Platform floor*

Raised storage floors

Approved Document B suggests that for large raised storage floor areas (50% or more of the ground floor area) that are likely to be occupied by significant numbers of people or members of the public structural elements should have the necessary fire resistance.

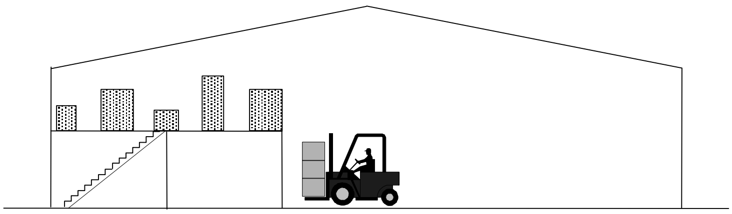


Figure 4.2 *Unprotected raised storage floor*

Protection may not be necessary in the case of automated storage systems such as automatic stacking car parks, where almost by definition people do not normally go.

In situations where a single tier is used primarily for storage, reduced levels of fire resistance may be acceptable if the area is likely to be occupied by only a few people, and those people would be readily aware of a fire starting at the lower level. In such cases, the required fire resistance of the floor may be less than that required for other parts of the structure. This could enable an unprotected steel structure to be used or less fire protection to be provided to the structure. In these circumstances, at least one stairway serving the floor should discharge within 4.5 m of an exit from the building.

Other elements of construction

It should also be recognised that there are situations where steel members do not constitute part of the structural frame and where their failure in a fire would not directly affect 'the safety of persons in or about the building'. In these circumstances they should not be required to have fire resistance. Some examples are:

- guide members in lift shafts
- stair chords

- escalator structures.

Removal of these members would not lead to distortion/failure/collapse of the building framework.

4.2 Boundaries and the fire resistance of walls

It is not always necessary for external walls to have fire resistance. One of the main reasons for providing external walls with fire resistance is their proximity to the site boundary. As the distance to the site boundary increases, the proportion of the wall area that may be unprotected also increases. Any part of an external wall not having the required fire resistance, such as a window, should be regarded as unprotected when assessing the adequacy of the distance of the wallfrom a site boundary.

The distance that an external wall (having little or no fire resistance) needs to be from a boundary increases relative to the area of wall and the anticipated fire load intensity. The fire load intensity is considered to be low for residential, offices and assembly/recreation uses and normal or high, for other uses. Most larger buildings have fire load intensities that are considered as either normal or high and therefore the fire resistance of the boundary wall must be considered. As an example, for walls having little fire resistance and using the enclosing rectangle method set out in the BRE Report 187[6], a single storey warehouse wall 30 m long by 12 m high would have to be a minimum of 18.5 m from the adjoining boundary. By comparison, the wall of a single or multi-storey office, with all floors being compartment floors 12 m long by 3 m high (or with a storey height of 3 m in the case of a multi-storey office) would only need to be 3.5 m from the adjoining boundary.

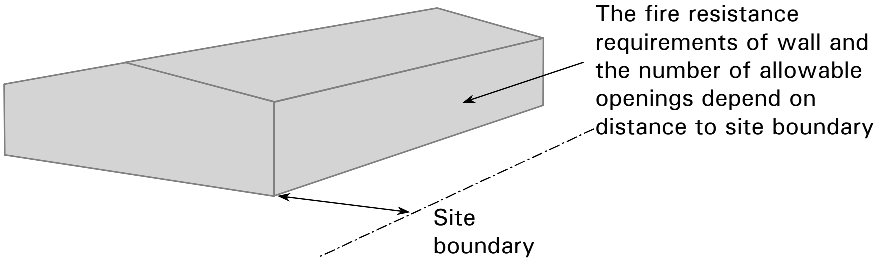


Figure 4.3 *The importance of distance to the site boundary*

4.3 Single storey buildings

The fire resistance requirements for single storey buildings sometimes cause confusion. Single storey buildings do not normally require fire resistance as the elements of structure only support a roof (subject to the limitations in Clause 7.4(a) mentioned in 4.1, above).

The elements of structure will however need to be fire resistant if they:

- are part of, or support, a wall that is required to have fire resistance as a consequence of its position close to a boundary or
- are part of, or support, a compartment wall or
- support a gallery.

The required fire resistance will normally be that for a building where the height of the top floor is not more than 5 m (See Table 5.1).

Portal frames

As mentioned above, a roof structure is required to be fire protected if it provides support to a compartment wall. This can arise in single storey buildings where an unprotected portal frame structure provides support to an internal compartment wall that separates two users or functions within the building. In these circumstances, if the structure within each separated area is sufficiently robust to maintain stability when the other collapses as a result of a fire, no protection should be necessary to the roof structure, although some care may be necessary when detailing the junction.

Design guidance has been prepared for portal frame structures when the building is constructed close to the site boundary and the external wall is required to be fire resistant to restrict fire spread across the boundary. The portal frame will provide support to the external wall. Collapse of the portal rafter can initiate failure of the column. Hence if the external wall is required to exhibit fire resistance, consideration should be given to the fire performance of both the column and the rafter. Research has shown that if the columns are designed with fixed bases, failure of the rafter does not induce instability of the column (see Figure 4.4). Hence in these boundary wall conditions, if the columns have fixed bases, the rafter can be left unprotected. The column must have the required fire resistance and this would normally be achieved by the application of fire protection. Design guidance may be found in the SCI publication, *The behaviour of steel portal frames in boundary conditions*[7]. The need to supply the boundary columns with base fixity may be relaxed if sprinklers are installed.

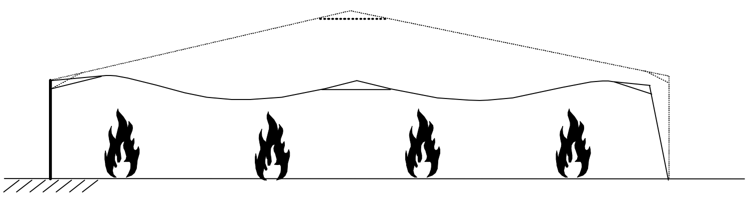


Figure 4.4 *Portal frame in fire - The column base and wall may be designed to withstand the collapse of the rafter.*

5 WHAT FIRE RESISTANCE?

In the United Kingdom in 1997, approximately 70% of buildings constructed, on the basis of floor area, were designed to have a fire resistance of 60 minutes.

Although it is common to talk of a building requiring fire resistance, as mentioned earlier, strictly it is the 'elements of structure', not the building, that may be required to have fire resistance. The required fire resistance of an element of structure is usually established as a function of the type and use of the building in which it is situated and its location within the building. The type and use of a building is usually called its 'purpose group'.

For a particular purpose group, the required fire resistance depends on whether the element of construction is located in a basement or above ground. If it is in a basement, the fire resistance depends on depth of the basement. If it is above ground, the fire resistance depends on the height of the top floor.

Reductions in the required period of fire resistance may be obtained in buildings fitted with automatic sprinkler systems. This is particularly true in industrial and storage buildings, but less so in offices, shops, commercial, assembly and recreational buildings, where, for certain heights of building, there is no benefit. It should be appreciated that automatic sprinkler systems (see Section 5.4) may also be beneficial in terms of property insurance premiums.

5.1 Periods of fire resistance

The minimum periods of fire resistance for most elements of structure are set out in Appendix A, Table A2 of Approved Document B, with the specific provisions of test set out in Appendix A, Table A1. These minimum periods are summarised here in Table 5.1 (definitions of height measurements are given in Figure 5.1).

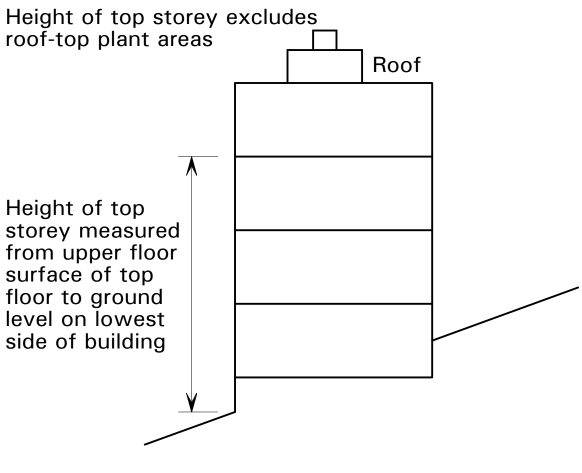


Figure 5.1 *Measurement of building height for determination of required fire resistance*

Single storey buildings are subject to the periods shown in the Table under the heading "not more than 5 m", although elements in such buildings are generally excluded from requiring fire resistance. See Section 4.3 and Approved Document B, Appendix A, Notes to Table A2.

Table 5.1 *Minimum periods (minutes) of fire resistance for elements of structure (based on Approved Document B, Table A2)*

Purpose group of building	Basement storey($) including floor over		Ground or upper storey			
	Depth (m) of lowest basement		Height (m) of top floor above ground in building or separated part of building			
	$10	Ý10	#5	#20	#30	>30
1. Residential (domestic):						
a. flats and maisonettes	90	60	30*	60**†	90**	120**
b. and c. dwellinghouses	not relevant	30*	30*	60@	not relevant	not relevant
2. Residential Institutional and Other Residential	90	60	30*~	60	90	120#
3. Office						
Not Sprinklered	90	60	30*	60	90	✖
Sprinklered (1)	90	60	30*	30*	60	120#
4&5. Shop, Commercial, Assembly and Recreation						
Not Sprinklered	90	60	60	60	90	✖
Sprinklered (1)	60	60	30*	60	60	120#
6&7a. Industrial, Storage and other Non-Residential not described elsewhere						
Not Sprinklered	120	90	60	90	120	✖
Sprinklered (1)	90	60	30*	60	90	120#
7b. Car Park for light vehicles						
Open sided (2)	✖	✖	15*+	15*+	15*+	60
Any other car park	90	60	30*	60	90	120#

Modifications

- $ The floor over a basement (or if there is more than one basement, the floor over the top-most basement) should meet the provisions for the ground and upper storeys if that period is higher.
- * Increased to a minimum of 60 minutes for compartment walls separating buildings.
- ** Reduced to 30 minutes for any floor within a maisonette, but not if the floor contributes to the support of the building.
- ~ Multi-storey hospitals designed in accordance with the NHS Firecode documents should have a minimum 60 minutes standard.
- # Reduced to 90 minutes for elements not forming part of the structural frame.
- + Increased to 30 minutes for elements protecting the means of escape.
- † Refer to 7.12 (in the Approved Document) regarding the acceptability of 30 minutes in flat conversions.
- @ 30 minutes in the case of three storey dwelling houses increased to 60 minutes minimum for compartment walls separating buildings.
- ✖ Not permitted/applicable.

Notes to Table

1. "Sprinklered" means that the building is fitted throughout with an automatic sprinkler system meeting the relevant recommendations of BS 5306-2; i.e. the relevant occupancy rating (light, ordinary or high hazard) together with the additional requirements for life safety.

2. The car park should follow the relevant guidance in Approved Document B on requirement B3, section 11.

Many structural elements of single storey buildings do not need to have fire resistance.

5.2 Protection of escape routes

Not all escape routes need to be protected by fire resisting construction. Corridors serving locations where escape is only possible in a single direction and protected stairways should, however, be protected by construction having a minimum fire resistance of 30 minutes.

The design of escape routes is otherwise controlled by:

- limiting travel distances to an exit, or storey exit
- providing routes of sufficient width and capacity.

Fire fighting shafts

Fire fighting shafts should be provided:

- in any building having a floor more than 20 m above the ground or a basement floor more than 10 m below the ground or access level, or
- an upper storey having an area of 600 m^2 at least 7.5 m above ground or access level, or two or more basement floors having an area of 900 m^2 or more.

Fire fighting shafts should be protected by construction having a minimum fire resistance of 120 minutes irrespective of the fire resistance of the rest of the elements of structure. Additional guidance is included in BS 5588-5[8].

5.3 Interactions of structural elements with fire separating elements of construction

The interaction of a steel frame with other elements of fire resisting construction requires consideration and may require careful detailing.

The steel structure will frequently be used to provide support to other forms of fire resisting construction such as compartment walls and cavity barriers. The deflection of the main structure under fire conditions should not induce premature failure of such elements.

Careful detailing is therefore required to consider interaction and relative movement, particularly when lightweight materials are used to form the compartment walls.

Cavity barriers are required in most concealed voids in buildings. These cavity barriers are required to have fire resistance (30 minutes Integrity and 15 minutes Insulation, see Approved Document B, Table A1[4]) and their spacing depends upon their location and the nature of the exposed surfaces within the void.

Cavity barriers could be supported from an unprotected steel structure within a void between a ceiling and a roof. Failure of the roof structure would lead to failure of the cavity barrier. However, it is normal practice to support the cavity barriers from the unprotected members, as they have sufficient inherent fire resistance to perform the required function adequately.

5.4 Benefits of sprinkler systems

'Active fire protection systems' is a general term used to describe systems designed to control or extinguish fires, or to alert people to their presence. The system that makes the greatest contribution to structural fire safety and property protection is an automatic water sprinkler system.

Traditionally, passive and active fire protection measures have been considered as independent components of an approach to fire safety. The use of active protection systems has been promoted by insurers, who recognise the value of such systems in controlling fire growth and, therefore, in reducing the extent of fire damage in buildings. Statistical information from insurance sources confirms that sprinkler systems can play an important role in reducing financial loss.

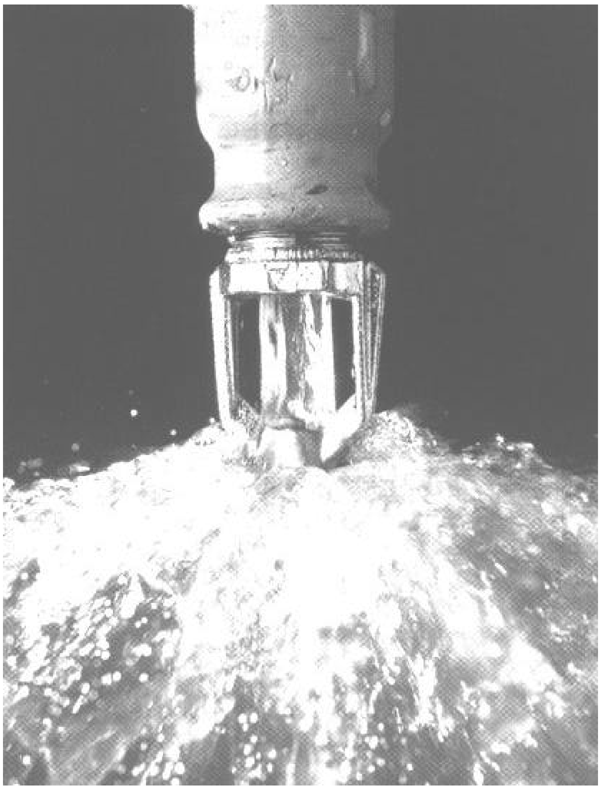


Figure 5.2 *A sprinkler head in operation*

More recently, it has been recognised that sprinkler systems, particularly those incorporating 'fast response' sprinkler heads, can make a significant contribution to improving life safety in a wide variety of building types.

Approved Document B (Table A2) indicates that the incorporation of a suitable sprinkler system will allow a reduction in the required fire resistance period by 30 minutes. In certain situations, i.e. for buildings with a floor above 30 m in height, the use of sprinkler systems is considered essential by the Approved Document.

Sprinklers generally should be designed and installed following the guidance presented in BS 5306-2[9], and/or the LPC *Rules for automatic sprinkler installation* [10].

The Approved Document recommends that the additional requirements concerned with “Life-Safety Systems” in BS 5306-2, should be adopted. These requirements are intended to improve the reliability of the system.

These requirements include:

- the use of bypass systems around the main valve sets to avoid the entire system being turned off during maintenance
- the limiting of the number of sprinkler heads in any zone to a maximum of 200
- the electronic monitoring of water supply and the positioning of valves to ensure that they are in the correct operational position
- management procedures to control maintenance of the system.

Clearly, if the fire can be controlled or extinguished at an early stage, the damaging effect of the fire on the structure can be restricted and smoke damage can be reduced. Smoke spread influences escape, so the viability of certain escape routes can be maintained more easily in sprinklered buildings.

The reliability of a sprinkler system depends on its design, installation and maintenance.

The effectiveness of sprinkler systems in controlling fire growth and the consequential benefits in terms of structural safety and other aspects of fire safety are discussed in an article published in March 1993 in the magazine *Fire Prevention*. Copies of the article are available from British Steel.

6 STRUCTURAL FIRE DESIGN

The most common approach to structural fire design is based on the performance of single elements or simple assemblies subject to heating in a gas fired furnace test. The behaviour of an element in a fire test should not be confused with the behaviour of a whole structure in an actual building fire.

For many years research has been taking place into the behaviour of structures in fire and this has led to the development of new design methods that are now incorporated into design codes.

6.1 Design codes

BS 5950-8, *Code of practice for fire resistant design* [11], was published in 1990. This was one of the first structural fire design codes in the world, and contains both general principles for structural fire design and specific design information for some common cases.

BS 5950-8 contains information on composite and noncomposite steel construction. During 1999 the equivalent Eurocodes will be published in the UK. EC3-1-2[12] covers the fire resistant design of non-composite structures and EC4-1-2[13] covers the design of steel and concrete composite structures. Each of these Standards will be published with an accompanying National Application Document (NAD). The NAD contains official national deviations from the Eurocode document, and small changes to safety factors to bring the Eurocode requirements into line with existing national standards.

All three Standards present design rules for elements that are either based on the analysis of a number of fire tests, or are based on some mathematical model of structural behaviour. All these Standards are based on the assumption that the fire is considered to be an accident that will rarely occur. At the time of a fire, the building is not likely to be loaded to its full design loading and some reductions from the normal, in-service design loads are allowed. For example, for an office, BS 5950-8 allows the designer to assume that only 80% of the superimposed floor load is present.

Strength of materials at elevated temperature

All design standards contain information on the strength of materials. Design methods in fire are generally based on the normal ‘cold’ methods but utilise reduced material properties at elevated temperatures.

All materials lose strength and stiffness at high temperatures. The commonly used grades of structural steel and concrete lose about half their strength at 600°C. The reduction is illustrated in Figure 6.1.

Stainless steel generally retains more of its strength and stiffness than other steels at high temperatures although it begins to lose strength at lower temperatures.

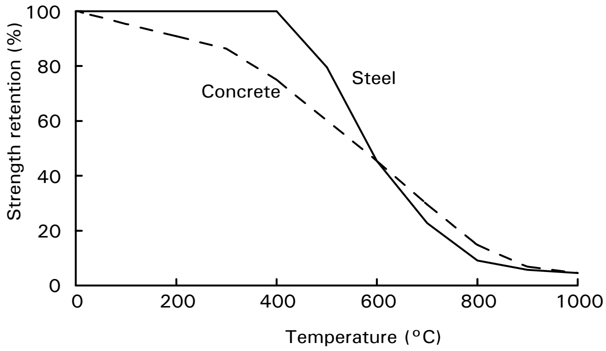


Figure 6.1 *Variation of material strength with temperature*

Structural elements are designed at normal temperatures with a safety factor on strength of about 2, so at 600°C they could have lost their initial reserve of strength and they may fail. However, in any practical design the safety factor may vary from about 1.6 to 2.5. This is because the initial design may be based on a deflection limit rather than strength. Depending on applied load, the failure temperature in fire will normally vary from about 550°C to 700°C. If the failure temperature is high it may be possible to reduce the thickness of fire protection and some savings may be made.

It is not the intention in this publication to go deeply into structural fire engineering, but the simple, and commonly used, concepts of section factor, load ratio and limiting temperature are described.

6.2 Thermal response and section factors

The rate at which a steel beam or column will heat up depends on the surface area exposed to the fire and the mass or volume of the section.

The rate of increase in temperature of a steel cross-section is determined by the ratio of the heated surface per metre length of the member (A) to the volume per metre length of the member (V) (see Figure 6.3). This ratio A/V is known as the "section factor" and is used in the Eurocodes. This ratio has the same numerical value as the term H_p/A used in the UK. In calculating H_p/A, H_p refers to the heated perimeter and A to the cross-section area. In both expressions the units are the same, metres^{-1}, but the term A is different. It is likely that the term A/V will be more and more commonly used.

The section factor is a measure of the thermal response of a steel member. In a given fire, members with low section factors heat up more slowly than members with high section factors. Additional information on the use of section factors is given in Section 8.

Tests on typical structural forms have shown that 30 minutes fire resistance can be achieved for a limited range of beams and columns, with section factors up to certain limits, without applied fire protection. Details are given in BS 5950-8,Clause 4.3.2.

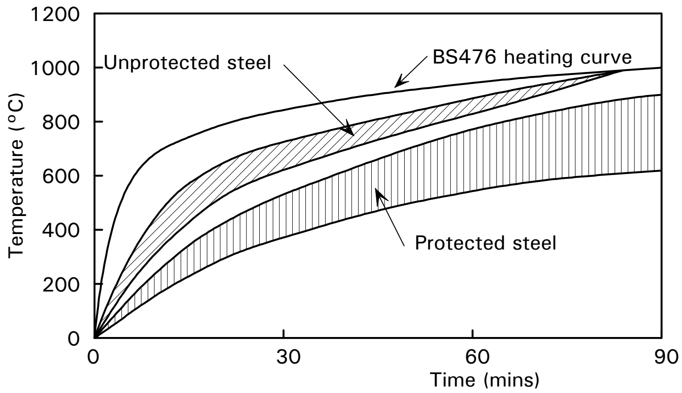


Figure 6.2 *Rates of temperature rise of protected and unprotected steel*

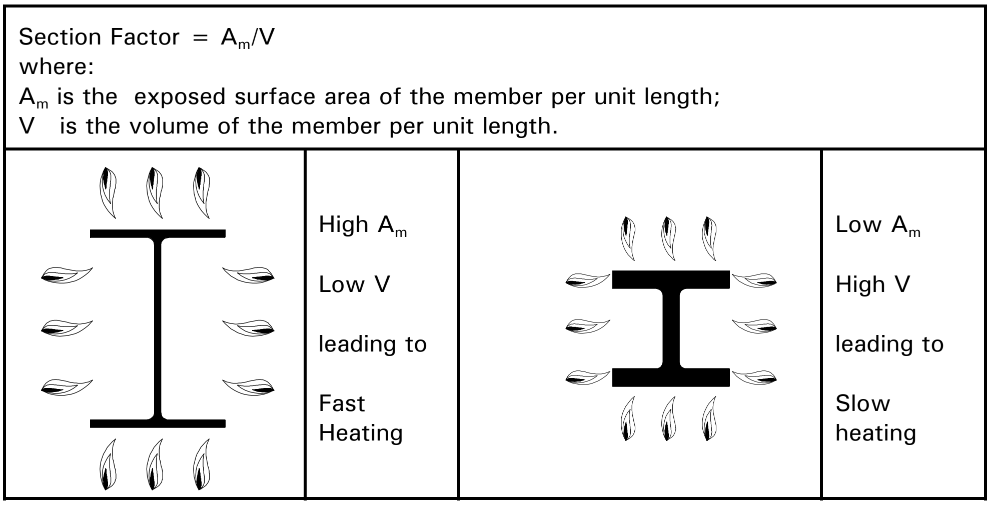


Figure 6.3 *Section factor and thermal response*

6.3 Load ratio

The behaviour of a steel structure depends on the temperature distribution within the members. It is not, to any significant extent, dependent on the time to reach those temperatures. This is useful because it allows information on the strength of steel members to be presented in a way that is applicable to any fire resistance period.

The design codes make use of this variation of member strength with temperature. BS 5950-8 uses the concept of 'load ratio' as a measure of the applied load that a member can resist at the time of a fire. The Eurocodes use a similar concept of 'load level'. The load ratio or load level is a useful concept, because it allows different size elements to be considered in the same way. A 200 mm deep beam will fail at approximately the same temperature as a 400 mm deep beam, if they are both working at the same load ratio.

The load ratio is defined as:

$$\text{Load ratio} = \frac{\text{Applied load or moment at time of fire}}{\text{Load or moment resistance at } 20\,^{\circ}\text{C}}$$

In any particular case, the value of the load ratio will vary, depending on the factor of safety used in the design. It has a theoretical upper limit of about 0.7 for elements carrying mainly dead loads, but for practical designs it will rarely exceed 0.55. This is because the size of most structural elements is not decided purely on the basis of strength. Sometimes deflection may govern and sometimes simplicity in design may govern, and in all cases the designer is forced to take the "next size up".

Another factor influencing the actual value of load ratio is the safety factor for fire specified in design codes. BS 5950-8 allows the imposed load on floors to be reduced to 80% of the nominal value in many cases and the Eurocodes allow the imposed load to be reduced to 50%.

The temperature at failure is known as the limiting temperature in BS 5950-8 and as the critical temperature in the Eurocodes. The assessment of the load ratio (load level) and limiting (critical) temperature of any member should be carried out only by a suitably qualified person.

For illustrative purposes only, the load ratios and limiting temperatures for columns and laterally restrained beams (the most common type in mult-istory buildings) are given in the table below. The data are taken from BS 5950-8.

Table 6.1 *Limiting temperature for typical beams and columns in multi-storey buildings*

Description of member	**Limiting temperature (°C) for a load ratio of:**					
	0.7	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**
Typical multi-storey building column	510	540	580	615	655	710
Typical multi-storey building beam	590	620	650	680	725	780

6.4 Advanced methods

In many prestigious and complex structures such as airports, sports stadia and auditoriums, the codified design methods may not be entirely appropriate. In such cases, a more detailed consideration of the requirements for fire safety and how these will be met may be required. This type of analysis may involve a number of stages covering the development of a fire, the smoke movement within the building, the response of occupants and the response of the structure. The use of an advanced method can allow engineers the opportunity of demonstrating that a structure would have the required levels of safety rather than using the more traditional techniques. The resulting structure may often prove more economical and practical than one designed using more traditional approaches.

The Eurocodes relating to the fire engineering design of structures, EC3-1-2[12] and EC4-1-2[13], allow the use of these so called 'advanced methods'. These methods of verifying the structural fire safety of a building, using complex computer programs, are usually based around the finite element method or other such numerical procedures. The Eurocodes do not give any detail of how the analyses might be carried out, instead they give general guidelines as to the procedures that should be followed and some 'dos and don'ts'.

The modelling of a structure will involve three stages. The first stage is to model the fire scenario to determine the heat energy released from the fire and the resulting atmospheric temperatures within the building. The second stage is to model the heat transfer between the atmosphere and the structure. Heat transfer involves three processes (conduction, convection and radiation) all of which contribute to the rise in temperature of the structural materials during the fire event. The third stage is the determination of the response of the structure.

The use of analytical techniques is likely to increase as the relative cost of computing power continues to reduce and the benefits of more rational approaches to fire engineering become more widely known. In the following sections some of the terms and concepts that designers may come across in relation to numerical modelling of structures during fire are described.

6.4.1 Structural response modelling

Considerable progress has been made in recent years in understanding how structures behave when heated in fires and in developing mathematical techniques to model this behaviour. Some of the methods developed are now contained in the design codes. However, because of the requirement for the codes to contain simple checks that lend themselves to 'hand' calculation, the range of structural types that could be considered is often limited. These simple checks should not be undervalued, as in the majority of building designs they will provide an economic and readily accessible method of design.

It is now possible to predict the behaviour of certain types of structure with a reasonable degree of accuracy. The most common form of analysis is a *finite element method*. Structural engineers use finite element methods to predict structural and sometimes thermal performance. The structure under consideration is divided into many small elements, the response of each of which can easily be determined. By determining the response of the individual elements and knowing the interactions between these elements, the overall behaviour of the structure can be predicted.

In fire, the behaviour of a structure is much more complex than at ambient temperatures. Changes in the material properties and thermal movements will cause the structural behaviour to become nonlinear and inelastic. It is nonlinear in that doubling the load or temperature will normally cause the displacements to more than double. It is inelastic in that after the fire the structure will be permanently, or plastically, deformed.

6.4.2 Fire modelling

In a fire resistance test the gas temperature is increased to follow a predefined time/temperature curve. This heating regime is very different from that occurring in real fires. The maximum temperature attained in a real fire and the rate at which temperatures increase depend on a number of factors relating to the fuel available, the geometric and thermal properties of the compartment and the availability of openings through which oxygen can be supplied to the fire. Techniques have been developed to mathematically describe a "real" fire. The analysis determines the rate at which heat is released from the available fuel. This is a function of the amount of ventilation available and the density and distribution of the fuel itself. Heat loss from the compartment via convection and radiation from the openings, and conduction through the other solid boundaries, must be calculated before the resulting atmospheric temperatures can be determined.

Some terms and concepts used in fire modelling are described below.

Cellulosic and hydrocarbon fires

There are the two forms of fire used in standard fire resistance tests. They are based on:

a) Cellulosic or timber fires
The Building Regulations relate to this type of fire when referring to periods of fire resistance.

Or

b) A hydrocarbon fire
Regulations governing the petrochemical industry will normally be based on this type of fire.

Time equivalent

The periods of fire resistance specified in regulations attempt to relate the damaging effect of a real fire to an equivalent period of exposure in a standard fire resistance test. Safety factors are introduced to account for building use and height. The severity of the fire depends upon several factors such as the fire load density, the size and shape of the ventilation openings, and the thermal characteristics of the enclosing compartment. Standards, such as EC1-2-2[14], give a mathematical expression for time equivalent. They can provide an overall guide to the likely damaging effect of the anticipated real fire. Although convenient, such formulae are only approximate and claims of time equivalence based on their use should be treated with care.

Time equivalence is very useful when comparing the performance of an element in a real fire with the known performance of the same element in a fire resistance test. It is useful for researchers and fire investigators to know that the real fire was approximately equivalent to so many minutes in a standard test.

Fire load

The *fire load* is the amount of combustibles available to burn. For normal buildings it would include furniture, paper and carpets, etc. On an offshore platform it might be the quantity of gas or oil available to burn.

In buildings the fire load is expressed in a number of ways. Traditionally, it was expressed in terms of the equivalent weight of timber (kg/m^2). It is now often expressed in terms of energy released (MJ/m^2). In the latter case, the reference area is normally the floor area but sometimes the total internal surface area of the compartment is used.

Ventilation or opening factor

All mathematical models of fires require the openings or air supply to be quantified. The *ventilation* relates the size of openings, such as windows and doors (their height as well as their area), to the size of a fire compartment or room.

Heat flux

The rate at which an element heats up depends, among other things, on the incident heat flux. This is the amount of heat, normally measured in kW/m^2, that an element receives in a fire. The heat flux is made up from radiation and convection. In fully developed fires the radiation is the dominant flux. For a fully developed fire in an office the heat flux will typically be 50 kW/m^2. In a severe hydrocarbon fire it could be as high as 250 kW/m^2. It is more commonly used in describing hydrocarbon fires than cellulosic or building fires.

Parametric fire

A *parametric fire* is a mathematical idealisation of a 'real' fire in a compartment. The gas increases to a maximum and then declines, as it would in a real fire. The fire temperature is a function of the ventilation factor, the fire load and the thermal properties of the wall linings.

CFD

Some advanced computer programs use a technique called computational fluid dynamics (CFD). CFD is a method of predicting the flow of gases. It can be used for predicting smoke movement and fire development. This is likely in turn to be used as a basis for a more refined approach to predicting the heating regime to which structural elements are exposed.

7 INHERENTLY FIRE RESISTANT FORMS OF STEEL CONSTRUCTION

There are many occasions when it is appropriate to use steel without applied fire protection. For example:

- It is often desirable to use an exposed steel frame to fulfill a design objective or obtain an architectural effect.
- It is often cost effective to design steel members in such a way that they are not fully exposed to fire and require no additional protection.
- It may be more reliable to use unprotected steel as an alternative to an applied fire protection system, because an applied system can be damaged or removed during the life of a building.
- Sometimes it is possible to argue that although fire protection would normally be required, there are special, low risk, circumstances that would logically justify its omission.

The use of unprotected steel can be justified in two ways. Firstly, it can often be shown that the required fire resistance can be achieved without applied protection and, secondly, it can sometimes be shown that there other ways of achieving the regulatory requirements without fire protection.

In this Section, both approaches are discussed, and some examples are given.

7.1 Methods of achieving fire resistance without applied fire protection

The SCI publication, *The design of steel framed buildings without applied fire protection*[15] describes the engineering aspects of the use of unprotected steel members in building frameworks to achieve up to 60 minutes fire resistance. Some examples of the use of unprotected steel, taken from the publication, are given below.

Open sided car parks

Totally unprotected steel will normally achieve 15 minutes fire resistance and can ideally be used in car parks; Approved Document B[4] states that in open sided car parks, less than 30 m high, 15 minutes fire resistance is all that is normally required. This allows the steel structure to be designed without any additional fire protection.

The term "open sided" means each car parking level is naturally ventilated by permanent openings having an aggregate area of at least 5% of the floor area at that level, with at least half the minimum area in opposing walls.

Further information may be obtained from Approved Document B, from a British Steel publication *Steel framed car parks*[16] and the above mentioned SCI publication[15].

Unprotected steel with up to 60 minutes fire resistance

Fully exposed I or H steel sections can only achieve 30 minutes fire resistance in certain limited cases where the loading is low or the section is very large. Their use is generally impractical.

Some types of steel beam or column may be used without applied fire protection and achieve up to 60 minutes fire resistance. In most cases the steel will be partially encased in concrete or masonry.

Unprotected beams

Examples of a number of types of beam are now given. In many cases the overall structural depth of the beam and floor slab is similar to that which can be achieved using reinforced concrete construction. In each case some indication is given of the range of spans and structural depths that are required in a typical office.

The use of the beams is described in Reference 15. In many cases a separate design guide has been published and a reference to those guides is made in this publication. Where there is no published design guide, the appropriate design code reference is given.

Shelf angle floor beam

Shelf angle floor beams have been used for many years to reduce construction depths (Figure 7.1). The structural depth is reduced by supporting the floor slab, normally constructed using precast concrete units, on angles positioned below the top of the beam. Applied fire protection is conventionally required, however by using slightly heavier angles (typically 125×75×12) and positioning the angles with the short leg pointing upwards and shielded from fire by the floor slab, 30 minutes fire resistance may be achieved economically.

Typical spans are in the range 5 to 9 m, with total structural depths in the range 300 to 550 mm.

See SCI Technical Report *Fire resistance of shelf angle floors beams to BS 5950: Part 8* [17] for further guidance.

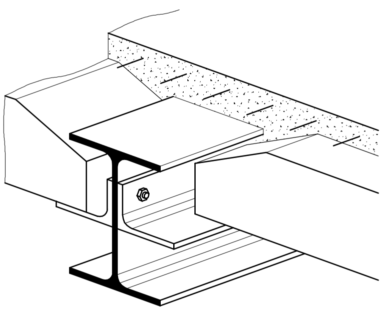


Figure 7.1 *Cut-away view of shelf angle floor beam*

The next three types of beam, together with the deep deck composite slab (see 7.1.1) form the *Slimdek®* system.

Fabricated Slimflor beam

A fabricated *Slimflor* beam is formed by welding a plate (normally 15 mm thick) to the bottom flange of a Universal Column. The plate extends beyond the steel flange and supports the floor slab. The floor slab may be constructed using precast concrete hollowcore units or a deep deck composite slab (Figure 7.2). Typical spans are in the range 6 to 9 m with total structural depths in the range 250 to 450 mm.

See SCI publications on *Slimflor* design[18][19] for further guidance.

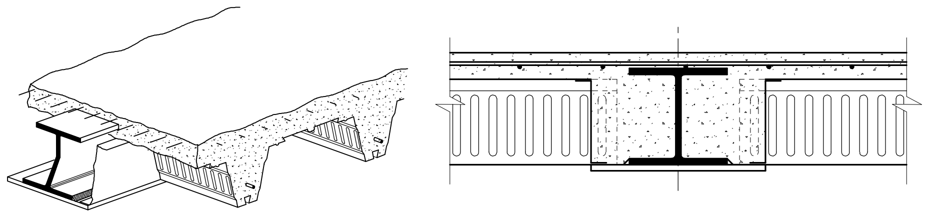


Figure 7.2 *Cut-away view of a Slimflor beam with deep decking*

Slimdek system using an Asymmetric Beam (ASB) section

The ASB is a specially rolled range of steel beams designed to be used with deep steel decking. The bottom flange is wider than the top flange and is used to support the floor slab (Figure 7.3). The section is unique in that it has been specially designed to achieve 60 minutes fire resistance without any applied protection. A special feature is the very thick web, which is generally thicker than the flanges. The thick web is specially important in fire when the bottom flange loses much of its strength. Typical spans are in the range 6 to 9 m, with total structural depths in the range 280 to 400 mm.

See SCI publication 175, *Design of Asymmetric Slimflor Beams using deep composite decking*[20] for further guidance.

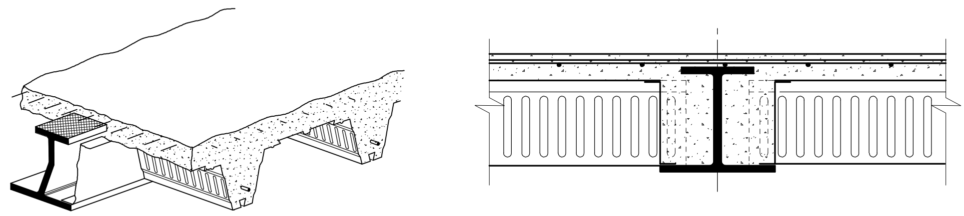


Figure 7.3 *Cut-away view of the Slimdek system using an ASB section*

Rectangular Hollow Section (RHS) Slimflor edge beam

These beams are formed by welding a plate to a RHS (Figure 7.4) and are specially designed to form edge beams. They are often used at the perimeter of buildings with ASB or fabricated *Slimflor* beams forming the internal beams. They are torsionally stiff which is particularly useful in the construction stage. Typical spans are in the range 5 to 7 m with total structural depths in the range 380 to 400 mm.

See SCI publication 169, *Design of RHS Slimflor edge beams*[21] for further guidance.

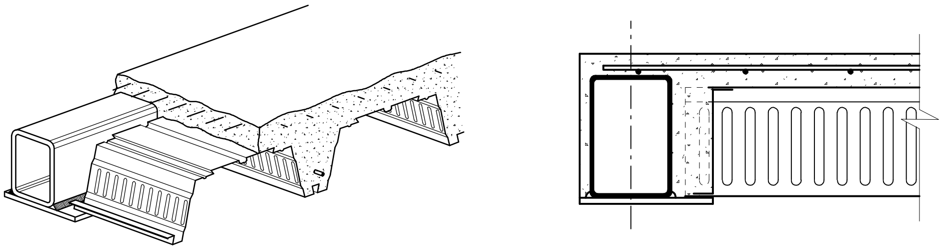


Figure 7.4 *Cut-away view of the RHS Slimflor edge beam*

Partially encased composite beam

In this type of beam the steel section is partially encased in concrete leaving the bottom flange exposed (Figure 7.5). These beams can achieve up to 120 minutes fire resistance and are commonly used in other European countries. In some cases, 60 minutes fire resistance may be achieved without longitudinal reinforcement.

Typical spans are in the range 6 to 12 m with total structural depths in the range 300 to 600 mm.

See EC4-1-2 [13] for further guidance.

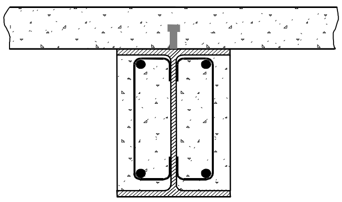


Figure 7.5 *Partially encased beam*

Unprotected columns

In many situations a rectangular column is required so the need to use a column without applied protection is not an important consideration. However, there are a number of ways of achieving fire resistance without applied fire protection, some of which are illustrated in Figures 7.6 to 7.8. In all cases the fire resistant column will be very robust and is suitable for heavily trafficked areas.

The smallest column that can be used is approximately 200 mm square and could be used for normal office applications. The maximum practical size is about 450 mm and this would be suitable for very tall buildings or buildings with large column free areas.

Blocked-in column

Placing concrete blocks between the flanges of a Universal Column (Figure 7.6) can increase the fire resistance to 30 minutes for almost all Universal Column sections. The exposed flanges may have a decorative finish. This is a low cost solution that has already been used in schools.

See BRE Digest 137 [22] for further guidance.

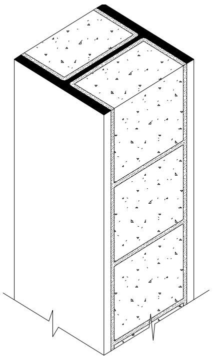


Figure 7.6 *Typical blocked-in column*

Web-infilled column

By filling between the flanges of a universal Column with unreinforced concrete (Figure 7.7), 60 minutes fire resistance can be achieved. The concrete is contained between web stiffeners and held in place with nominal shear connectors, but it does not extend to the connection area. This area must be shielded by the floor slab or fire protected at the same time as the incoming beams.

See SCI Technical Report *The fire resistance of web-infilled steel columns*[23] for further guidance.

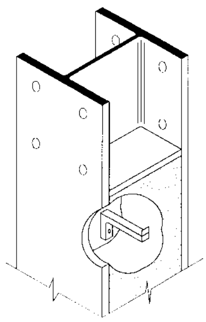


Figure 7.7 *Web-infilled column*

Partially encased column

By filling between the flanges of a Universal Column with reinforced concrete (Figure 7.8), 120 minutes fire resistance can be achieved. The concrete and reinforcement must be continuous through the connection area, and care must be taken in detailing this system. It is commonly used in continental Europe, where the costs of applying conventional fire protection are generally high.

See EC4-1-2 [13] for further guidance.

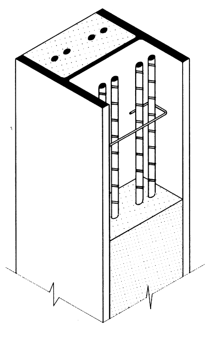


Figure 7.8 *Partially encased column*

Concrete filled structural hollow sections

By filling a hollow section with concrete, up to 120 minutes fire resistance can be achieved. For 60 minutes fire resistance the concrete may normally be unreinforced. Concrete filling is invisible and allows the hollow section to be exposed. It is particularly useful when fire resistance is required for external columns or when making a feature of a column.

See SCI publication[15], British Steel publication[24] and EC4-1-2[13] for further guidance.

7.1.1 Unprotected composite floor systems

The use of unprotected composite floors is very common in steel framed buildings. They are constructed using a profiled steel deck that supports a lightly reinforced concrete topping. For almost all applications the profiled steel deck may be left unprotected (see *The fire resistance of composite floors with steel decking*[25]). During a fire the steel deck is largely sacrificial and the reinforcement carries the tensile loads.

Two types of composite floor are used. For many years comparatively thin slabs have been used in most multi-storey steel framed buildings. These slabs are in the range 110 to 150 mm deep and use steel decking about 60 mm deep. They can span up to 3.6 m. More recently, a deeper floor slab has been introduced. This is commonly used in slim floor construction. It comprises a 225 mm deep ribbed steel deck with a concrete topping. These slabs can span up to 7.5 m. Floor slabs with deep decking are typically in the range 285 to 350 mm deep.

7.1.2 Special requirements for protected composite beams

When a conventional, downstand, composite beam is constructed using a profiled steel deck (Figure 7.9), a series of voids is created between the deck and the top flange of the beam. It is not always necessary to fill these voids.

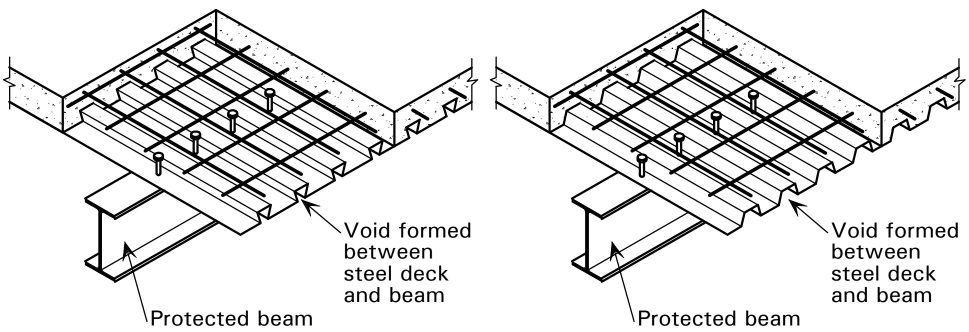


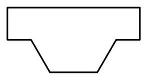
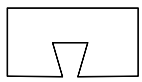
Figure 7.9 *Composite beams; dovetail decking and open trapezoidal*

With open trapezoidal steel decks this void is comparatively large and could be 180 mm wide and 60 mm high. With a “closed dovetail” deck the void is much smaller with an opening of between 12 and 15 mm. In the case of the open trapezoidal deck the fire resistance of the composite beam might be reduced because of the additional heat entering the steel beam through the top surface of the flange. Recommendations for when voids may be left unfilled are given in Table 7.1. This table should be used in conjunction with the thicknesses of fire protection specified in the ‘Yellow Book’ *Fire protection for structural steel in* *buildings*[26]. When using intumescent coatings, "filling the voids" may be achieved by applying the coating to the inside of the void. The void need not be "filled" and the exact thickness of coating is not important.

For decks running parallel to beams, no special recommendations are made for spray applied materials but, for board protection, the boards should be taken past the edge of the flange to abut the underside of the deck.

Any voids above beams that form part of a compartment wall must be effectively fire stopped to contain hot gases and smoke. A failure to do this would be considered as a breach of the *integrity* of the wall and could lead to fire spread. In cases where the voids are filled, it is not necessary to use the same material to fill the voids as was used to protect the beam. Any noncombustible material may be used.

Table 7.1 *Recommendations for unfilled voids in composite and non-composite beams*

Trapezoidal deck				
Beam type	Fire protection on beam	Fire resistance (minutes)		
		Up to 60	90	Over 90
Composite	Insulating sprays and boards (assessed at 550°C)	No increase in thickness	Increase thickness by 10 % or assess thickness using A/V increased by 15%*	Fill voids
	Intumescent coatings (assessed at 620°C)	Increase thickness by 20% or assess thickness using A/V increased by 30%*	Increase thickness by 30% or assess thickness using A/V increased by 50%*	Fill voids
Non-composite	All types	Fill voids		
Dovetail deck				
Beam type	Fire protection on beam	Up to 60	90	Over 90
Any	All types	Voids may be left unfilled for all periods of fire resistance		

* *The least onerous option may be used*
This Table should be used in conjunction with the thicknesses of fire protection specified in the 'Yellow Book' [26]

7.2 External unprotected steel

There are situations where main structural steel elements that are external to the building envelope can be unprotected. Calculation methods have been developed that demonstrate that, in some circumstances, steel external to the building envelope will not reach a temperature at which its function will be significantly impaired. Several buildings have been designed using this approach.

Such calculations only justify the use of fully unprotected members when:

1) the fire load in the building is extremely low or
2) the member is located at a position beyond the anticipated flame front emerging from the building
3) the member is shielded by fire resisting construction, e.g. is located at a position that is offset from the edge of the window, and the external wall is of a fire resisting type.

The method imposes some restrictions on where the steel may be situated in relation to windows. Columns should be ideally placed in a shielded area, for example between windows. A steel column placed directly in front of a window may have to be at least 2 m away from the window to allow the protection to be omitted.

The calculation does not justify a value of the fire resistance in the sense that the fire resistance test does. It is one of the so called "fire engineering" methods that are often acceptable to the regulatory authorities.

Further information may be obtained from an SCI publication *Fire safety of bare external structural steel*[27] and the Eurocodes, EC3-1-2 [12] and EC1-2-2 [14].

7.3 Low risk buildings

In some circumstances the requirement to have fire resistance may be unnecessarily onerous or illogical. In these cases it is sometimes possible to put forward arguments justifying the use of unprotected steel

7.3.1 Low risk - or extremely low fire load density

There are situations where the fire load density in the building would not be expected to be high. Furthermore, it would be expected that management systems would be available to control this fire load density during the life of the building. Consequently, any fire occurring in such a location would have restricted severity, and would not be of sufficient magnitude to initiate structural failure.

Examples of such situations are highlighted below:

Steel members exposed within emergency escape staircase enclosures

In order to perform their intended functions in a fire emergency, staircases should be 'sterile', i.e. extremely low fire load. Furthermore, they should be enclosed using fire resisting construction. Hence, a fire of sufficient severity to cause failure of structural members is unlikely.

Steel members in open concourses such as sports stadia

Open concourses (Figure 7.10) in certain buildings such as sports stadia are used as part of the escape route from the seating terrace and, as such, they should be areas of extremely low risk. Associated areas of risk should be separated from the concourses by fire resisting construction, e.g. roller shutters to the fronts of kiosks, fire resisting walls around plant rooms and stores, etc. Hence, a fire of sufficient severity to cause failure of structural members is unlikely. See British Steel publication, *Fire engineering sports stands*[28], for further information.

Figure 7.10 *Unprotected steel beams supporting a grandstand*

Steel structures in industrial plant and factories

Steel frameworks are frequently used within industrial buildings to support equipment and plant. Frequently the structures will have several levels, and the floors created provide access to operators, visitors, and maintenance personnel within the main building envelope, i.e. the building incorporates floors projecting into the main space.

Clearly a fire in such buildings could impose a threat to the safety of personnel, but the main risk would be created by smoke movement or heat and direct flame impingement, which would arise due to the open nature of the structure, rather than collapse of the floors due to excessive temperature rise and loss of loadbearing capacity.

In these situations the positioning of escape routes, particularly those enclosed in fire resisting construction, along with the positions of final exits, needs careful consideration. There may be a need to provide early warning systems or automatic extinguishing devices.

Iit is frequently recognised, however that fire protection of the steel structure is not required unless collapse of the members supporting the plant access floors causes failure of some other main component that is required to exhibit fire resistance, e.g. a compartment wall/compartment floor, etc.

7.4 Bracing

The cost of fire protecting bracing members is often high because the members are comparatively light and therefore have high values of section factor (A/V). However, for the reasons now discussed, it is often unnecessary to fire protect them.

Bracing within a structure has two roles. It resists lateral wind forces but, especially for tall buildings, it also contributes to the overall stability of the structure. In fire, it is important to recognise these two roles. In the case of wind some guidance is offered by the structural design codes. BS5950-8 recognises that it is highly unlikely that a fire will occur at the same time as the building is subject to the maximum design wind load, and consequently recommends that for buildings over 8 m in height, only one-third of the design wind load need be considered; for buildings less than 8 m in height, wind loading may be ignored. None of the design standards give guidance on overall frame stability, but it is self evident that for tall buildings the designer must consider it. It therefore follows that there may be some justification for reducing the degree to which bracing members may need to be protected in some cases.

Based on a consideration of the risks and consequences recommendations are presented in Table 7.2 for assessing the necessary protection to bracing. In any case, consideration should be given to the following features:

a. Shielding bracing from fire by installing it in shafts or within walls. The shielding will often provide the necessary fire protection.
b. Masonry walls, although often designed as non-loadbearing, may provide appreciable shear resistance in fire.
c. Bracing systems are often duplicated and loss of one system may be acceptable.
d. In single storey buildings an unprotected bracing system can still contribute to the stability of the building even after exposure to fire.
e. In many steel frames, connections are designed as "pinned". These connections actually have a reasonable inherent stiffness and will add to building stability.
f. Bracing forming part of a roof structure only would not normally be required to have fire resistance.

Recommendations for fire protection to bracing members are given in Table 7.2.

Table 7.2 *Assessment of fire protection requirements for bracing*

Building size	Degree of fire protection to bracing system
Single storey Not more than 8 m to eaves	None
Single storey More than 8 m to eaves	Generally none.
Two storey	Generally none. Walls and frame stiffness will contribute considerably to stability.
Other multi-storey	Fully protected to achieve full standard. However the selection of thickness should follow the guidance in BS 5950-8, using the load factor for wind of 0.33.

Good detailing can reduce the extent of the fire protection required. For instance, light tubular members are often selected because they are structurally efficient and architecturally pleasing. These sections are often fire protected with a thin film intumescent coating, but high thicknesses of coating are required, which can be costly. Alternative approaches, which may involve changing the section size, can therefore be more cost effective.

8 PROTECTING STEEL

Various generic and proprietary fire protection systems are used to protect structural steelwork. Manufacturers and/or specialist contractors offer comprehensive information on characteristics of materials, test results, advice about suitability for particular applications and installation procedures. A list of manufacturers and installers is available from the trade association, The Association for Specialist Fire Protection (ASFP)[29].

The thickness of fire protection material required to satisfy a specific fire resistance period can be selected from authoritative material performance data sheets, published in *Fire protection for structural steel in buildings*[26]. This publication, which is referenced in Appendix A of Approved Document B, is commonly referred to as the "Yellow Book".

8.1 The use of section factors

As discussed in Section 6, the section factor (A/V or Hp/A) is a measure of the thermal response of a steel member and, along with its shape, orientation (beam or column, three or four sided protection) and the fire resistance required, is used to determine the necessary protection thickness (see Figure 8.1).

In calculating the section factor, the full volume of a metre length (V) of the member is used. The heated surface area per metre length (A) is determined both by the extent of the member's exposure to the fire and by the nature of the fire protection material(s) used. For coating materials applied directly to the surface of the steel member (often referred to as 'profile' protection), the value is taken as the area of this exposed steel perimeter per metre length. For 'box' or 'encasement' systems the heated perimeter is defined as that of the area of smallest enclosing rectangle per metre length, except in the case of circular hollow sections, where again the area of the exposed steel perimeter per metre length is used.

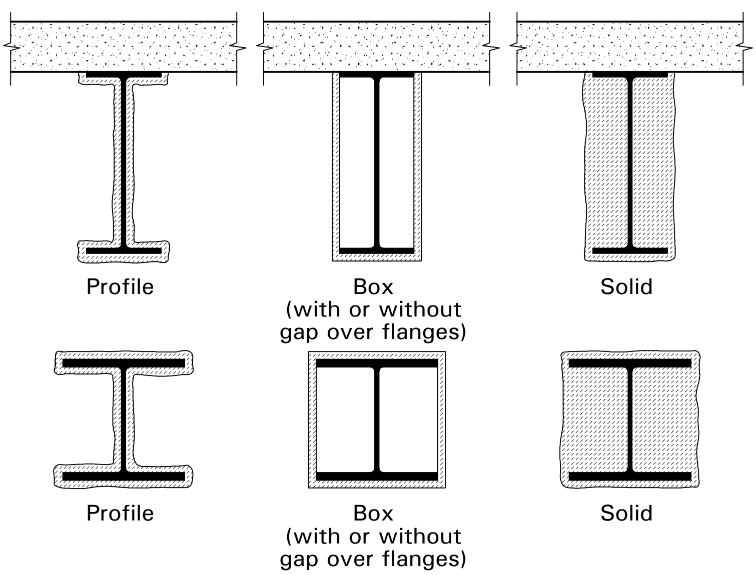


Figure 8.1 *Techniques for three and four sided protection*

Surfaces built into or adjoining fire resistant construction, which itself can be expected to remain in position for the required fire resistance period, for example a masonry wall or concrete floor, are excluded from the heated surface area calculation.

Further guidance and tables of section factor values for all common steel sections are presented in the Yellow Book[26].

8.2 Generic fire protection materials

Guidance on the fire performance and use of generic materials such as concrete, brickwork, blockwork, and certain types of plasterboard or gypsum plaster is presented in the Building Research Establishment publication, *Guidelines for the construction of fire resisting structural elements*[30] and in Appendix 2 of the "Yellow Book".

8.3 Proprietary fire protection materials

Many forms of proprietary structural fire protection materials are available from UK and overseas manufacturers. Such materials should have been fire tested to the requirements of BS 476-20 and BS 476-21. Guidance on suitable fire test programmes and appraisal procedures for different types of material are described in the Yellow Book. These normally involve a number of full scale loaded I-section beam and column fire tests supported by temperature data derived from unloaded one metre long specimens of differing section factors, orientations and fire protection thicknesses.

For some materials, rules are available for the transfer of I-section test data to tubular sections, although for intumescent coatings full testing programmes involving loaded tests on circular hollow sections and/or square hollow sections are required before specifications can be developed. The Yellow Book lists guidance on defining protection thicknesses for use of castellated sections, lattice members and lightweight wind bracing.

The types of fire protection systems available can be classified into three main product groups, i.e. sprays, boards and intumescent coatings.

A summary of the main factors affecting product selection in each of these groups is given in Table 8.1.

Table 8.1 *Characteristics of fire protection systems*

	Spayed cementitious or gypsum based coatings	Boards and blankets	Intumescent coatings
Relative cost	Low to medium	Low to high	Medium to high
Wet or dry	Wet	Mainly dry	Wet, thick film may be preformed
Cleanliness of application	Messy with protection required to adjacent surfaces	Relatively clean	Protection required to adjacent surfaces
Tools required for application	Specialist equipment required	Simple application tools	Application by painting equipment for thin films. Thick film requires specialist equipment
Internal/ external use	Internal and external	Internal use. Additional protection required for external use	Internal with some external systems
Preparation	No primer required for internal use, but steel surfaces to be clean and compatible	Contact surfaces for noggins, etc. to be clean and compatible	Compatible primer required on cleaned steel surfaces
Robustness	Relatively brittle and may be vulnerable to mechanical damage. Some coatings unsuitable for use behind plenum ceilings or in clean areas	Some rigid boards relatively brittle and may be vulnerable to mechanical damage. Batts and blankets may require additional covering	Similar to that of paint systems. Thick film very tough and durable.
Finish	Textured finish	Variable: boards mainly smooth with joints visible unless a wet finishing coat is applied; batts/blankets are textured with fixings visible	Smooth or slightly textured surface. A coloured decorative finish can be applied
Mechanical retention	Necessary where no re-entrant angles available or thickness is high	Normally requires some mechanical retention	Mesh retention required at higher thicknesses
Thickness range	10 to 75 mm	Multiple layers used. Boards 6 to 100 mm; batts/blankets 12 to 76 mm	Thin film 0.3 to 6.5 mm Thick film 2.0 to 32 mm
Maximum fire resistance	240 mins	240 mins	Thin film 120 mins Thick film 240 mins
Class O surface	Yes	Usually	Possibly

Sprayed cementitious or gypsum based coatings

Cement or gypsum based materials containing mineral fibre, expanded vermiculite, expanded perlite and/or other lightweight aggregates or fillers, are generally the least expensive forms of fire protection.

These coatings can provide up to 240 minutes fire resistance and usually are defined as being non-combustible in accordance with BS 476-4 [31].

While most coatings are applied *in situ* (Figure 8.2), some can be used externally and may be applied to the steelwork before erection if suitable care is taken during subsequent handling.

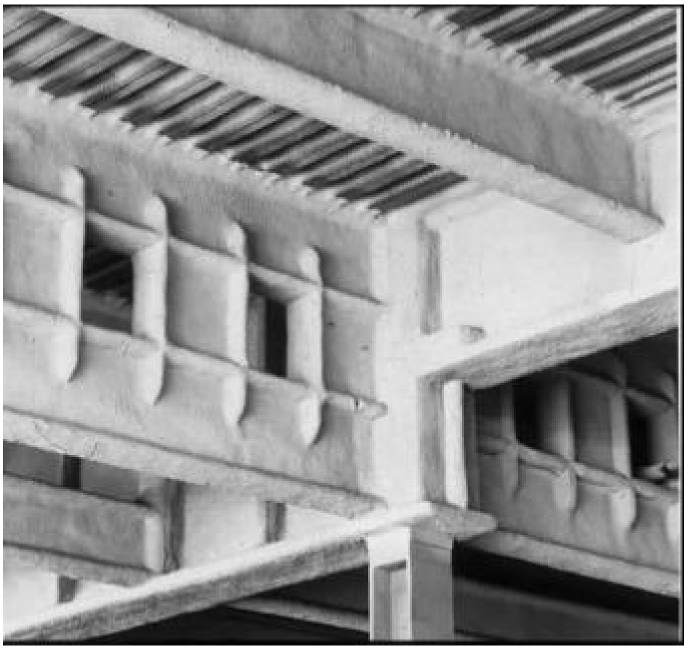


Figure 8.2 *Sprayed protection applied to complex beam detail*

Mineral fibre based materials are delivered dry to the spray head, where they are mixed with water and compressed air. Vermiculite or perlite sprays are usually premixed with water before being pumped to the spray head.

Steel surfaces should normally be degreased, with loose mill scale and rust removed. Any primer applied to the steel should be compatible with the protection material.

The coatings appear textured and are often susceptible to mechanical damage. Some may require additional surface protection to prevent air erosion, when used, for example, behind plenum ceilings, or to meet cleanliness requirements. When mechanical retention is required, steel chicken wire, weld mesh or expanded metal lath (EML) is mechanically attached to the steel surface by capacity discharge welded pins. EML is normally used to provide boxed protection to I-sections. Guidance on the use of sprayed cementitious or gypsum based coatings, including thickness measurement, is presented in BS 8202-1[32].

These coatings can provide up to 240 minutes fire resistance and usually are defined as being non-combustible in accordance with BS 476-4[31].

Boards and blankets

Blankets, semi-rigid and rigid boards are used as dry forms of fire protection installed *in situ* as either profile or boxed protection (Figures 8.3, 8.4, 8.5). Base materials include ceramic fibres, calcium silicate, rock fibre, gypsum and vermiculite. Most are only suitable for interior use or limited external exposure during construction. However a few board systems can be subjected to full external exposure.

Up to 240 minutes fire resistance can be provided and many materials are defined as being non-combustible and therefore meet the requirements of Class O.

Calcium silicate and vermiculite boards are hard and smooth in appearance but also vulnerable to impact damage. Mineral fibre boards are softer to the touch while the blanket materials are fully flexible. Potential problems associated with 'loose' fibres in the latter products may be minimised by an outer sheathing of aluminium foil or similar, and by the use of taped joints. Visual appearance will vary with the system chosen.

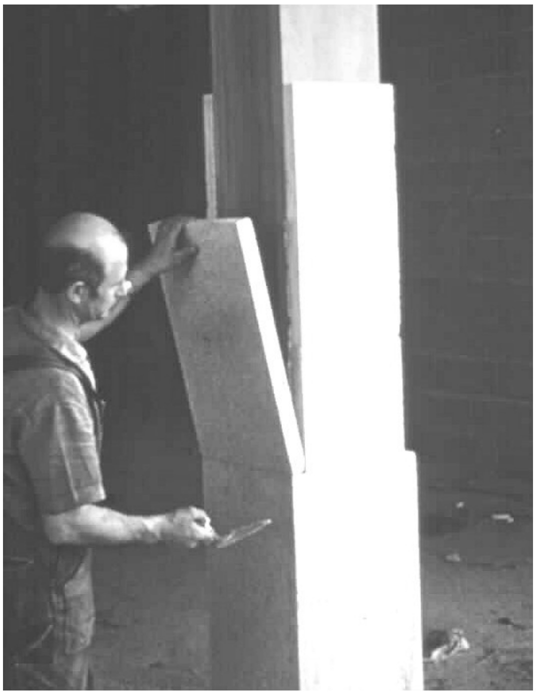


Figure 8.3 *Board fire protection applied to a column*

Flexible blanket materials are fixed to steel with steel weld pins and non-return washers, wire ties and chicken wire. Rigid boards may be retained by a variety of methods such as noggins for I-section steel and a combination of steel pins or nails, special spiral 'screws' and sometimes a bonding agent. When noggins are friction fixed, contact surfaces may require to be degreased and to have loose mill scale, loose rust and existing paint finishes removed. Lightweight galvanised mild steel internal framing members are used with the plasterboard and calcium silicate board encasement systems.

Longer fire resistance periods often require the use of multiple layers of boards. In this case the joints in the layers are staggered. Where only a single layer of board is required, joints are normally backed by noggins or a fillet of the same board material.

Figure 8.4 *Foil covered fibre board applied to beams*

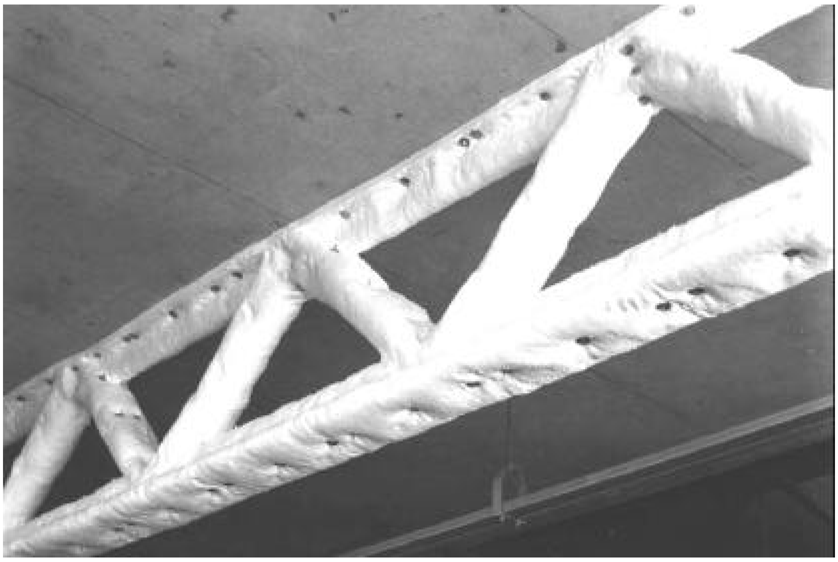


Figure 8.5 *Pin-fixed blanket applied to truss*

Intumescent coatings

Intumescent coating systems are classified as either 'thin film', which account for the vast majority of systems used in general construction, or 'thick film', sometimes referred to as 'mastics'. The materials are 'reactive', swelling to many times their original thickness when exposed to fire, with the resultant char insulating the underlying steel substrate (Figure 8.6).

Thin film intumescent coating systems are similar in appearance to conventional paints and are applied either by airless spray, brush or roller. They may be solvent based, or water borne, and usually include a compatible primer(s), the intumescent coat(s) and a top coat or sealer coat (often available in a wide range of colours). Steel substrates are normally required to be blast cleaned to a minimum standard of SA2½[33].

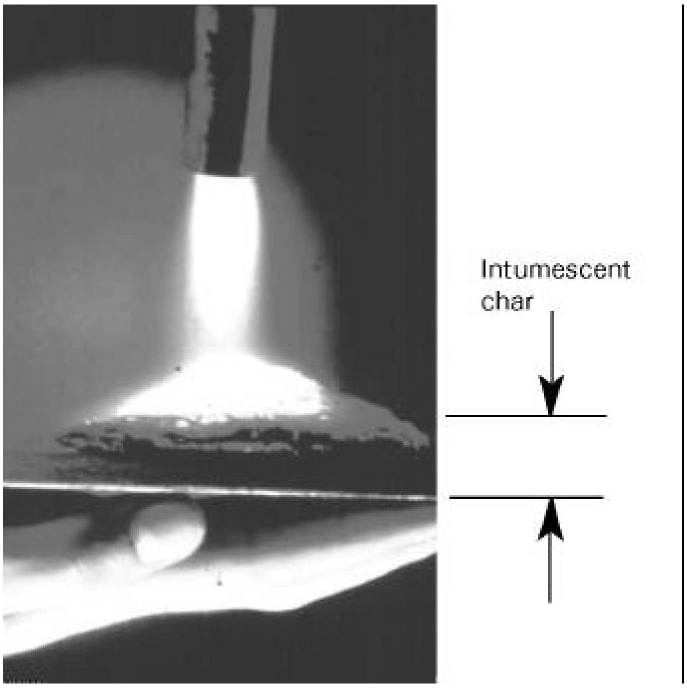


Figure 8.6 *Demonstration of intumescence*

Most coatings are applied *in situ* and are suitable for interior or limited exterior exposure during construction. However, a few coatings may be used externally and/or applied to steelwork off site, if appropriate care is taken during handling and erection.

The use of off-site application for intumescent coatings is increasing. Off-site application has the advantage of removing fire protection from what is sometimes the critical path in the construction programme. Further guidance on the off-site application of intumescent coatings is given in the SCI publication, *Structural fire design: Off-site applied thin film intumescent coatings*[34].

General guidance on the selection and use of intumescent coatings can be found in BS 8202-2[35]. Guidance on the measurement of coating thickness can be found in an ASFP document *On site measurement of intumescent coatings*[36].

When applied by spray (Figure 8.7) or roller, the coatings appear smooth or slightly rippled. When applied by brush, some texture can be expected. The coating systems offer reasonable resistance to mechanical damage; any damage that does occur can be repaired using normal application techniques.

Thin film intumescent coatings can provide up to 120 minutes fire resistance.

Specifiers should be aware that the required coating thickness for hollow sections may be greater than for a comparable I section, with a consequential increase in cost.

Figure 8.7 *Thin film intumescent coating being applied*

Thick film intumescent coatings, developed primarily for the heavy industrial, petrochemical and offshore oil and gas industries, often comprise two pack epoxy coatings that cure to provide very tough and durable systems suitable for both internal and external use. Surface preparation and primer requirements are similar to those for the thin film systems, and sealer coats may be required in external situations or for decoration.

Application is by airless spray, by special heated plural pump spray equipment, by trowel, or by casting, either into preformed mouldings or directly onto the steel sections. The latter technique is particularly useful for off-site applications prior to the erection of the steelwork, and very smooth finishes can be achieved. Otherwise an 'orange peel' finish can be expected from spray application.

Whilst these materials are relatively expensive, their intrinsic toughness and durability make them most suitable for situations where impact or abrasion can be expected, where future access for maintenance will prove difficult, for external application and in heritage applications, where the appearance of the building must be maintained.

Thick film intumescent coatings can provide up to 240 minutes fire resistance.

8.4 Avoiding selection pitfalls

The following check list may be helpful in avoiding some common pitfalls:

1. Ensure that the system or material chosen is compatible with the paint systems, the steel surface preparation and the overcoating system.
2. Ensure that the selected material is capable of providing *all* the steelwork with the required fire resistance and that it can be applied within the specified construction programme.

3. Ensure that the thickness of protection can be accommodated, particularly with regard to services above suspended ceilings, where secondary enclosures are envisaged, and where services pass through holes in beams.
4. Specify the finish required and ensure that the material and the application method selected can provide that finish.
5. Select a material with mechanical and physical properties suited to the intended use and long term environment.
6. Cost comparisons should consider “total costs” including the effect on the building programme, the need for decoration, the need for maintenance, etc.

8.5 How to specify

The following minimum information is required by the applicator/installer of a fire protection system:

1. General arrangement drawings showing the steelwork to be protected and the required fire resistance.
2. A schedule of the steel sizes including weights.
3. Detailed drawings showing the relationship of the steelwork to be protected to adjacent fire resistant construction, to enable section factors to be calculated.
4. Details of the general type of protection system(s) to be used and, where appropriate, the required finish to be achieved.
5. Information on matters concerning access, power supply, water supply, etc.
6. Details of areas of the structure that must be shielded from overspray or otherwise protected from damage or contamination.
7. Details of any special programming requirements.

8.6 Certification schemes

Product certification schemes

Some products carry third party performance certification through their registration with an independent product certification body such as Certifire, a joint Warrington Fire Research/ British Standards Institution body, or with LPCB, which is run by the Loss Prevention Council. In addition to the appraisal of fire performance, such schemes require the manufacturer to operate a quality management system to the requirements of BS EN ISO 9002 [37].

Fire protection system applicators and installers

The installer or applicator must be both skillful in handling the material and have a knowledge of the underlying principles of fire protection.

A need for formal training and third party appraisal of the fire protection contractors’ management systems has led to the formation of the FIRAS accreditation scheme for structural fire protection contractors, introduced by Warrington Fire Research with the active help and support of industry through the ASFP.

In addition to operator and supervisor training, the scheme involves random management audits and site inspection both during and after application or installation. Support is available for the contractors to resolve contentious technical issues. The fire protection products used must be selected from the Yellow Book or alternatively full test details must be submitted to FIRAS, thereby ensuring that they have been properly tested and appraised.

9 FIRE SAFETY ENGINEERING

The General Introduction to Approved Document B advises that *a fire engineering approach that takes into account the total fire safety package can provide an alternative approach to fire safety*.

Approved Document B and BS DD 240, *Fire safety engineering in buildings*[38] offer some guidance as to what is meant by a total fire safety package. This does not mean that a total fire safety package is the only form of fire engineering. It does however represent the other extreme of a range of potential technical solutions that starts with fully following the guidance in the Approved Document.

The test of acceptability always has to be whether a solution is adequately safe, which is often interpreted as meaning whether it satisfies the functional requirements of the Building Regulations. Even if the guidance in the Approved Document is strictly followed it is still sensible to consider whether a solution is adequately safe.

Any fire safety engineering solution to a problem needs to consider and take into account the context in which it is used.

Fire engineering may be used as a means of 'fine tuning' some aspects of the overall fire safety problem. Enhancements in certain measures may allow a change in another feature of the design, i.e. they 'Provide a compensatory measure'. For example, the installation of a fire detection and alarm system, and/or a smoke control system, may permit an increase in travel distance, the installation of a sprinkler system should permit a reduction in fire resistance period for elements of structure. There are many examples of fire engineering factors that can be cited to justify an appropriate change in the design while maintaining acceptable standards of safety.

Fire engineering enables the results of research and development to be applied to practical problems without having to go through the lengthy process of being formally recognised in an Approved Document. Statutory Authorities are not however obliged to accept fire engineering solutions, but will find them difficult to reject if a few simple principles are followed in their presentation. A fire engineering solution should:

- state the context in which it is used
- present the basis of the approach, including references to any published information or research
- develop in a logical and structured way the argument offered
- provide the source(s) of any equations used
- summarise the argument in a conclusion
- append any supporting documentation or calculations.

Transparency is everything when presenting a fire safety engineering solution. If the argument is presented in an incomplete and evasive manner, it is unlikely to be accepted. Not everything will be calculable, and any fire safety engineering solution inevitably has to include an element of judgement.

Part of the fire safety engineering approach may be an evaluation of hazards and risks. These terms have different meanings and are often confused.

Hazard — This is a feature of the design or operation of the building that could cause a threat to its occupants or cause damage to the property or its contents.

Risk — This is a probability based term, and is related to the frequency of occurrence of a hazard and its consequences to the occupants, the property, and its contents.

There is a trend in European legislation towards using a risk-based approach to safety issues, and it is inevitable that this will have a consequential effect on our approach to fire safety. It is likely to influence the way in which fire safety engineering solutions should be presented.

Considerable research has been carried out in recent years modelling the performance of structures and components under load and evaluating these models against large scale fire tests, particularly at the BRE, Cardington (Figure 9.1). Detailed analysis of the results of large scale compartment fire tests and fire tests in a full scale eight-storey steel framed building are likely to have a profound influence on our approach to fire safety design. New models may provide tools to define more effectively levels of fire performance for the whole assembly of structural components, in relation to the anticipated use of a building or specific parts of a building. When used in connection with risk and hazard analyses, these tools should offer a more economic approach to the safe design of both individual structural members and whole structural frameworks under fire conditions.

Figure 9.1 *Photograph of the Cardington eight-storey fire test*

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