Corus Construction & Industrial

Fire design of steel structures

Engineered for safety and economy

In the heat of the moment

The idea of precautions against the effects of fire in buildings is not new. Some of the principles have been in existence for many years and may often been taken for granted. For example, the Great Fire of London led to the identification of the importance of adequate separation between neighbouring buildings to prevent fire spread, a concept which is universally accepted since that time.

As knowledge increased over the years, so did the sophistication of the precautions against fire. The current regulations for example, which were founded upon the Fire Grading Report of 1947, recognise a relationship between fire loading and the level of structural fire resistance required in a building. In 1985, the regulations moved away from fixed prescriptive requirements to a functional approach which relied on statements of broad principle. For example the requirement for structural stability required only that the "building shall remain stable for a reasonable period." For England & Wales, the Government provided guidance on one way that this and other functional requirements could be met by publishing Approved Document B (Ref 1); the requirements in this document are prescriptive but they recognise that alternative approaches can also be used. Indeed, it states that:

"Fire safety engineering can provide an alternative approach to fire safety. It may be the only practical way to achieve a satisfactory standard of fire safety in some large and complex buildings and buildings containing different uses."

In the England & Wales context, fire safety engineering can be defined as a process that adopts a rational scientific approach which ensures that fire resistance/protection is provided where it is needed rather than accepting universal provisions which may over or under estimate the level of risk. It is a means by which the functional obligations of the Building Regulations can be met by means other than the prescriptive requirement

contained in sources such as Approved Document B. The Approved Document outlines the general principles of the elements of a fire safety engineering approach which are applicable to structural fire engineering.

The limitations of fire safety engineering should also be understood; it is not a panacea. CIBSE Guide E: Fire Engineering (Ref 2), states that:

"Where a building design is straightforward and conventional, then it would normally be expected that designers would apply the prescriptive approach of Approved Document B and the associated British Standards with little or no need to vary the detailed recommendations."

Nevertheless, as can be seen from the case studies in this document, some building forms which meet this definition can offer opportunities for the structural fire engineer to optimise the value of fire precautions.

There is no single right or wrong way of designing for fire safety. The engineer uses an armoury of regulations, codes and standards as well as guidance provided through many of the engineering organisations and institutions (Figure 1). In recent years a global investment in research and development by the steel construction industry has resulted in major advances in understanding the behaviour of fire and steel framed buildings. This understanding enables Architects & Engineers to use fire safety engineering to design against the effect of fire in increasingly cost effective and innovative ways and to develop optimum solutions for fire safety. This publication explains how it works and illustrates it with examples of good practice.

General approaches

In broad terms, structural fire safety engineering design requires an understanding of some or all of a number of phenomena: fire behaviour, thermal response of structural members, structural response and behaviour of suppression systems (Figure 2). A framework for fire engineering analysis is contained in BS7974 (see page 13).

Figure 1

Fire safety solutions are achieved using a variety of engineering tools

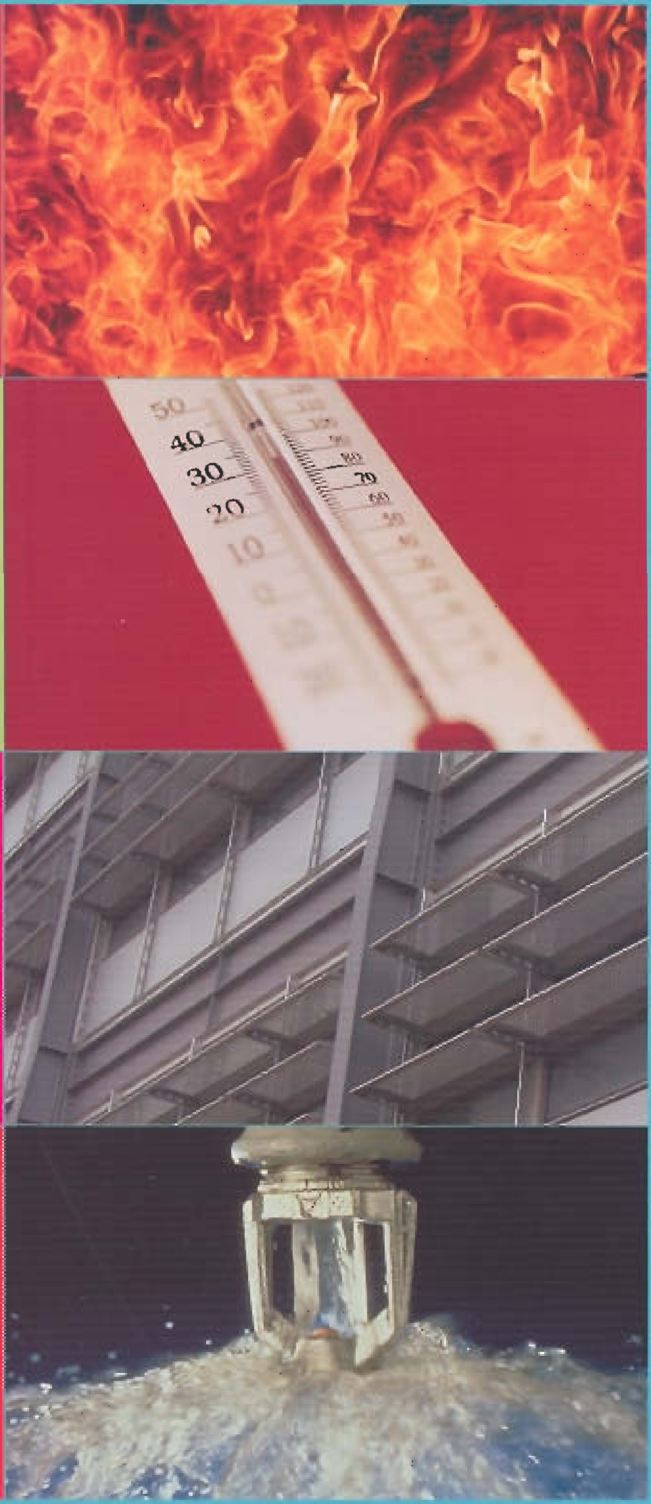
Fire Safety Engineering BS 7974

Building Regulations
- England & Wales, Scotland, N Ireland

British Standards Codes of Practice
- BS5588 (BS9999), Eurocodes, BS5950: Part 8

Design Guides
- CIBSE, LPC Guide
- Safety of sports grounds
- Steel Construction Institute Fire Publications

Figure 2



Fire behaviour

- Standard furnace test
- Natural fires
  - Initiation and growth
  - Fire load density
  - Ventilation
  - Building materials
  - Geometry

Thermal response of the structural members

- Heat transfer-radiation, convection
- Section type and geometrical properties
- Exposure conditions
- Protection

Structural response

- Elevated temperature strength
- Loading conditions
- Expansion
- Restraint
- Continuity

Effect of suppression systems

Fire behaviour

Traditional methods of determining the fire performance of elements of building construction involve conducting a fire resistance test. For structural elements, these are carried out on beams and columns at recognised test centres. The furnace heating conditions are specified in accordance with the harmonised European standard BS EN 1363: Part 1 (Ref 3). The most common of these for testing of components in buildings is referred to as the cellulosic fire curve (Figure 3).

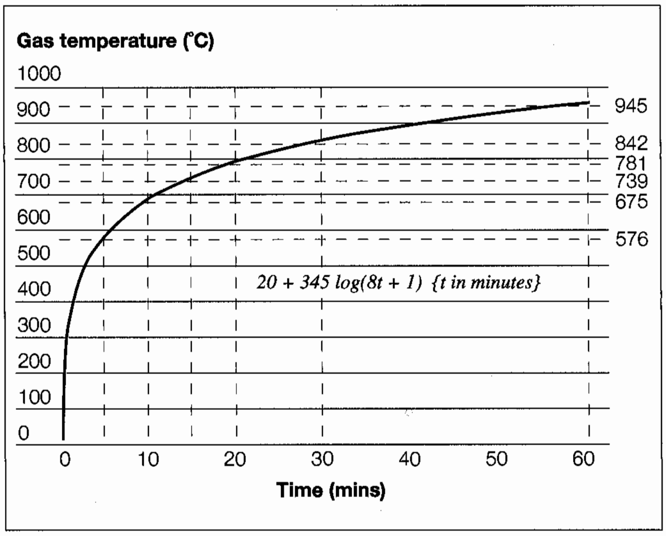


Figure 3

Increasing knowledge of natural fire behaviour is now beginning to have an impact on the manner in which structural performance is assessed. Where a natural fire is likely to cause significant threat to structural stability, it is normally necessary for the full compartment contents to be engulfed by the flames. This condition is called flashover.

Flashover occurs when sustained flaming from combustibles reach the ceiling and the temperature of the hot gas layer is between 550°C and 600°C. The rate of heat release will then increase rapidly until it reaches a maximum value for the enclosure. For simplified design, it may be assumed that when flashover occurs, the rate of heat release instantaneously increases to the maximum value set by the available air. This is the second of three stages in a natural fire (Figure 4), the first and third stage being the growth and decay phases respectively.

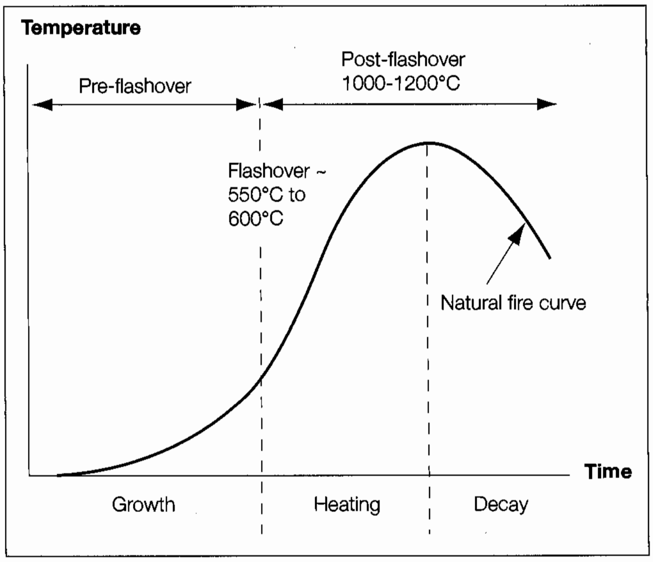


Figure 4

Growth rate of a flaming fire in the growth or pre-flashover stage can be determined by considering the following:

- The item first ignited.
- Flame spread.
- Potential for fire spread from item to item.
- Potential for fire spread from ceiling.
- Effect of suppression systems.

Typical fire growth rates adopted for various occupancy types are given in Table 1.

Table 1

Building Use	**Fire Growth Rate**
Picture gallery	Slow
Dwelling	Medium
Office	Medium
Hotel reception	Medium
Hotel bedroom	Medium
Shop	Fast
Industrial storage or plant room	Ultra fast

The heat release rate for some occupancies are given in Table 2.

Table 2

Occupancy	Heat release rate per unit area kW/m²
Shops	550
Offices	290
Hotel room	249
Industrial	260

When flashover occurs, the behaviour of a fire in a compartment depends on a number of factors:

- The fire load density.
- The form and method of storage of the combustible material.
- The distribution of the combustible material.
- The quantity of air supplied per unit time.
- The compartment geometry.
- The thermal properties of the structural materials/linings.

The fire load density is a measure of the quantity of the materials available to burn in a fire. In design, it is common practice to refer to the characteristic fire load density for the occupancy in question, Table 3, and adopt the 80% fractile value.

Table 3

Occupancy	Fire Load Density			
	Average	Fractile		
	MJ/m²	MJ/m²	MJ/m²	MJ/m²
		80%	90%	95%
Dwelling	780	870	920	970
Hospital	230	350	440	520
Hospital storage	2000	3000	3700	4400
Hotel bedroom	310	400	460	510
Offices	420	570	670	760
Shops	600	900	1100	1300
Manufacturing	300	470	590	720
Manufacturing and storage[2]	1180	1800	2240	2690
Libraries	1500	2250	2550	–
Schools	285	360	410	450

Figure 5 shows the influence ventilation has on the temperatures attained during the fire process. Ventilation is normally expressed as the opening factor (OF), which is a measure of the area through which air can enter the fire compartment compared to its total surface area.

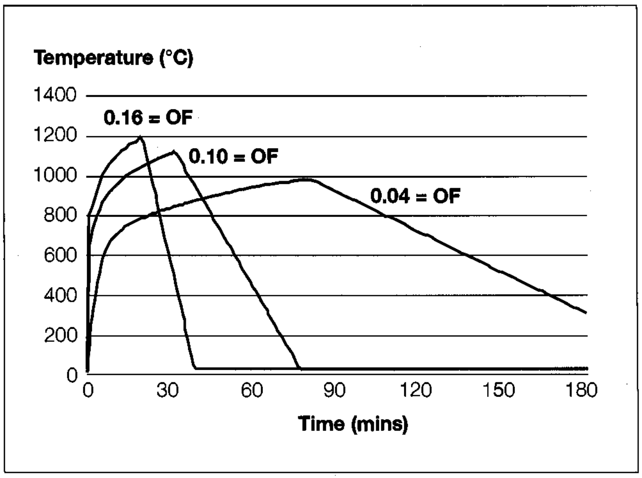


Figure 5

Temperature distribution in compartment fires can be analysed using zone models. Where it is assumed that the whole compartment is burning at the same time and attains the same temperature throughout, this is referred to as a single zone model. Two zone models exist in which the height of the compartment is separated into two gaseous layers each with their own temperature cycle. Three zone models exist in which there is a mixed gas layer separating the upper and lower gas levels.

In Eurocode 1 Part 1.2 (Ref 4) single zone post flashover fires can be described using parametric expressions that describe the entire heating and cooling cycle. These consider the fire load, ventilation characteristics, compartment geometry, and the thermal properties of the surrounding walls floor and ceiling.

Computational fluid dynamics (CFD) may be used to analyse fires in which there are no boundaries to the gaseous state. This type of analysis is widely adopted in very large compartment or enclosures. For example, airport terminals, atria, shopping centres, leisure and sports stadia.

Thermal response of structural members

The temperature rise of steel members in fire depend upon the duration of heating and the physical characteristics of the steel. The latter include:

- The size/massivity/shape of the steel members – described by the section factor (Figure 6). [The section factor, *Hp/A* or *A/V* is the heated perimeter divided by the cross sectional area. It is calculated for most common situations in Corus sections brochures.]
- Whether the steel members are protected or bare.
- The location of the members in relation to the fire.

***Hp/A* concept**

The heating rate of a steel section in a fire depends upon:
a) The perimeter of the steel exposed to flames – *Hp (m)*
b) The cross sectional area of the section – A (m^2)

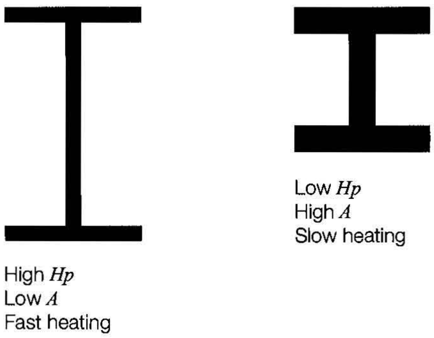
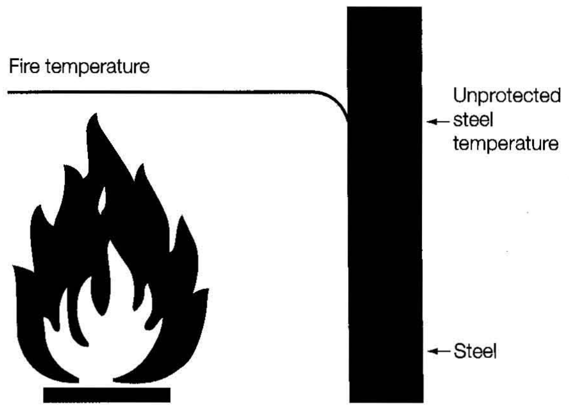


Figure 6

The temperatures attained by unprotected steel members can be determined using heat transfer relationship given in Eurocode 1 Part 1.2 in combination with Eurocode 3 Part 1.2 (Ref 5), (Figure 7). In BS5950 Part 8 (Ref 6) the temperatures attained in the standard fire test are also given in tabular format based upon the flange thickness. These are referred to as design temperatures and are provided for fire ratings from 15 to 60 minutes.

The temperatures attained by protected steel members can also be calculated according to Eurocode 3 (Figure 8). In addition, reference may be made to the 'Yellow Book' (Ref 7) which provides information on thickness of fire protection materials for beams and columns to meet the current levels of fire resistance specified in the UK Regulations.



Temperature increase in time step Δt:

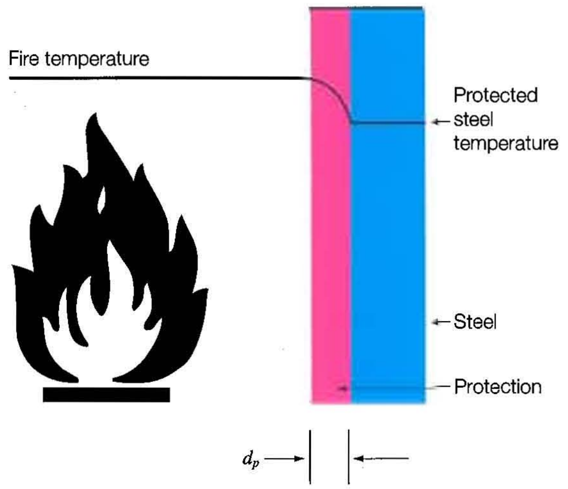
$$\Delta\theta_{a.t} = \frac{1}{c_a\,\rho_a}\,\frac{A_m}{V}\,h_{net.d}\,\Delta t$$

Heat flux $h_{net.d}$ has 2 parts:

Radiation: $h_{net.r} = 5{,}67x10^{-8}\,\Phi\varepsilon_{res}\left((\theta_r + 273)^4 - (\theta_m + 273)^4\right)$

Convection: $h_{net,c} = \alpha_c\,(\theta_g - \theta_m)$

Figure 7



Heat stored in protection layer relative to heat stored in steel

$$\phi = \frac{c_p\,\rho_p}{c_a\,\rho_a}\,d_p\,\Delta t\,\frac{A_p}{V}$$

Temperature rise of steel in time increment Δt

$$\Delta\theta_{a.t} = \frac{\lambda_p/d_p}{c_a\,\rho_a}\frac{A_p}{V}\left(\frac{1}{1+\phi/3}\right)(\theta_{g.t} - \theta_{a.t})\Delta t - (e^{\phi/10} - 1)\Delta\theta_{g.t}$$

Figure 8

Architects sometimes design structures to show the elegance of members external to the building façade. Members located outside the building will usually experience a reduced fire severity compared to an equivalent section within the building and depending upon their location in relation to window and other openings, they may often be left totally exposed. Detailed calculations enabling the temperatures of external members to be calculated for steady state fires are contained in Eurocode 3 Part 1.2. An example where this approach has been successfully employed by Buro Happold FEDRA is the DSS building in Newcastle (Figure 9).

Figure 9

Time equivalent

Time equivalent is a methodology that is widely used to relate the exposure of a structural element in a real fire to an equivalent period of heating in the standard fire resistance test. Over the years, a number of relationships have been established largely based upon experimental tests.

The most widely used of these is given in Figure 10. This has been validated against a large body of data from fire tests carried out in the UK. It may be used for unprotected steel for up to 60 minutes fire resistance and for protected members.

EC1: $t_e = q_f k_b w$

Where:

q_f = design fire load density

k = conversion factor

c or k_b = factor to take account the thermal properties of the enclosure

w or w_f = ventilation factor taking into account vertical & horizontal openings

Figure 10

Structural response

Current UK Building Regulations refer to a standard fire resistance test to demonstrate compliance with a requirement to provide an appropriate level of structural stability. The details of this test are outlined in BS EN 1363 (Ref 8 & 9). Tests are conducted at recognised accredited test laboratories in which single elements (beams, columns and floors) are constructed in-situ, loaded to their normal maximum permitted design levels and then subjected to the standard furnace heating regime (See P. 6). The limit of stability is achieved when either a given deflection limit or rate of deflection is reached. Detailed calculations on the performance of structural steel elements at the fire limit state are given in BS 5950 Part 8 and Eurocodes 3 and 4 Parts 1.2 (Ref 10).

In BS 5950 Part 8, reference is made to the load ratio which is given as the load applied divided by the capacity of the member. Critical steel temperatures for various construction systems versus loading conditions are specified in the form of limiting temperatures. These values should not be exceeded for the specified period of fire resistance and can be used in any further analysis to determine whether steel members can remain unprotected. Should protection be required, limiting temperature criteria are also provided to calculate the thickness of insulation required to prevent these limiting values being exceeded.

Design of composite metal deck floors

The majority of structural fire response calculations are carried out on the basis of response to single element testing. However, recent research into the behaviour of composite metal deck buildings (i.e. where the floors are constructed using shallow composite beams with profiled steel decking attached by shear connectors to downstand beams) has demonstrated that such buildings have considerable reserves of strength over and above that which can achieved from single element testing. This effect can be utilised in buildings of all sizes by leaving some of the beams unprotected. Most commonly, these are the secondaries.

Observations from large scale fire tests and other large building fires have shown that the behaviour of the composite floor slab plays a crucial role in providing enhanced fire resistance. Where significant numbers of beams are not protected, this has the effect of greatly increasing the distance which the floor slab spans in the fire condition. The tests demonstrated that, in these conditions, the slab acts as a membrane supported by cold perimeter beams and protected columns. As the unprotected steel beams lose their load carrying capacity, the composite slabs utilise their full bending capacity in spanning between the adjacent cooler members. With increasing displacement, the slab acts as a tensile member carrying the loads in the reinforcement which then become the critical element of the floor construction. In the case of simply supported edges, the supports will not anchor these tensile forces and a compressive ring will form around the edge of the slab. Failure will only occur at large displacements with fracture of the reinforcement.

The Building Research Establishment (BRE) has developed a simple structural model which combines the residual strength of the steel composite beams with the slab strength calculated using a combined yield line and membrane action model designed to take into account the enhancement to slab strength from tensile membrane action (Ref 11). The Steel Construction Institute has developed this model into a series of design tables in Fire Safe Design: A New Approach to Multi-storey Steel-Framed Buildings (Ref 12), Figure 11. Use of these tables allow the designer to leave large numbers of secondary beams unprotected in buildings requiring 30 and 60 minutes fire resistance although some compensatory features, such as increased mesh size and density, may be required. The process of creating design tables has resulted in some simplifications and use of the BRE calculation method from first principles may lead to additional economies. The BRE calculation method may be used for fire resistance periods of up to 120 minutes.

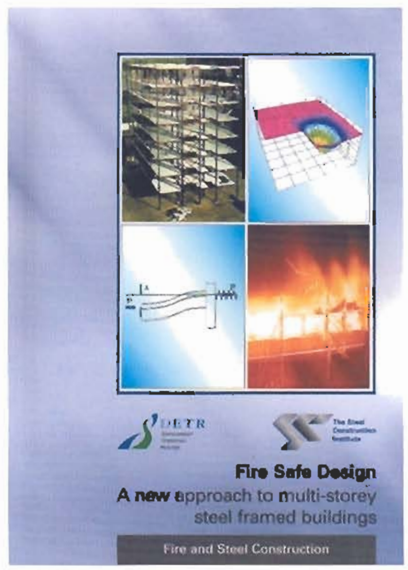


Figure 11

The software used to develop the tables can be utilised for loads and spans, within certain limits, other than the relatively limited number contained in the tables. This software can be found at:

www.steel-sci.org/it/software/fire

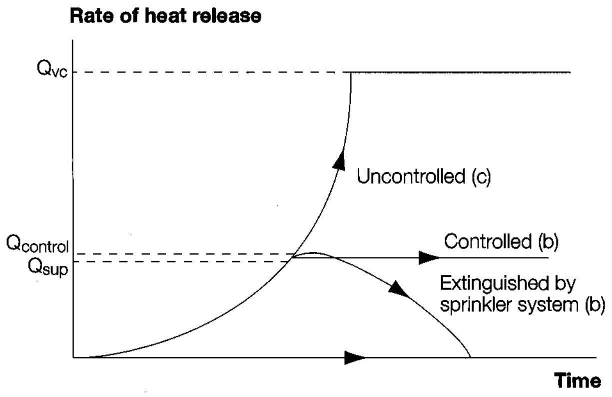
Fire Safe Design: A New Approach to Multi-storey Steel-Framed Buildings assumes rectangular grids. Where grids are not regular and/or the loading and/or the spans are outside the limits in the publication or web site, large scale whole frame modelling may be used. The use of such modelling is demonstrated in the Mincing Lane and Nuffield Hospital case studies in this publication.

Effect of suppression systems

Sprinkler systems are designed to control fires until the intervention of the fire brigades. In the United Kingdom and Europe their success rate is extremely high and this has given considerable confidence that they can be traded off against other methods of protection in a fire engineering approach.

For fire design purposes, three fire scenarios should be considered where sprinklers are installed (Figure 12).

- *Fire extinguished* – the rate of heat release is reduced to zero.
- *Fire controlled steady state* – the rate of heat release is held at a constant rate or continues to grow more slowly.
- *Fire uncontrolled* – the rate of heat release continues unchecked.



Q_{vc} is the rate of heat release under ventilation-controlled conditions.
Q_{sup} is the rate of heat release at which suppression activates.
$Q_{control}$ is the maximum rate of heat release at which the fire can be controlled.

Figure 12

CIBSE Guide E says that, *"In room equipped with sprinklers, a fire may grow until the heat in the plume sets off the first sprinkler heads; the effects of the sprinklers on the design fire size can be taken into account by assuming that the fire stops growing when the sprinklers are activated. Since the sprinklers will cool most of the smoke layer to below 100°C, flashover is not likely to occur It can be assumed conservatively that the fire will have a constant rate of heat release."*

The effects of sprinkler activation can be taken into account in a fire safety engineering analysis in two ways:

- By calculating the thermal and structural response based on the reduced heat input.
- By taking the sprinklers into account by reducing the effective fire load. This is the approach taken in the Eurocodes where the effective fire load is reduced to 60% of its design value in the presence of sprinklers.

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12. Fire Safe Design: A New Approach to Multi-storey Steel Framed Buildings. Available from the Steel Construction Institute.
13. Health Technical Memorandum 81, Fire Precautions in New Hospitals. Available from HMSO.

Case study
Dubai Autodrome and Business Park

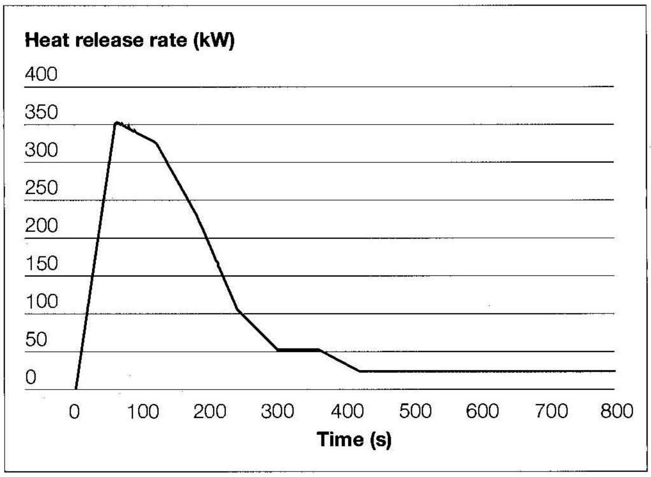
Fire Engineer: **SAFE**
Client: **Union Properties**
Concept Architect: **HOK, Kansas**
Main Contractor: **Al Naboodah Laing O'Rourke**
Structural Engineer: **Buro Happold**
Steel Fabricator: **Bone Steel Ltd**

Complete with the 5.4km international FIA approved Formula One track, multi-purpose grandstands with hospitality suites, pit lane and media complex, the Dubai Autodrome is the regions first fully-integrated automotive and motor sports facility.

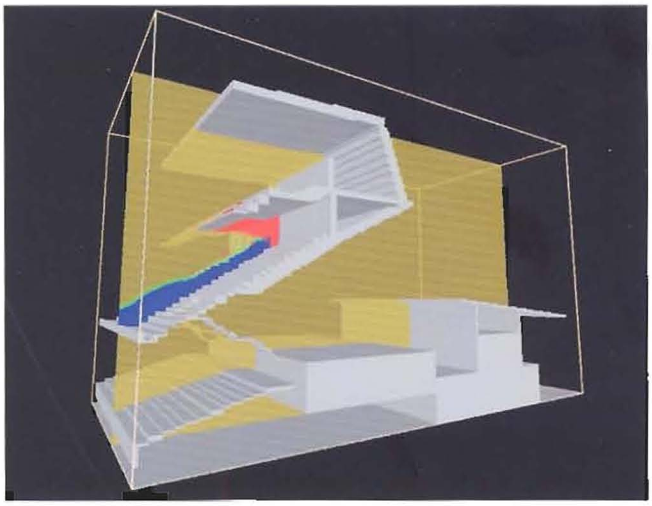
The steel structure for the 250m long multi-functional grandstand, with hospitality suites and an open seating deck for 6,000 spectators, required 60 minutes fire protection according to the NFPA 101 Life Safety codes and NFPA 220 Standard on Types of Construction. However, it was felt that by adopting a performance-based design approach, taking into account potentially low fire loads, and significant ventilation factors (being an external environment) that this requirement could be reduced (as proposed by NFPA 102 Standard for Grandstands).

The worst-case fire load in each area of the grandstand was determined and calculations were used to demonstrate the impact of such a fire on the structure in those areas. These calculations took into account the type of construction, ventilation, and the maximum fire load.

It was demonstrated using calculations, verified by computational fluid dynamic modelling (see right) and ultimately agreed with the Dubai Municipality, that the inherent resistance of the steel structure was adequate to survive any likely fire and that no passive fire protection was required to the structure.



Heat release rate Vs Time lapsed: The maximum heat release rate is 350kW at 66 seconds.



Heat distribution at 66 seconds when the maximum heat-release rate of 350kW is achieved.

This page:
Grandstand front
Left:
Grandstand rear

(Images courtesy of HOK sport venue event architecture)

Case study
Queen Mary New School of Medicine and Dentistry

Fire Engineer: **Warrington Fire Research**

Client: **Queen Mary New School of Medicine and Dentistry**

Concept Architect: **Alsop Architects**

Main Contractor: **Laing O'Rourke**

Structural Engineer: **Adams Kara Taylor**

Steel Fabricator: **Westbury Structures**

Warrington Fire Research was commissioned to prepare a fire strategy for the Queen Mary New School of Medicine and Dentistry. The building is designed by Alsop Architects and located in central London. The fire strategy included a detailed structural fire protection analysis.

This case study relates to that analysis as it was carried out for the pavilion building, shown on the opposite page. The analysis achieved substantial reductions in the amount of fire protection that was required, giving large cost savings and helping to maintain the architectural concept for the building.

Following the provisions of Approved Document B, the structure would have required 60 minutes fire resistance. This would have included the structure supporting the rooftop plant level.

However, the building is very open in nature and so the 60 minute fire rating was seen to be excessive. The objective of the analysis was to calculate the amount of fire protection that would be needed for each section of structure to prevent failure in the event of a fire.

The main areas of the structure that were analysed were:

- External perimeter columns.
- Stair cores.
- Raking columns supporting the rooftop plant floor.
- Structure supporting pods (these contain meeting rooms).

The raking columns and meeting room pods are clearly shown at the top of the page.

The open areas of the building have a very high ceiling and contained natural smoke vents at roof level. There is no real risk of flashover occurring in these areas. The analysis therefore considered localised fires adjacent to or below the structure.

The building contains some cellular enclosed offices at ground level and so flashover fires in these areas were analysed. In each case the analysis involved the following stages:

- Prediction of the maximum fire size.
- Analysing the impact of the fire on the structure.
- Calculating the maximum temperature reached by the structure.
- Liaising with the structural engineers to determine if the structure could tolerate these temperatures.
- Determining the fire protection required (if any).

Some areas of structure were in low fire risk areas and so no fire protection was needed. These included the raking columns shown above. The supporting structure for the meeting room pods also did not need any fire protection.

The analysis was carried out in liaison with the design team, HCD Building Control and the fire brigade and was documented in a detailed report that explained the analysis and the recommended levels of fire protection that were needed in the various areas.

Right:
Pavilion building
Left:
Interior of pavilion

(Images copyright Virtual Artworks and Alsop Architects Ltd)

Case study
Basement Car Park, Whitehall Waterfront Project, Leeds

Fire Engineer: **WSP Fire Engineering**

Client: **K. W. Linfoot**

Concept Architect: **Carey Jones Architects**

Main Contractor: **Barr Construction**

Structural Engineer: **Barr Construction**

Steel Fabricator: **Barr Steel**

On the Whitehall Waterfront project in Leeds, steel sheet piling in the basement areas was approved without the application of fire protection. This approval was achieved without resorting to complex modelling techniques and is a good example of a situation where solutions to a difficult problem can be found by application of common sense and sound engineering judgement.

The structure at Whitehall Waterfront

The basement walls at the Whitehall Waterfront project are formed using a steel sheet piling system which is load bearing. The structural frame for some of the building superstructure is supported off a ring beam which is in turn supported directly off the piles.

Basement fires and car parks

Approved Document B to the Building Regulations (AD-B) places a number of specific requirements on designers with respect to basements. Many basements are used for adhoc storage, are infrequently visited and are difficult for fire fighters to enter. Car parks are treated in a much less onerous fashion by AD-B. It makes the specific point that fire spread in car parks is rare and reduced levels of fire resistance in certain circumstances.

The basement at Whitehall Waterfront is used as a car park. The view was taken that, irrespective of the below ground nature of the space, the low risk nature of the use could be applied. This allowed the fire protection requirements to the steel sheet piling to be assessed on a qualitative risk assessment basis.

Assessing the risk at Whitehall Waterfront

The basis of allowing a reduced standard of fire resistance in open sided car parks is that the ventilation allows smoke and heat to be vented, reducing the impact on the structure. This, and the shielding provided by the vehicles in the car park, limits the ability of fire to spread. The basement car park at Whitehall Waterfront is isolated from the rest of the building by compartment floors and small areas not used purely for parking are also compartmentalised. Instead of natural ventilation, the car park is provided with a mechanical impulse fan system for engine fume removal and smoke clearance, the latter to assist fire fighters.

The system was provided by PSB who have carried out tests to demonstrate that their ventilation system can reduce the temperatures in car park fires and provide smoke clearance more effectively achieved in an open sided car park. In particular, fire spread between vehicles is prevented and smoke temperatures are reduced to a level well below that at which steel is significantly affected.

It was also noted that the piles at Whitehall Waterfront are welded together to form a continuous structural element and are backed by the earthworks behind. These design factors suggested that a localised reduction in the load bearing capacity of the piles would not significantly affect the structure above, the potential for buckling of the piles was remote and the earthworks could assist in reducing the steel temperature by acting as a heat sink. These general design factors would become beneficial in the event that the ventilation system failed.

On the basis of these features, the potential for a fire to develop within the Whitehall Waterfront basement area which could significantly affect the structure was considered to be remote and the steel piles were not fire protected.

This page:
Unprotected steel sheet piling
Left:
External view

Case study
Mincing Lane, London

Fire Engineer: **Arup Fire**

Client: **British Land**

Concept Architect: **Arup Associates**

Main Contractor: **Bovis**

Structural Engineer: **Arup Associates**

Steel Fabricator: **William Hare Limited**

Recent research in the field of structures in fire has been used to determine a robust design solution for the passive fire protection arrangement at Mincing Lane, an 8 storey, composite metal deck office building in the City of London designed by Arup Associates. The building required 120 minutes fire protection plus a sprinkler system but the fire strategy developed by Arup Fire demonstrated that 90 minutes was sufficient. The strategy also included finite element analysis (FEA) intended to assess the whole frame structural response to fire and thus apply an appropriate level of fire protection. Detailed FEA of composite steel structures, like Mincing Lane, under various fire conditions allows a comprehensive understanding of the structural mechanics involved. Such analysis can identify areas where fire protection may be safely omitted and highlight areas where additional precautions may be required. More importantly it identifies the critical areas of structure in a fire and therefore allows designers to detail the structure to limit detrimental effects in these zones.

The analysis lead to enhanced confidence in the ability of the structure to survive a total burnout of the contents on a compartment floor and determined that most of the secondary steel beams could be left unprotected while satisfying the functional requirements of the Building Regulations, 2000 that the building remain stable for a reasonable period.

A parametric time-temperature equation contained in Eurocode 1 was used to determine credible design fires acting within one floor of the building. Two ventilation conditions – which affect the temperatures and duration of the fire – were used to investigate the structural response.

In traditional prescriptive design, it is generally assumed that passive fire protection will limit deflections in a fire to such an extent that compartmentation and services will not be affected. In practice this is not necessarily the case. A performance based design approach allows such checks to be made. This gives designers the freedom to alter the design and detailing of the structure in order to improve the overall response to fire if necessary.

A comparison of the proposed design solution with the structural response to a 90 minute standard fire was also calculated for a conventionally protected office floor (i.e. all steelwork protected). This allowed a check on the deflections experienced in a conventional design and was very informative as a basis for reviewing the fire resistance design proposals. Predicted deflections of the floor in the proposed protection arrangement were 490mm and, with all the steel protected, were 380mm.

The final design includes the following features: columns, primary and edge beams including connections are fully protected to a 90 minute standard as are beam to core connections; the mesh reinforcement in the slab is anchored to the perimeter beams and the core; conventional lapping of the mesh reinforcement is a requirement of the fire design; secondary steel beams are unprotected.

Arup Fire would like to acknowledge their analysis partners Edinburgh University, Arup Associates, City of London District Surveyors office and the Fire Engineering group of the LFEPA (London Fire and Emergency Planning Authority), for their involvement in this project.

This page:
External view
Left:
Unprotected secondary beams

Case study
Nuffield Hospital, Leeds

Fire Engineer: **Buro Happold FEDRA**

Client: **Nuffield Hospital**

Concept Architect: **Carey Jones Partnership**

Main Contractor: **Shepherd Construction**

Structural Engineer: **Waterman Group**

Steel Fabricator: **Wescol Glosford and Westok Ltd**

One of the functional requirements of the Building Regulations in terms of structural stability is that the building remain stable for a reasonable time. Guidance in documents such as Approved Document B and, in the case of health buildings, HTM 81, Fire Precautions in New Hospitals (Ref 13) support this requirement. However, the guidance in these documents is based on a standard fire test with a defined time-temperature relationship. This assumes that the behaviour of whole frames can be approximated by the performance of single elements and this may not always be correct. A fire engineering approach which uses real fire behaviour and structural interaction can offer an alternative and more efficient solution. A good example of this principle is Leeds Nuffield Hospital.

The approach adopted by FEDRA in this building took into account the relatively low fire load and high level of compartmentation to be found in most modern hospitals. Both characteristics act to reduce effective fire severity. Also, as most hospital designs tend to be dominated by vibration requirements, which leads to the use of large structural components, there is usually significant inherent fire resistance in the structure.

On a strict interpretation of HTM 81, the building required 120 minutes fire resistance. Analysis based on the type and duration of fire likely to occur in the building and the temperatures which could be expected was used to justify a reduction to 60 minutes fire resistance.

Further assessment of the whole frame behaviour using finite element analysis demonstrated that, in the event of a fire, secondary effects such as catenary action and tensile membrane action would dominate leading to enhanced capacity of the floor slab. The key issue was that the slab would remain relatively cool and insulate the reinforcement. This led to an alternative equilibrium in the fire condition to that assumed in the standard fire test. This analysis, in combination with a qualitative risk assessment on the compartmentation requirements, resulted in a situation where beams framing into columns were fire protected but combinations of intermediate beams were unprotected.

This page (main photograph):
Internal view
Inset picture:
External view
Left:
Unprotected steel

Case study
T-Mobile Headquarters

Client: **Arlington Securities**

Concept Architect: **Scott, Brownrigg & Turner**

Main Contractor: **Kier Build**

Structural Engineer: **Baynham Meikle**

Steel Fabricator: **William Hare Limited**

T-Mobile Headquarters is part of Arlington Securities' Hatfield Business Park, a structured mixed-use location combining business park, leisure and retail amenities, educational facilities and housing, located just off the A1, north of London.

The project consists of six, three-storey buildings, generally on a 9x9 metre grid. Each floor measures approximately 2600m^2 and the total project floor area is approximately 43000m^2.

Originally designed as concrete frames, the buildings were eventually built in steel because of the programme advantages which it was able to create. The fabrication was carried out by William Hare Ltd. of Bury who also decided to see if it was possible to achieve additional economies by reducing the cost burden of structural fire protection. A decision was made therefore to use guidance developed by the BRE and published by the Steel Construction Institute following a series of large scale fire tests at Cardington in the mid-1990's (See Page 10-11). The guidance is applicable only to composite metal deck floors and works on the basis of dividing the floor area into a series of rectangular slabs generally bounded by beams spanning onto columns. Tables are available which tell the designer whether it is possible to allow the secondary beams within the slab to be unprotected and whether compensating features must be added.

Approved Document B required that these buildings have 60 minutes fire resistance. The appropriate data from the guidance for a 9 metre square grid, re-entrant deck and a mesh strength of 460N/mm^2 is as shown in Table 4. So, to leave the secondary beams unprotected, an A252 mesh was provided, the secondary beams could be fully loaded and an additional load of 49kN was required in the fire condition on the boundary beams parallel to the secondaries. This last requirement did not result in any increases in the relevant beam sizes. As a consequence of this approach, William Hare Ltd. estimate that approximately a third of the floor beams did not require fire protection.

Table 4

LOAD	Mesh	A252
3.5+1.7	Beam	OK
	Load	49

This page:
Internal view, T-Mobile Headquarters
Left:
External view, T-Mobile Headquarters

(Pictures by kind permission of Arlington Securities)

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