STEEL CONSTRUCTION
Fire Protection

TATA STEEL

BCSA

Tata Steel and the British Constructional Steelwork Association (BCSA) have worked closely together for many years to promote the effective use of structural steelwork. This collaborative effort ensures that advances in the knowledge of the constructional use of steel are shared with construction professionals.

Steel is, by some margin, the most popular framing material for multi-storey buildings in the UK and has a long track record of delivering high quality and cost-effective structures with proven sustainability benefits. Steel can be naturally recycled and re-used continuously, and offers a wide range of additional advantages such as health and safety benefits, speed of construction, quality, efficiency, innovation, offsite manufacture and service and support.

The steel sector is renowned for keeping specifiers abreast of the latest advances in areas such as fire protection of structural steelwork and achieving buildings with the highest sustainability ratings. Recent publications have provided detailed guidance on CE Marking and what it means for the construction sector. Guidance is provided on all relevant technical developments as quickly as is possible.

The sector's go to resource website – *www.steelconstruction.info* – is a free online encyclopedia for UK construction that shares a wealth of up-to-date, reliable information with the construction industry in one easily accessible place.

Tata Steel Europe

The European operations of Tata Steel comprise Europe's second largest steel producer. With the main steelmaking operations in the UK and Netherlands, they supply steel and related services to the construction, automotive, packaging, lifting and excavating, energy and power, aerospace and other demanding markets worldwide. The combined Tata Steel group is one of the world's largest steel producers, with an aggregate crude steel capacity of more than 28 million tonnes and approximately 80,000 employees across four continents.

British Constructional Steelwork Association

BCSA is the national organisation for the steel construction industry: its Member companies undertake the design, fabrication and erection of steelwork for all forms of construction in building and civil engineering. Associate Members are those principal companies involved in the direct supply to all or some Members of components, materials or products. Corporate Members are clients, professional offices, educational establishments etc which support the development of national specifications, quality, fabrication and erection techniques, overall industry efficiency and good practice.

Contents

Fire Design of Steel Framed Buildings

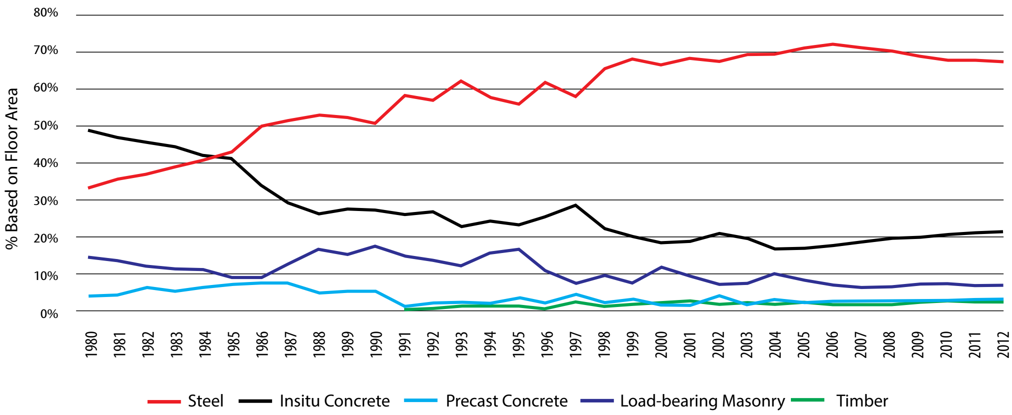
More is known about structural steelwork in fire than any other construction material. Its performance has been determined through a series of full-scale fire tests, which are unparalleled for other materials. There is certainty in how structural steelwork performs and certainty that finite element models and other tools accurately reflect how it actually behaves in fire.

Determining the fire protection requirements for the structural steelwork of a building is a simple and straightforward process, consistent across all types of common buildings.

The procedure is clearly set out in this document, which is intended to be a reference aid for designers at all levels. Whilst it is a standalone guide, it also points the designer to the wealth of information on structural steelwork available on *www.steelconstruction.info,* the free encyclopedia for UK steel construction information.

Steel frames consistently capture a market share in the multi-storey non-residential buildings market of around 70% and cost advantages are often cited as a key reason in selection of the framing material. Advances in the science of fire protection by systems manufacturers have ensured that this cost continues to fall, with the cost in real terms of fire protection today lower than it has ever been.

Market Share for Structural Frames in Muti Storey Buildings



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Articles of interest:

- FIRE AND STEEL CONSTRUCTION
- COST OF STRUCTURAL STEELWORK (Updated quarterly by Gardiner & Theobald)

Fire Safety Engineering

Recognition of how real buildings react in fire and of how real fires behave has led many authorities to acknowledge that fire safety may now be achieved by an analytical fire engineered approach. This change has proved beneficial to the construction industry as a whole, but particularly to the steel construction sector, which has carried out most of the research and whose structures consequently offer the greatest potential for improved solutions using fire engineering.

Fire safety engineering is a specialist discipline which can combine a risk based approach to determining the fire period with detailed finite element modelling to predict actual performance of the structure and fire protection measures in a fire. It is most commonly used on buildings where the prescriptive provisions given in Approved Document B, Technical Handbook 2 and Technical Booklet E can be shown to be more demanding than are really neccessary. The majority of all tall and complex steel buildings are now engineered for fire in the UK.

Fire safety engineering will result in an integrated package of measures designed to achieve the maximum benefit from the available methods of preventing, controlling or limiting the consequences of fire. It may consider some or all of the following:

- means of warning and escape
- internal fire spread
- structural response
- external fire spread
- access and facilities for the fire service

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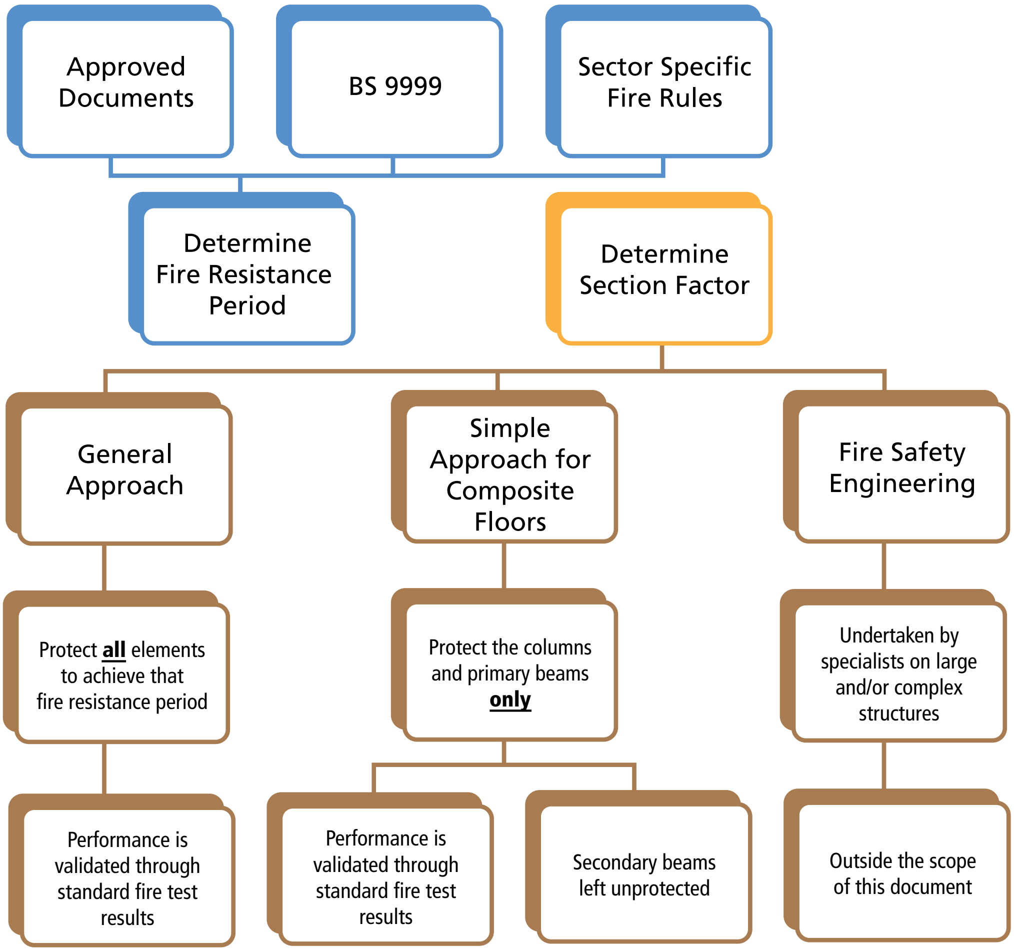
Articles of interest:

- STRUCTURAL FIRE ENGINEERING
- HERON TOWER, LONDON
- MAXIM OFFICE PARK GLASGOW
- THE SHARD, LONDON

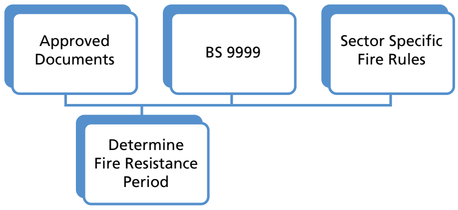
Design Procedure

The procedure for determining the fire protection requirements for structural steelwork is straightforward, but there are three distinct stages:

1. Determine the fire resistance period through Approved Documents[1], BS 9999 or specific sector requirements
2. Determine the section factor for the structural steelwork that is to be used
3. Provide the required fire resistance period through:
   a. General approach for all types of construction
   b. Simple approach for composite floor construction
   c. Fire safety engineering



[1] 'Approved Documents' within this document is used as a generic term to simplify the text by replacing full reference to Building Regulations Approved Document B in England and Wales, Building (Scotland) Regulations Technical Handbook 2 in Scotland and Building Regulations (Northern Ireland) Technical Booklet E in Northern Ireland in each case.



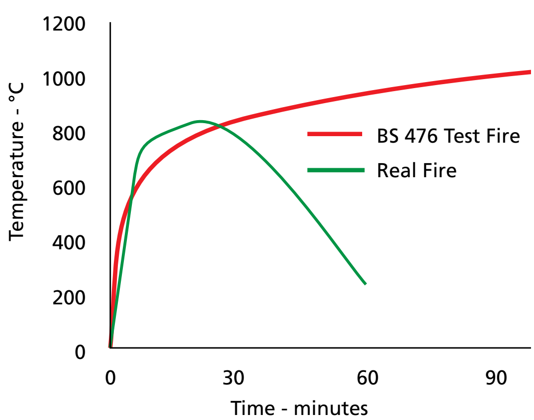
Determine the Fire Resistance Period

Introduction

The fire resistance requirement for a building and therefore the frame is defined in terms of the fire resistance period and stated in terms of minutes (15, 30, 45, 60, 75, 90 or 120 minutes).

The purpose of setting a fire resistance period is to ensure that in the event of a fire within a building, the load-bearing capacity of the building will continue to function until all occupants have escaped, or been assisted to escape.

Comparison between a fire test and a real fire



The ability of a component or material to achieve the required fire resistance period is demonstrated by subjecting it to a standard fire test as defined in BS 476-20 or BS EN 1363-1.

It can be seen that the time-temperature relationship bears little relationship to what happens in most real fires.

The temperature in a standard fire rises quickly and then increases indefinitely. In a real fire, once the combustible material (the fire load) has been consumed, the fire will decay and/or move. The movement of fire in a compartment is related to both fire load and ventilation, neither of which is considered in a standard fire test.

Fire resistance test results are expressed in terms of time to failure against one or more of three criteria for the product/element being considered. These performance criteria are:

- Load-bearing capacity, i.e. the ability to support the applied load and to resist collapse
- Integrity, i.e. the ability to resist the passage of flames/hot gases
- Insulation, i.e. the ability to restrict the temperature rise on the unexposed face

Some building elements require that all three criteria are met, others two and some only one. Structural columns are required to meet only the load-bearing capacity. Structural floors between two fire compartments must meet all three criteria and it is usually insulation, rather than structural criteria, which dictates the thickness of the slab.

Fire resistance is not the length of time that a structure will survive in a real fire, it is simply a standard measure that is used to compare the performance of different designs in a consistent manner

As can be seen from the graph, there is no direct relationship between a standard test and a real fire. Fire resistance is not the length of time that a structure will survive in a real fire, it is simply a standard measure that is used to compare the performance of different designs in a consistent manner. It is therefore extremely unlikely that buildings with elements tested to 60 minutes fire resistance will collapse if subject to a 60 minutes duration real fire.

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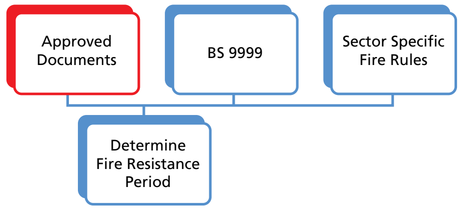
Articles of interest:

- FIRE TESTING
- STRUCTURAL FIRE RESISTANCE REQUIREMENTS
- SPRINKLERS IN UK FIRE CODES



England and Wales[1]: Approved Document B

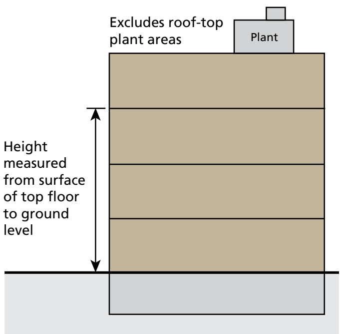
Building height is defined as height to the top floor in the Approved Documents

Structural fire resistance requirements in Approved Document B for multi-storey buildings are a function of occupancy and the height of the building. It should be noted that height is not the overall height of the building but is the distance from the ground to the the top floor.

The required fire resistance periods are contained in Table A2. They should not be read in isolation but in conjunction with the accompanying notes and Table A1: Specific provisions of test for fire resistance of elements of structure.

The different heights set within the Table A2 may seem to be a little arbitrary at 5m, 18m and 30m but they represent changes in the equipment required by the fire services to enter the building, reinforcing again that the regulations are about maintaining stability to allow safe evacuation of people from the building.

Definition of building height



Most multi-storey non-residential buildings in England and Wales are two, three or four storeys in height (≤18m) and the majority are classed as offices, shops, commercial or assembly. This means that the dominant period of fire resistance is 60 minutes.

Almost all buildings over 30m in height must be fitted with a life safety sprinkler system, installed in accordance with the appropriate British Standards. The presence of life safety sprinklers can be used to reduce structural fire resistance requirements by 30 minutes in most buildings under 30m in height. However, this is only rarely invoked as the cost of the sprinklers is usually greater than the cost savings from the reduction in the fire resistance period for the passive fire protection systems.

Approved Document B – Extract from Table A2

Purpose group of building	Minimum periods of fire resistance (minutes)			
	Height of top floor above ground			
	≤ 5m	≤ 18m	≤ 30m	> 30m
Office	30	60*	90*	120 plus sprinklers
Shops and commercial	60*	60	90*	
Assembly and recreation	60*	60	90*	
Industrial	60*	90*	120*	
Storage	60*	90*	120*	
Car parks - other	30	60	90	
Car parks - open	15	15	15	60

* Reduced by 30 minutes when sprinklers are installed

Basements in buildings generally require fire resistance periods of 60 minutes where the depth of the basement is less than 10m. For basements over 10m in depth, 90 minutes is normal.

[1] Building Regulation powers were devolved to Wales on 31 December 2011. The Approved Documents current on 31 December 2011 for England and Wales will continue to apply to Wales. As guidance is reviewed and changes made Approved Documents for Wales will be published. The Welsh Government has set out its review schedule to 2014 but Approved Document B has not been included.

Scotland: Technical Handbook 2

Dominant fire resistance period in the UK is 60 minutes or less

Structural fire resistance requirements are contained in Section 2.1.1 of the Scottish Technical Handbook 2 for multi-storey buildings.

They are a function of height of the building to the upper surface of the top floor, occupancy and compartment floor area. Fire resistance requirements are short (30 minutes), medium (60 minutes) or long (120 minutes). Unlike England and Wales, where periods of fire resistance of 120 minutes usually occur in buildings over 30m in height, in Scotland this can occur at any height if the compartment floor area is large enough. The most significant trade-off for life safety sprinklers is that allowable floor areas may be doubled when an automatic fire suppression system is installed in the building.

Structural fire resistance requirements in basements are either 60 or 120 minutes. They are also a function of the floor area of the compartment and are not influenced by the depth.

Technical Handbook 2 – Fire resistance in minutes

Building use	Maximum total area of any compartment (m^2)	Minimum fire resistance duration The topmost storey of a building is at a height of		
		≤7.5m	≤18m	>18m
Office	2000*	Short	Medium	Long
	4000*	Medium	Medium	Long
	8000*	Long	Long	Long
Shop and commercial	500*	Short	Medium	Long
	1000*	Medium	Medium	Long
	2000**	Long	Long	Long
Assembly and recreation	1500*	Short	Medium	Long
	3000*	Medium	Medium	Long
	6000*	Long	Long	Long
Industrial (Class 1)	500*	Medium	Medium	Long
	6000*	Long	Long	Long
Storage (Class 1)	200*	Medium	Medium	Long
	1000*	Long	Long	Long
Car park - open	Unlimited	Short	Short	Medium

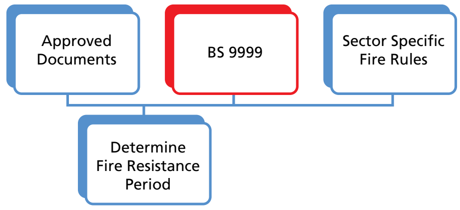
* Area may be doubled if sprinklers are installed

** Unlimited if sprinklers are installed

Northern Ireland: Technical Booklet E

Structural fire resistance requirements are contained in Table 4.2 of Technical Booklet E for multi-storey buildings. They are broadly the same as those in Approved Document B and are a function of height and occupancy.

The main exception is that the requirement to install sprinklers in blocks of flats over 30m in height, a relatively recent addition in England and Wales, has not yet been implemented in Northern Ireland.



BS 9999

Use of BS 9999's risk based approach can lead to a reduced fire resistance period

BS 9999 is recognised by Local Authorities and other approved bodies as a complementary approach to that used within the Approved Documents.

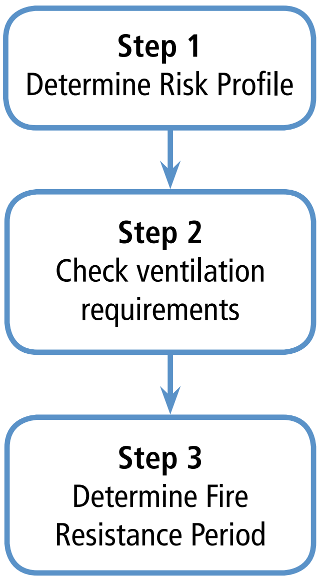
Consequently, BS 9999 gives fire resistance periods in Table 25 identical to those within Approved Document B if a building is simply considered in terms of height and occupancy.

However, whereas the Approved Documents adopt a standard, prescriptive approach for all buildings, BS 9999 allows designers to use a risk-based approach to determine the fire resistance period for their building. It is presented in a logical and straightforward way that walks designers through the procedure step-by-step. It is therefore available for non specialists to use.

BS 9999 – Table 25

Occupancy Characteristic	Use	Minimum periods of fire resistance (in minutes) – Height of top occupied storey above access level: ≤5m	≤18m	≤30m	>30m
A	Office	30	60*	90*	120 + sprinklers
B	Shops and Commercial	60*	60	90*	
B	Assembly: ordinary hazard	60*	60	90*	
A	Industrial: ordinary hazard	60*	90*	120**	90 + sprinklers
A	Storage: low hazard	30	60*	90*	60 + sprinklers
A	Car park - closed	30	60	90	120
A	Car park - open	15	15	30	30

* Reduced by 30 minutes when sprinklers are installed
** Reduced by 60 minutes when sprinklers are installed



Step 1 is to determine the Risk Profile. This is a function of occupancy characteristic (A, B or C) and the fire growth rate (1, 2, 3 or 4), which are combined to give the Risk Profile (A2, B3 etc). Table 2 gives the occupancy characteristic, Table 3 the fire growth rates and Table 4 describes the resultant Risk Profiles.

Table 5 gives the examples of the Risk Profiles appropriate to the majority of occupancy types and can be referenced directly if the required occupancy is present. The different occupancies are listed alphabetically in the BS 9999 but are presented here in terms of the Risk Profile.

BS 9999 – Table 5 extract

Risk Profile	Occupancy
A2	Office (open-plan exceeding $60m^2$)
A2	Classroom
A2/A3	Factory production area
A2/A3/A4	Storage and warehousing
A3	Workshop
B2	Office (closed-plan or office less than $60m^2$)
B2	Concourse or shopping mall
B3	Shop sales area

Use of BS 9999 to determine the fire resistance period means that its requirements for other aspects of fire safety must also be adopted

Step 2 is to check that the ventilation requirements of Table 27 are met so that Table 26 may be used to determine the fire resistance period. (If the Table 27 requirements are not met, then the designer must use Table 25.) Most buildings would be expected to meet these ventilation requirements.

BS 9999 – Table 27

Occupancy Characteristic	Use	Ventilation conditions for application of Table 26	
		Minimum potential area as a percentage of the floor area %	Height of opening as a percentage of the compartment height (i.e. from floor to ceiling) %
A	Office	5	30 to 90
B	Shops and Commercial	5	50 to 100
B	Assembly: ordinary hazard	2.5	30 to 80
A	Industrial: ordinary hazard	2.5	30 to 80

Step 3 is then to determine the fire resistance period from Table 26. The fire period is a function of building height and Risk Profile.

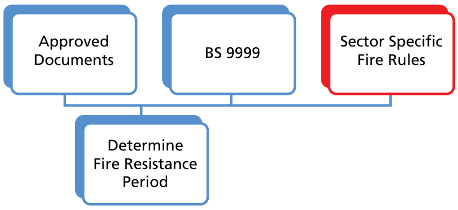
BS 9999 – Table 26

Risk Profile	Minimum periods of fire resistance, (in minutes)					
	Height of top occupied storey above access level					
	≤ 5m	≤ 11m	≤ 18m	≤ 30m	≤ 60m	> 60m
A2	30 D)	30	60	90	120 + sprinkler*	150 + sprinkler*
A3	60	60	90	120	300 + sprinkler*	300 + sprinkler*
B2	30	30	60	75	90 + sprinkler*	120 + sprinkler*
B3	30	45	75	105	135 + sprinkler*	180 + sprinkler*

D) Reduced to 15min when ground floor area is less than 1,000m^2

* Sprinklers required on all buildings > 30m high (Section 31.2.2)

Easily overlooked is the implication of footnote D) on buildings with Risk Profile A2 and two storeys high, which reduces the fire resistance period to 15 minutes for buildings with a ground floor area of <1000m^2. Risk Profile A2 covers buildings such as open plan offices and a fire resistance period of 15 minutes means that the steelwork can probably be left unprotected (see section on Unprotected Steel). It should however be noted that though classrooms fall into the A2 Risk Profile group, the fire resistance period is governed by the requirements of Building Bulletin 100 (see section on Sector Specific Fire Rules).



Sector Specific Fire Rules

Single storey buildings

Single storey buildings normally require fire resistance only for a boundary wall condition

Single storey buildings do not normally require structural fire resistance (and therefore fire protection) as Section 7.4 of Approved Document B (England and Wales) considers them to be structures that only support a roof and excludes them. Exceptions occur where an element of the structure provides support or stability to elements such as:

- A separating wall
- A compartment wall or the enclosing structure of a protected zone
- An external wall that must retain stability to prevent fire spread to adjacent buildings (i.e. a boundary condition). The wall must achieve not only the required fire resistance period but also the insulation and integrity requirements too
- A support to a gallery or a roof which also forms the function of a floor (e.g. a car park or a means of escape)

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Articles of interest:

- SINGLE STOREY BUILDINGS IN FIRE BOUNDARY CONDITIONS
- CAR PARKS IN FIRE

Although single storey buildings can require fire protection where an insurance company or owner deems it necessary, it is commonly provided only where a boundary condition exists. Where this occurs, the Approved Documents expect the designer to follow the approach described in the Steel Construction Institute's (SCI) P313 Guide – Single storey steel framed building in fire boundary conditions.

The most common framing system for a single storey, non-domestic buildings is a portal frame. SCI P313 Guide includes a design method that limits provision of fire protection only to the boundary wall columns provided that the column bases have been designed to resist the overturning moments and forces caused by the collapse of the unprotected parts of the building in the event of a fire.

Car parks

Car parks are classified as either open or other.

Open car parks are above ground and have large openings in the façade for natural ventilation. A car park is defined as open if it has an aggregate vent area not less than 1/20th of the floor area, of which at least half should be provided between two opposing walls. They are recognised as posing a relatively low risk to life and are generally required to have only 15 minutes fire resistance for structures <30m in height (<18m in Scotland [2]). The 15 minutes fire period is normally achieved using unprotected steel.

[2] It should be noted that Section 2.1.1 in Scottish Technical Handbook 2 states that open car parks up to 18m in height require 30 minutes fire resistance (a period defined as 'short'). However, this is overridden in Section 2.D.3.

Open car parks usually achieve fire resistance periods with unprotected steel

Certain situations exist where the deemed to satisfy criteria for structural steelwork in an open car park may not apply:

- Where one element of structure gives support or carries or gives stability to another, the fire resistance of the supporting element should be no less than the minimum period of fire resistance of the other element (irrespective of whether that other element is load-bearing). An example of this is where a column gives stability to the open car park and also to a compartment wall surrounding an escape stairway. In that case, the supporting column should have the same fire resistance as the compartment wall.
- If the building is also used for any other purpose, the part forming the car park is a separated part and the fire resistance of any element of structure that supports or carries or gives stability to another element in another part of the building should be no less than the minimum period of fire resistance of the elements that it supports.

The fire resistance period for other car parks is typically consistent with those for commercial buildings of the same height.

Schools

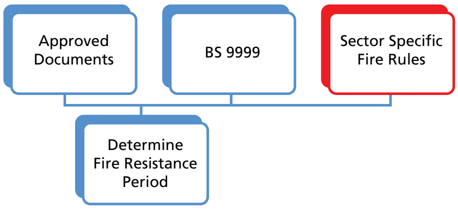
In England and Wales, Table A2 of Building Bulletin 100 provides guidance on fire resistance periods for schools.

Building Bulletin 100 – Table A2

	Minimum periods of fire resistance (in minutes)		
	Basement storey (including floor over) not more than 10m deep	**Ground or upper storey: Height (m) of top floor above ground, in a building or separated part of a building.**	
		Not more than 5	Not more than 18
Not sprinklered	60	60	60
Sprinklered	60	30	60

Whilst the option for construction without sprinklers is presented, the Department for Education has stated its expectation that all new schools will be sprinklered. This is due to around 1 in 20 schools experiencing a fire each year, with nearly 60% of school fires started deliberately.

Guidance is also available from the Scottish Executive in its publication, Fire Safety in Schools. However, this document does not impact the fire resistance period beyond the requirements of Technical Handbook 2.



Healthcare

Best practice guidance and recommendations for healthcare buildings in England and Wales is given in Health Technical Memorandum HTM 05-02. It provides guidance on the design of fire precautions in new healthcare buildings and major extensions. The fire resistance period required is defined in Table 2 of HTM 05-02.

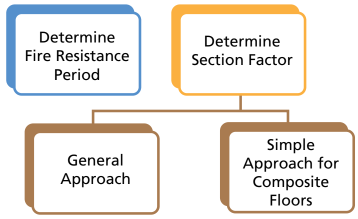
In Scotland, special Annexes 2A & 2B in Technical Handbook 2 provide guidance for healthcare buildings.

HTM 05-02 Table 2: Fire resistance of elements of structure		
	Minimum period of fire resistance provided by compartmentation	
	Unsprinklered	**Sprinklered**
Single storey healthcare buildings	30 minutes	30 minutes
Healthcare buildings with storeys up to 12m above ground or basements no more than 10m deep	60 minutes	30 minutes (60 minutes in respect of basements)
Healthcare buildings with storeys over 12m above ground or basements more than 10m deep	90 minutes	60 minutes
Healthcare buildings with storeys over 30m	120 minutes	90 minutes

Shopping centres

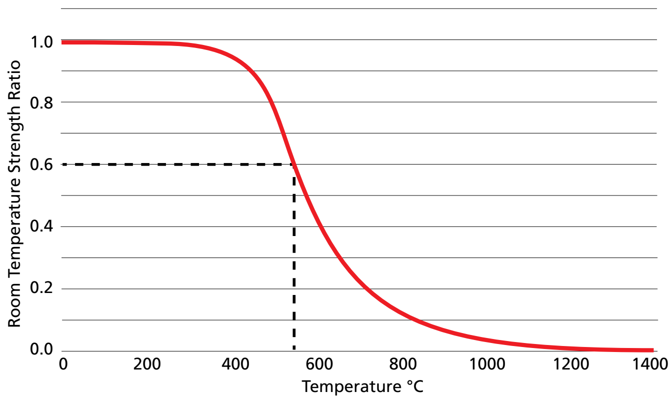
It is acknowledged that the provisions given for single shops in Section 11.7 of Approved Document B may not be suitable for shops that form part of a complex. The Approved Document therefore states that to ensure a satisfactory standard of fire safety in shopping complexes, alternative measures and additional compensatory features are required. Such features are set out in Sections 5 and 6 of BS 5588-10. Structural fire resistance requirements for elements of structure in the standard are 120 minutes and provision of a life safety sprinkler system is required.

Fire Protection



Introduction

Effect of temperature on steel strength



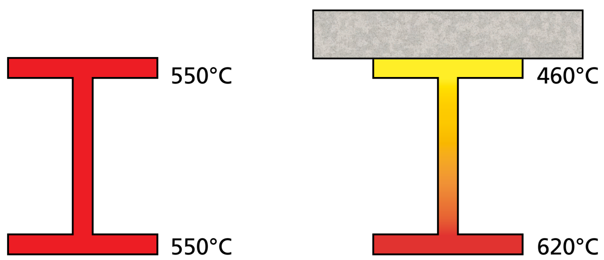
Fire limit state loading is an accidental loadcase and is therefore subject to lower load factors than ultimate limit state. Looking purely at applied loading, a member at 100% capacity under ultimate limit state load factors would typically be at only 60% capacity with the fire limit state load factors applied instead.

Any fire protection provided must therefore maintain the structural steelwork at a minimum of 60% of its room temperature strength.

550°C is limiting temperature for members heated on four sides. 620°C is limiting temperature for beams supporting a floor slab

All materials lose strength as they get hot and the plot of strength against temperature is shown for steel. To ensure 60% strength of the steelwork and therefore maintain the stability of a building, the temperature of the steelwork must not exceed 550°C. The design of fire protection is therefore based on this limiting temperature for elements exposed to fire on four sides.

Temperature profile in steel sections

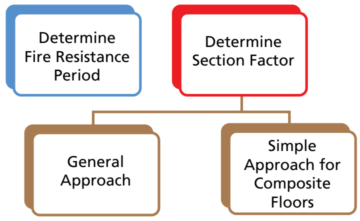


Fully loaded beam exposed on four sides, fails at 550°C

Fully loaded beam exposed on three sides, fails at 620°C

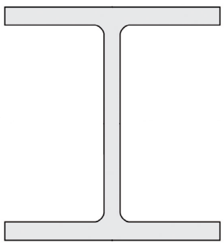
For a beam supporting a concrete slab, temperature profile also has an impact on load-bearing capacity. Tests have demonstrated that the limiting temperature for beams in this arrangement is 620°C.

This increased temperature is achieved because the heat sink effect of the concrete slab generates a significant temperature profile across the section. When the hotter part of the section reaches 550°C, it yields plastically and transfers load to the cooler regions of the section, which still acts elastically. As the temperature rises further, more load is transferred from the hot region by plastic yielding until eventually the load in the cool region becomes so high that it too becomes plastic and the member fails at 620°C. The design of fire protection is therefore based on this limiting temperature for beams supporting a concrete slab exposed to fire on three sides.

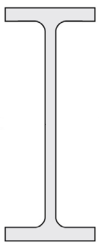


Determine the Section Factor

Low section factor
Slow heating



High section factor
Fast heating



The section factor is a way of describing the heating rate of a member, which is a key factor in determining fire resistance for that section. The shape of the member governs the time taken for it to reach its failure or limiting temperature and varies according to the relative dimensions of the section. A heavy, massive section will heat up more slowly than a light, slender section. This effect is quantified in the section factor.

Section factor is called A/V in BS EN 1993 and Hp/A in BS 5950 but the value is the same for both

The section factor is defined differently by BS EN 1993-1-2 and BS 5950-8, though the number is the same for both.BS EN 1993-1-2's A/V ratio dominates most current literature although BS 5950-8's Hp/A ratio can sometimes still be seen.

In BS EN 1993-1-2, it is defined as the surface area of the member per unit length (A_m) divided by the volume per unit length (V). It is measured in units of m^{-1}. BS 5950-8's terminology is perhaps simpler to understand as it defines the section factor as the heated perimeter of the exposed cross section (Hp) divided by the total cross sectional area (A). Both approaches give the same value for sections of constant cross-sectional area.

Section factors vary from $25m^{-1}$ for very large sections to over $300m^{-1}$ for small, slender sections.

Whilst the section factor can be calculated, it is usual to refer to the *Advance* Section Property Brochure or the eBlue Book to determine the section factor for UKB, UKC, UKPFC, UKA or UKT profiles. As can be seen, the section factor is also dependent on whether a boxed out fire protection system or a coating-based section profile system is adopted and on whether or not the section is carrying a floor slab.

Where a section is partially protected, for example when a column is built into a perimeter wall, the section factor should be calculated as standard tables do not represent this arrangement. The procedure is straightforward and a worked example is given in the online article on Calculating Section Factors.

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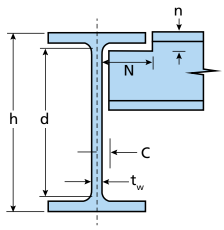
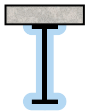
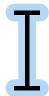
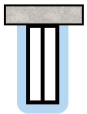
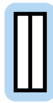
Articles of interest:

- CALCULATING SECTION FACTORS
- THE BLUE BOOK

Extract from Advance® Section Property Tables



UKB

Designation		A/V ratio (m^{-1})			
					
Serial size		Profile 3 sides	Profile 4 sides	Box 3 sides	Box 4 sides
457 x 191	161	75	85	60	65
	133	90	100	70	80
	106	110	125	85	100
	98	120	135	90	105
	89	130	145	100	115
	82	140	160	105	125
	74	155	175	115	135
	67	170	190	130	150

Where multiple layers of fire protection are required, it will sometimes be more economic to reduce the section factor by increasing the weight of the steel member to achieve the fire resistance with a single application

It should be noted that cellular beams can display complex failure mechanisms in fire. Research in this area has been led by The Association for Specialist Fire Protection (ASFP) and fire protection manufacturers. Working with the SCI, the ASFP have developed structural models for beams with circular and rectangular web openings.

These models enable the calculation of the limiting temperature as a function of beam geometry and load. This can then be used to determine the correct fire protection thickness for the required fire resistance period, based on a section factor calculated using the formula:

Section factor = 1400/t

where t is the web thickness in mm (if the web thickness varies, this is the bottom web thickness)

For all types of section, a reduced section factor may result in thinner fire protection to achieve the same fire resistance. Where multiple layers of fire protection are required, it will sometimes be more economic to reduce the section factor by increasing the weight of the steel member to achieve the fire resistance with a single application. The marginal increase in weight may be more than offset by the reduction in fire protection costs by application of a single layer of protection rather than multiple layers.

Having determined the section factor, the designer can then assess the type of protection required (if any) to achieve the required fire resistance period.

www.asfp.org.uk

Recommended reference:

• ASFP'S YELLOW BOOK GIVES DETAILED GUIDANCE ON FIRE PROECTION DESIGN PROCEDURES AND IS FREE TO DOWNLOAD

Unprotected Steel

Unprotected steel is deemed to have 15 minutes fire resistance in the Approved Documents

Approved Documents deem hot rolled structural sections and tubes under full design load in fire to have 15 minutes inherent fire resistance if they meet the following criteria:

- Beams supporting concrete floors – section factor of <230m^{-1}
- Sections heated on four sides (columns) – section factor <180m^{-1}
- Bracing – section factor <210m^{-1} (Note: bracing only requires fire protection where it provides structural stability to the building to ensure safe evacuation in the event of fire. There is often therefore no requirement to fire protect bracing in single storey sheds)

The vast majority of hot rolled structural sections meet these criteria. The small number of sections which have higher section factors may do so if the load applied at ultimate limit state is reduced. The threshold levels for these sections are given in the tables below for BS 5950-8 design.

UKB Maximum load ratio for 15 minutes fire resistance

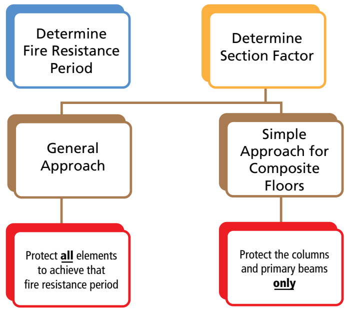
Section Size	Section factor (A/V)	Maximum load ratio[1] non-composite	Maximum load ratio 100% shear connection
127×76UKB13	280m^{-1}	0.53	0.41
152×89UKB16	270m^{-1}	0.53	0.41
178×102UKB19	260m^{-1}	0.55	0.43
203×102UKB23	235m^{-1}	0.64	0.5
203×133UKB25	245m^{-1}	0.54	0.42
254×102UKB22	280m^{-1}	0.47	0.37
254×102UKB25	250m^{-1}	0.58	0.45
305×102UKB25	280m^{-1}	0.49	0.38
305×102UKB28	250m^{-1}	0.59	0.47
356×127UKB33	250m^{-1}	0.59	0.46
406×140UKB39	240m^{-1}	0.59	0.46

[1] Load ratio is defined as load applied in fire condition divided by load capacity of the section at ambient temperature.

UKC Maximum load ratio for 15 minutes fire resistance

Section Size	Section factor (A/V)	Slenderness ratio	Maximum load ratio
152UKC23	305m^{-1}	81	N/A, Choose next in the section range
152UKC30	235m^{-1}	78	0.36
152UKC37	195m^{-1}	77	0.45
203UKC46	200m^{-1}	58	0.51

Fire Protecting Structural Steelwork



Structural fire protection systems

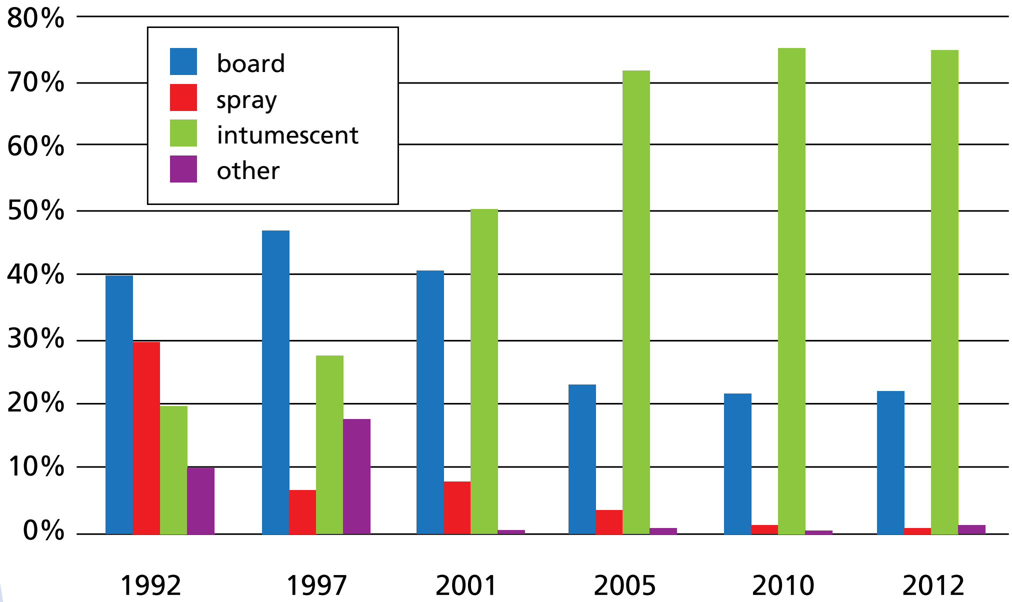
Thin film intumescent coatings and board systems dominate the UK market

UK fire protection market share over the last 20 years is shown in the chart below. The most striking point to note is the rise in popularity of thin film intumescent coatings on steel framed buildings. They have gone from a 20% market share in 1992 to 75% in 2012.

Industry dynamics have been the catalyst for continuous development in the science of intumescent coatings. Systems continue to develop but those in use today are more efficient and much more economic than those available 20 years ago. This has resulted in real term costs that are a fraction of what they were in the 1990s. The market share for intumescent coatings has also been assisted by the development of offsite applied systems, which contribute 20% to intumescent's total 75% market share.

The systems commonly used are thin film intumescent coatings, board protection, partial protection and concrete filled hollow sections. Implications on design of the floor slab are also considered for mesh and fibre reinforced systems.

Market Share of Fire Protection Systems



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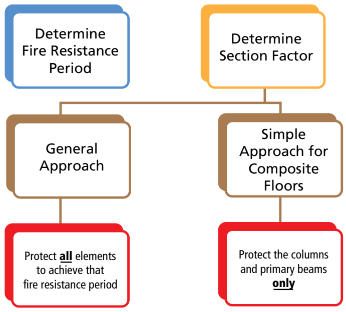
Article of interest:

- FIRE PROTECTING STRUCTURAL STEELWORK



Finishes must be detailed to allow room for expansion of the intumescent coating

Thin film intumescent coatings

Thin film intumescent coatings are paint-like materials which are inert at low temperatures but which provide insulation as a result of a complex chemical reaction at temperatures of approximately 200-250°C, a threshold temperature at which the properties of steel are still unaffected.

As the coating reacts, it swells to provide an expanded layer of low conductivity char that insulates the steel section. Typical expansion ratios are about 50:1, i.e. a 1mm thick coating will expand to about 50mm when affected by fire.

Thin film intumescent coatings are predominantly used in buildings where the fire resistance requirements are up to 90 minutes. In recent years, a number of products have been developed which can provide 120 minutes fire resistance.

Intumescent coatings can be applied either on-site or offsite and can be used to achieve attractive surface finishes. If a decorative or bespoke finish is required, this should be included in the specification. Thin film intumescents have the added advantages that they can easily cover complex shapes and post-protection service installation is relatively simple.

Offsite intumescent coatings are widely used in the UK, but generally only used on projects where the programme saving offsets the extra cost of additional work in the shop. The majority of commercial buildings in London tend to use this method.

Offsite application tends to be used where a non-aesthetic finish is required. Aesthetic finishes have been achieved using offsite application but it requires an additional level of care and attention. This is because bolts have to be coated on-site along with occasional damage during transit. As it is difficult to match the appearance of the on-site application to the rest of the coating, this adds a layer of complexity to the work.

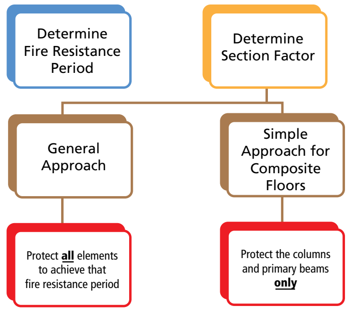
UKB/UKCs - 4 sided exposure - indicative data			
A/V	Critical temperature 550°C		
	Dry film thickness (mm) for fire resistance period		
	30 min	60 min	90 min
30	0.261	0.324	0.470
50	0.261	0.347	0.690
70	0.261	0.413	0.959
90	0.261	0.490	1.212
110	0.265	0.582	1.394
130	0.276	0.663	1.589
150	0.289	0.747	1.929
170	0.306	0.842	2.147

UKBs - 3 sided exposure - indicative data			
A/V	Critical temperature 620°C		
	Dry film thickness (mm) for fire resistance period		
	30 min	60 min	90 min
30	0.265	0.265	0.420
50	0.265	0.276	0.494
70	0.265	0.319	0.679
90	0.265	0.357	0.907
110	0.265	0.419	1.099
130	0.286	0.487	1.300
150	0.295	0.545	1.493
170	0.300	0.626	1.727

Intumescents are specified in terms of dry film thickness, based on the heating profile (3 sided or 4 sided), the section factor of the steel to be protected and the required fire resistance period. The requirements of each proprietary system are presented separately for open sections (UKB/UKCs) and for closed sections (Celsius). They can be found either in manufacturer's literature or in the ASFP's Yellow Book.

Behaviour of cellular beams in fire is complex. It is recommended that beam manufacturers and coating manufacturers are consulted

Cellular beams are normally protected using intumescent coatings. Designers should ensure that the beam manufacturer provides a limiting temperature for his product. The proposed coating should not only meet this limiting temperature but have also been tested to the ASFP's fire testing protocol for cellular beam protection. Further details on fire protection of cellular beams can be found in the ASFP's Yellow Book.



Boards

Boards are widely used for structural fire protection in the UK. They offer a clean, boxed appearance and have the additional advantage that application is a dry trade and can be applied to unpainted steelwork.

There are broadly two families of board protection, lightweight and heavyweight. Lightweight boards are not suitable for decorative finishes and are used where aesthetics are not important. Heavyweight boards will generally accept decorative finishes and are therefore used where aesthetics are important.


Courtesy of Promat

Boards are specified in terms of thickness required to achieve the limiting temperature for a particular section factor. The requirements of each proprietary system can be found either in manufacturer's literature or in the ASFP's Yellow Book.

In rare instances, cellular beams may be protected by boards. In this case the procedure given in the ASFP's Yellow Book should be followed.

UKB/UKCs - 4 sided exposure - indicative data			
A/V	**Critical temperature 550°C**		
	Board thickness (mm) for fire resistance period		
	30 min	**60 min**	**90 min**
30	15	15	15
50	15	15	15
70	15	15	15
90	15	15	15
110	15	15	20
130	15	15	20
150	15	15	20
170	15	15	20

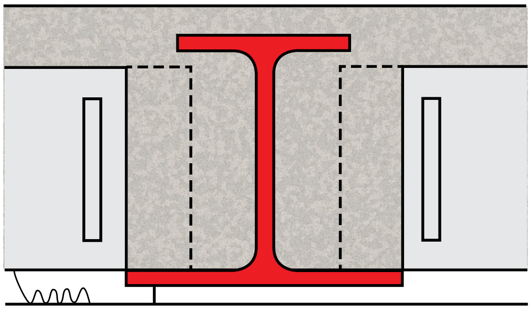
UKBs - 3 sided exposure - indicative data			
A/V	**Critical temperature 620°C**		
	Board thickness (mm) for fire resistance period		
	30 min	**60 min**	**90 min**
30	15	15	15
50	15	15	15
70	15	15	15
90	15	15	15
110	15	15	15
130	15	15	15
150	15	15	20
170	15	15	20

How to determine protection requirements for a partially exposed column can be found on ***www.steelconstruction.info***

Partial protection

Most commonly, partial protection refers to the general arrangement of either a beam cast into the depth of the floor slab that it supports or a column built into a cavity wall.

The most common example of this is the Slimdek system from Tata Steel, but it also applies to Slimflor beams (UKCs with a plate welded to the bottom flange to provide a similar profile to the Slimdek ASB) or for a standard rolled UKB supporting the floor slab on shelf angles to minimise the depth of construction.



Rather than providing protection to the required fire resistance period, designers can take advantage of the benefit of the heat sink effect of the slab to reduce the fire protection or eliminate it altogether. The most common application of this approach is the use of Slimdek's FE range of ASBs to achieve a 60 minutes fire rating without having to provide any fire protection.

For a partially exposed column, the fire protection required can be calculated from the section factor of the exposed part of the member rather than conservatively using the value for the whole profile, as given in the tables.

This is straightforward to calculate and a worked example is given in the online article Calculating Section Factors.

Concrete Filled Hollow Sections

Steel Construction .info www.steelconstruction.info

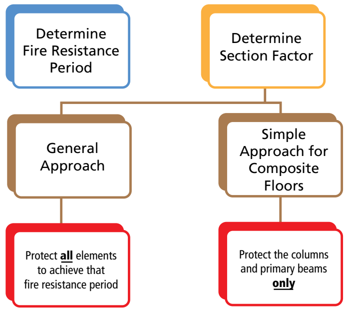
Articles of interest:

- CALCULATING SECTION FACTORS
- HOLLOW SECTIONS IN FIRE

By filling hollow sections with concrete, a composite section is produced resulting in increased load capacity compared to an unfilled section. For fire resistance periods of 60 minutes or greater, when using externally unprotected sections, they will usually need to contain reinforcement. Design of composite hollow sections in fire should be undertaken using the Firesoft design software from Tata Steel. Details at *www.tatasteelconstruction.com*

Fire protection may be provided by application of external fire protection, usually a thin coat intumescent. As the presence of the concrete core acts as a heat sink, the effective section factor should be used to determine the coating thickness required. Details of how to calculate the effective section factor can be found in the online article on Hollow Sections in Fire.

Design of Composite Steel Deck Floors for Fire



Reinforcement is the key to slab performance in fire

Composite steel deck floors consist of a profiled steel deck with a concrete slab. Mesh or fibre reinforcement is cast into the slab to control cracking, to resist longitudinal shear and, in the case of fire, to act as tensile reinforcement. Indentations in the profiled deck allow the concrete and steel to bond and share load. Composite action between the supporting beams and the concrete is created by welding shear studs through the deck onto the top flange of the beam.

ComFlor® 60 Span table - normal weight concrete

Span	Fire Rating	Slab depth (mm)	Mesh
Single span slab & deck	1 hr	130	A142
		130	A252
		160	A252
	1.5 hr	140	A193
		170	A252
	2 hr	150	A193
		180	A252
Double span slab & deck	1 hr	130	A142
		130	A252
		160	A252
	1.5 hr	140	A193
		170	A252
	2 hr	150	A193
		180	A252

FibreFlor CF60 Span table - normal weight concrete

Span	Fire Rating	Slab depth (mm)	FibreFlor dosage (kg/m²)
Single span slab & deck	1 hr	130	26
		130	26
	1.5 hr	140	31
		170	31
	2 hr	150	36
		180	36
Double span slab & deck	1 hr	130	26
		130	26
	1.5 hr	140	31
		170	31
	2 hr	150	36
		180	36

In the fire condition standard practice amongst designers is to assume that the steel deck makes no contribution to overall strength. The deck does however play an important part in maintaining integrity and insulation. It acts as a diaphragm preventing the passage of flame and hot gases, and it controls spalling. It is not normally necessary to fire protect the exposed soffit of the deck.

In fire the reinforcement becomes effective and the floor behaves as a reinforced slab with the loads being resisted by the bending action. Catenary action may develop away from the edges of the floor with the reinforcement then acting in direct tension rather than bending. Slab failure occurs when the reinforcement yields.

Most steel decking manufacturers provide software for the design of floors using their products and also produce literature with quick reference information with the reinforcement required to achieve the desired fire resistance period.

Filling of voids

Research has shown that filling the voids between the raised parts of the deck profile and the beam top flange in composite steel deck construction as part of the beam fire protection strategy is not always necessary. The upper flange of a composite beam is so close to the plastic neutral axis that it makes little contribution to the bending strength of the member as a whole. Thus, the temperature of the upper flange can often be allowed to increase, with a corresponding decrease in its strength without adversely affecting the capacity of the composite system significantly.

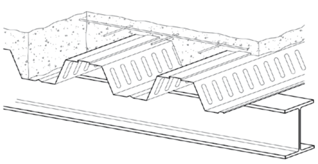
Treatment of voids in floor slabs depends on deck profile

Voids under decking with dovetail or re-entrant profiles can remain unfilled for all fire resistance periods. The larger voids which occur under trapezoidal profiles can be left open in many instances for fire ratings up to 90 minutes, although some increase to the thickness of fire protection applied to the rest of the beam may be necessary.

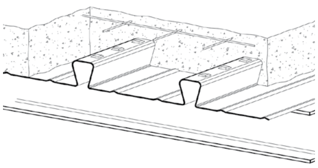
The ASFP offers two approaches to allow voids to be unfilled. Table 18 provides guidance on modification to fire protection thicknesses and Table 19 provides guidance on temperature modifications for beams with specified limiting temperatures.

For standard UKB sections, Table 18 offers the most straightforward procedure to enable voids to be left unfilled.

Trapezoidal deck



Dovetail deck



ASFP Yellow Book – Table 18: Recommendations for beams assessed at 550°C or 620°C

TRAPEZOIDAL DECK				
Beam type	**Fire protection on beam**	**Fire resistance (minutes)** Up to 60	90	Over 90
Composite	Materials assessed at 550°C	No increase in thickness	Increase in thickness by 10% or assess thickness using A/V increased by 15%*	Fill voids
Composite	Materials assessed at 620°C	Increase in thickness by 20% or assess thickness using A/V increased by 30%*	Increase in thickness by 30% or assess thickness using A/V increased by 50%*	Fill voids
Non-composite	All types	Fill voids above the flange		

*The least onerous option may be used

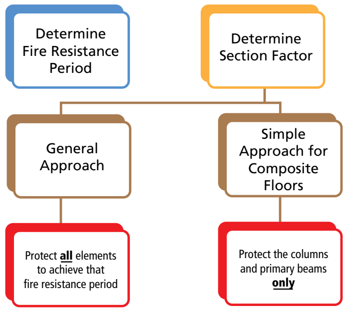
For cellular beams refer to manufacturer's specific data

DOVETAIL DECKS				
Beam type	**Fire protection on beam**	**Fire resistance (minutes)** Up to 60	90	Over 90
Any	All types	Voids may be left unfilled for all periods of fire resistance		

www.steelconstruction.info

Article of interest:

• DESIGN OF COMPOSITE STEEL DECK FLOORS FOR FIRE



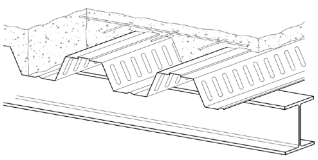
Voids must be filled where a beam forms part of a compartment wall

It should be noted that Tables 18 and 19 were intended to be used for solid beams only. When considering unfilled voids above cellular beams, the ASFP states that Table 18 should not be used and that Table 19 should only be used if the beam design specifies a limiting temperature provided by a suitably qualified structural engineer.

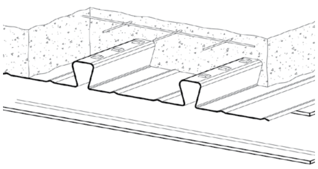
Designers should take care that voids are filled where the beam forms part of the compartment wall to ensure the integrity of the compartment. It should be noted that the material used to fill the voids does not have to be the same as that used to protect the beam, though it is required to meet the same fire resistance period.

In the rare case where non-composite steel deck construction is used, the voids must always be filled if trapezoidal decking is used.

Trapezoidal deck



Dovetail deck



ASFP Yellow Book – Table 19:
Temperature modifications for beams with specified limiting temperature

TRAPEZOIDAL DECK				
Beam type	**Temperature reductions for fire resistance (minutes) of**			
	30	**60**	**90**	**Over 90**
Composite	50°C	70°C	90°C	Fill voids
Non-composite	Fill voids			
For cellular beams refer to manufacturer's specific data				

DOVETAIL DECKS				
Beam type	**Temperature reductions for fire resistance (minutes) of**			
	30	**60**	**90**	**Over 90**
Any	No temperature modifications are required			
For cellular beams refer to manufacturer's specific data				

When to use Structural Fire Standards

In most instances, the performance of components and systems in fire is demonstrated through the standard test. However, there are occasions where the designer may wish to consider using structural fire standards (BS 5950-8, BS EN 1993-1-2 or BS EN 1994-1-2) to reduce the fire protection required to achieve the fire rating.

The limiting temperature method allows the designer to assess the need, or otherwise, for fire protection by comparing the temperature at which the member will fail (the limiting temperature) with the temperature of the hottest part of the section at the required fire resistance time (the design temperature). In BS 5950-8 this is done via a set of prepared tables. If the limiting temperature exceeds the design temperature, no protection is necessary.

This can be of particular value when assessing whether unprotected steel will achieve 30 minutes fire resistance without protection. It can also be of value when calculating failure temperatures to assess how much fire protection is required for higher periods of fire resistance. For example, if it can be shown that the failure temperature of a beam carrying a non-composite floor slab is say 700°C rather than 620°C (which is possible if for any reason the load on the beam is low) significant reductions in fire protection thickness may be possible. This can be important for any fire protection material but is particularly useful with intumescent coatings at high fire resistance periods and/or high section factors.

www.steelconstruction.info

Article of interest:

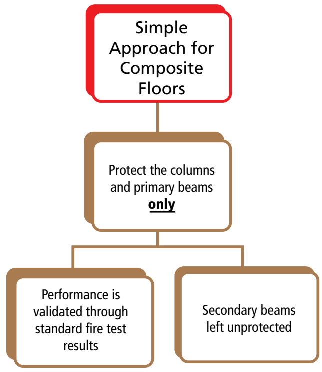
- STRUCTURAL FIRE ENGINEERING

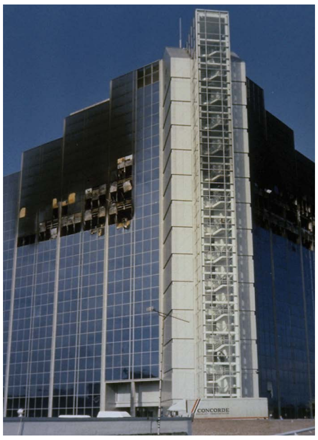
For external steelwork, the most common form of fire protection is thin film intumescent coating. It may be possible to reduce the fire protection through calculation since in the event of a fire it will be heated only by flames emanating from windows or other openings in the building façade. This will typically be less severe than the heating profile to which internal steelwork is exposed. BS EN 1993-1-2 Appendix B contains a method for calculation of the size and temperature of flames from openings and radiation and convection parameters for heat transfer calculations.

Steel is the most tested material in fire

Simple Approach for Composite Floors

Cardington Fire Tests



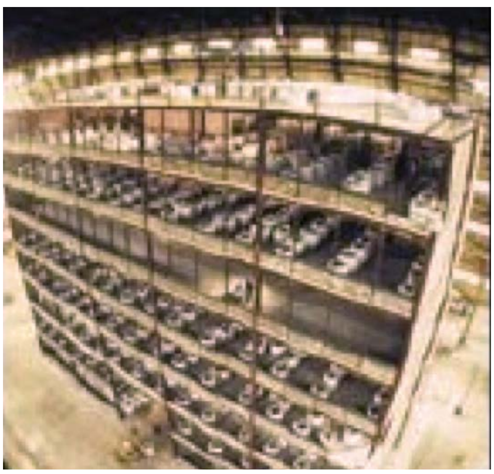


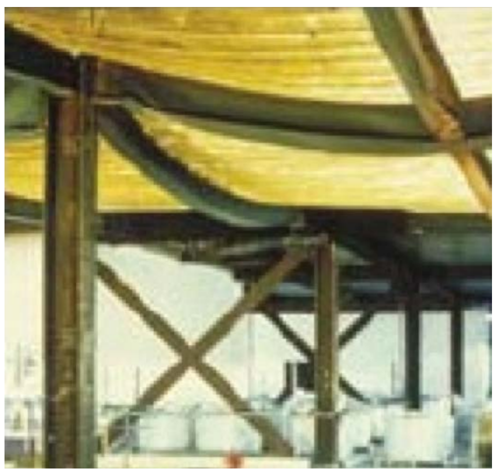
A fire at Broadgate Phase 8 in 1990 was the catalyst for a series of full-scale fire tests that transformed the understanding of how structural steelwork behaves in fire. The composite steel deck structure had some partially applied fire protection and was subject to a four hour fire. According to the knowledge of how buildings behaved in fire at that time, Broadgate Phase 8 should have collapsed. That it not only survived but came through such an onerous fire relatively unscathed demonstrated that buildings with this framing and floor system had much greater fire resistance than could be expected by predictions based on standard fire tests on individual sections in furnaces.

To explore this outcome, a series of seven full-scale fire tests were carried out on an eight-storey steel framed building with composite steel deck floors built at the Building Research Establishment's (BRE) Cardington facility between 1994 and 2003. The test programme comprised a single beam test and six compartment tests.

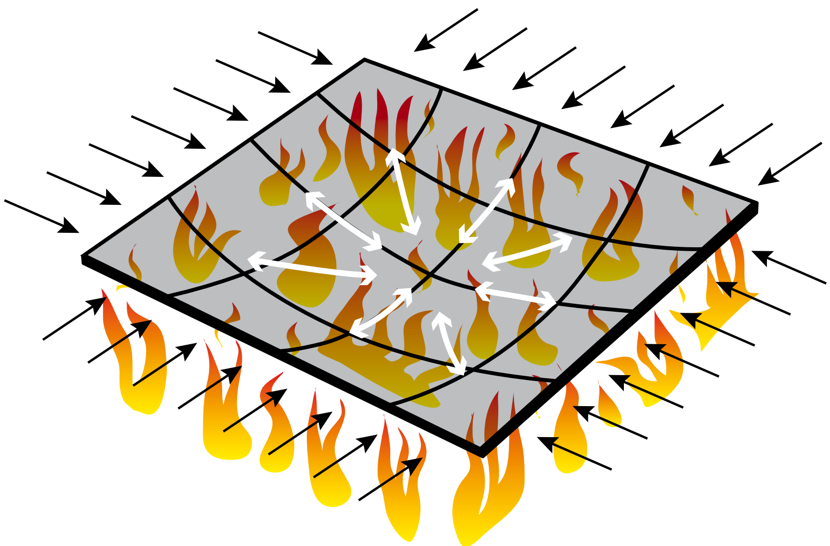
To obtain a direct comparison with the standard fire tests, the first test was carried out on a single unprotected beam and surrounding area of slab. Steel temperatures of over 1100°C were measured without failure, far greater than the temperature of 700°C at which the beam would have failed if tested in isolation.

Further tests were carried out in compartments varying in size from 50m² to 340m². Columns were protected but beams were not. Despite atmosphere temperatures of over 1200°C and temperatures on the unprotected steel beams of up to 1100°C, no structural collapse took place.

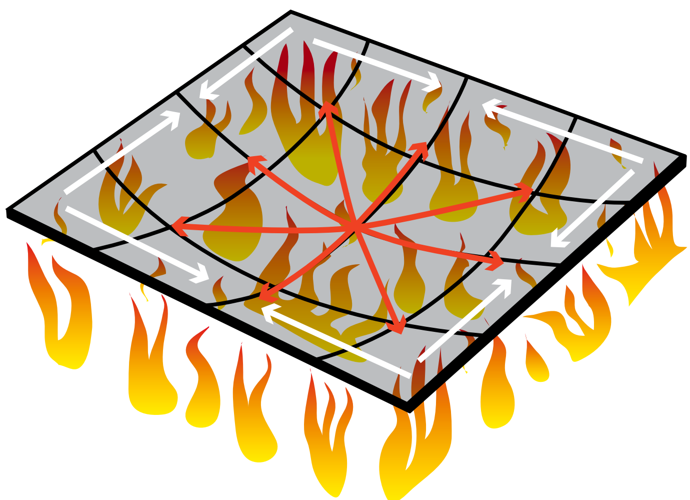




Compressive arching



Tensile membrane action



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Article of interest:

- STRUCTURAL FIRE ENGINEERING

The standard fire test doesn't reflect how buildings behave in real fires

It was found that a composite steel floor plays a crucial role in providing enhanced fire resistance not apparent by tests on single isolated elements of construction. Leaving the beams unprotected enabled the slab to deflect and to develop tensile membrane action at high temperatures. This provided greatly enhanced load carrying capacity.

The development of tensile membrane action was found to be a two stage process. At low deflections, there was compressive arching of the slab against the adjacent structure and thermal buckling of the slab.

At high deflections, tensile membrane action developed with biaxial tension in the reinforcement at the centre of the slab and a compressive ring in the concrete around the edge of the panel, rather like the rim and spokes of a bicycle wheel.

All that was required to develop tensile membrane action was to provide vertical support on all four edges of a slab panel and provide reinforcement to the slab.

The design strategy to take advantage of tensile membrane action requires the primary beams and columns to be fire protected, the primary beams to be designed to resist the additional compressive loading from the slab at low deflection and for the slab to be checked to ensure that there is sufficient tension reinforcement to support tensile membrane action between the protected primary beams at high temperature. The secondary beams must be left unprotected.

Design Process


Courtesy of Arup Fire

Following the Cardington tests, a number of simple structural models were developed which combine the residual strength of steel composite beams with the strength of the slab in fire. These models use the combined yield line and membrane action approach described in BRE Digest 462 to assess performance of a slab designed to generate tensile membrane action.

Using these models, the designer is able to leave large numbers of secondary beams unprotected in buildings requiring 30 to 120 minutes fire resistance although some compensating features, such as increased mesh size and density, may be required.

The most widely used of these models is TSlab v3, a straightforward spreadsheet tool developed by the SCI and Tata Steel. It is Eurocode compatible but, as a simple tool, it is restricted to rectangular grids.

Procedure for analysis using TSlab v3 is:

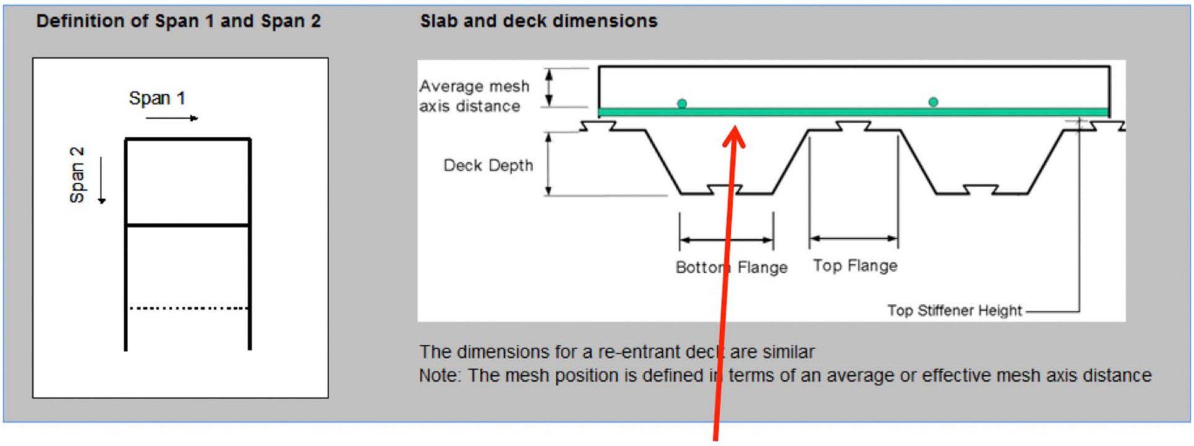
1. Input structural information
   a. Slab panel general arrangement
   b. Slab depth, deck profile, mesh reinforcement and concrete grade
2. Input loading
   a. Slab self weight is auto calculated
3. Specify beam sections and steel grade
   a. Secondary beams
   b. Primary beams
   c. Panel continuity for each primary beam (internal or external beam)
4. Input fire resistance period
   a. Input fire resistance required
5. Analyse using standard temperature-time fire curve

Results for the slab and perimeter beams are presented in tabular format with graphical plots of temperature, capacity and deflection over time for each component too. Slab capacity over time is presented in terms of the maximum unity factor. Mesh area and position are usually the critical factors to consider should the floor slab fail during an initial assessment.

A detailed description of TSlab and its methodology is in SCI P390 Guide, which updates and replaces P288 Fire Safe Design – a new approach to multi-storey steel framed buildings. TSlab v3 is free to download along with its user manual from *www.tatasteelconstruction.com*

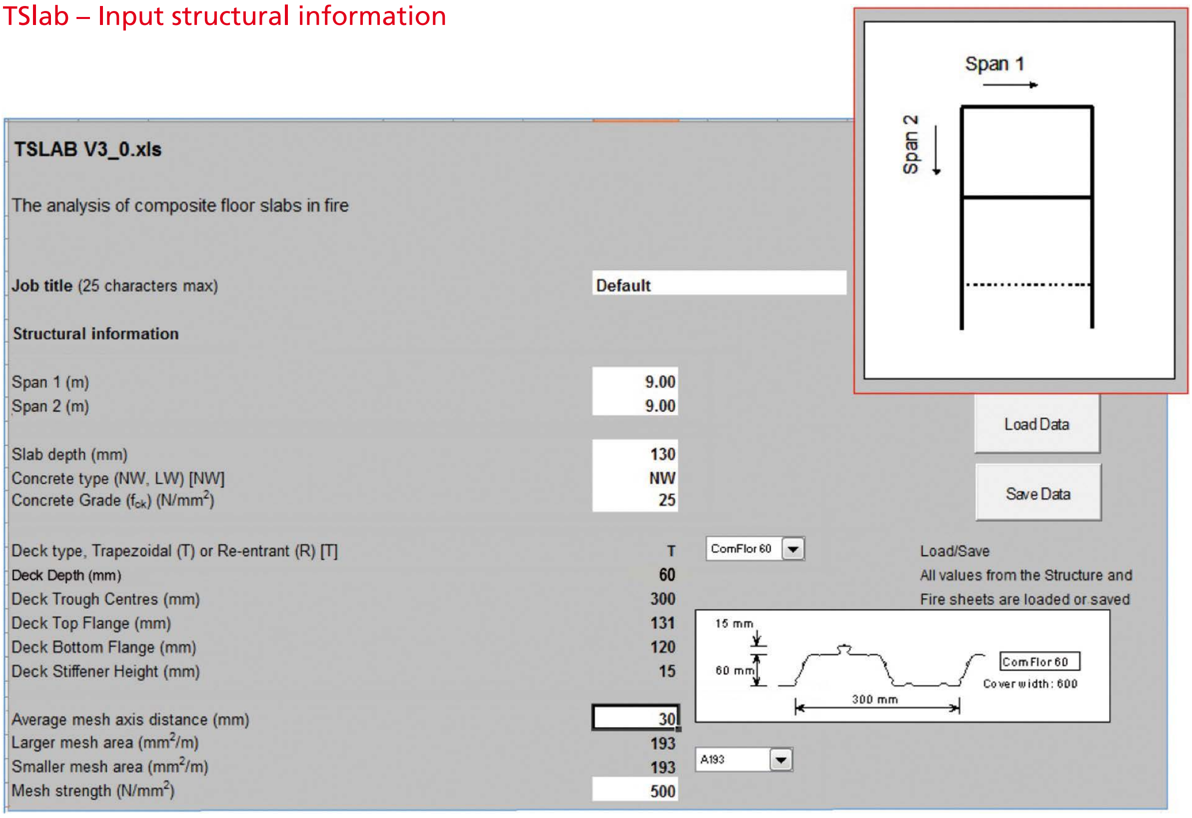
TSlab Design Tool Walkthrough

TSlab – Depends on a clear definition of the slab with critical dimensions



The mesh size and position is the critical parameter

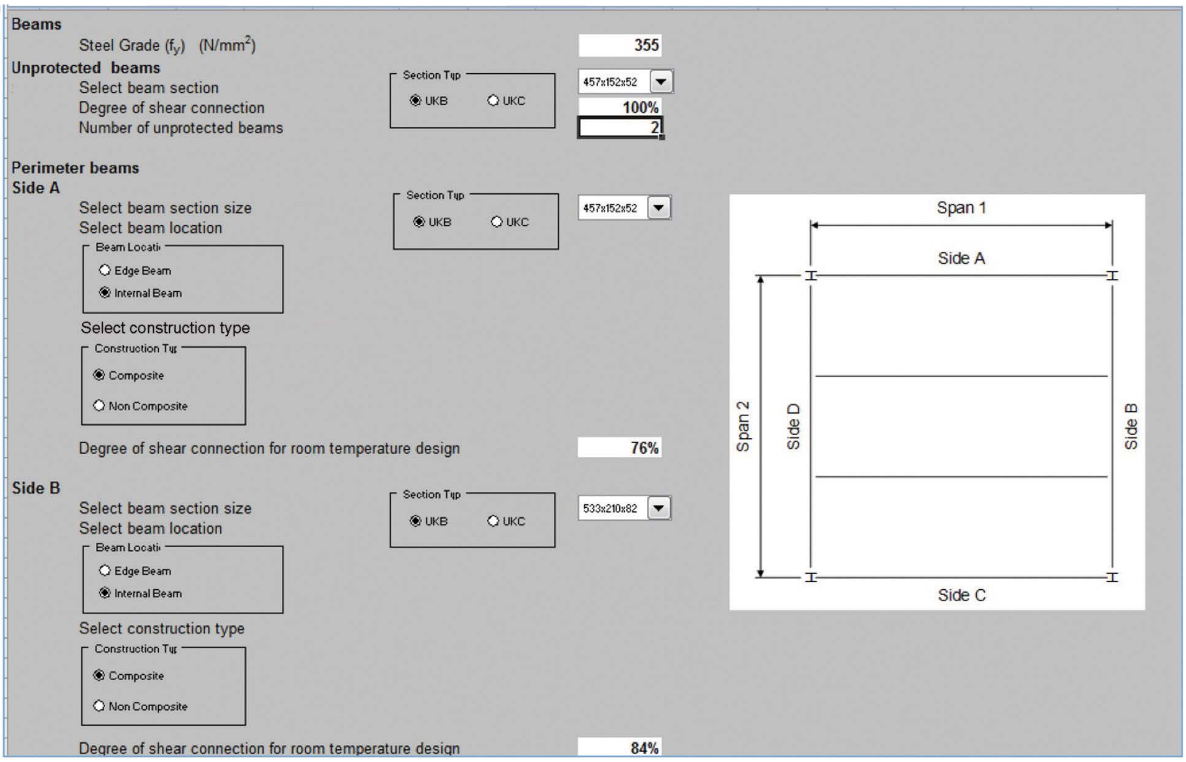
TSlab – Input structural information



TSlab – Input loading

Loading		
Normal (cold) (EN1990 Eqn 6.10)		
Leading variable action (kN/m²)	4.00	($\gamma_{Q,i}$ = 1.50)
Accompanying variable action (kN/m²)	1.00	($\gamma_{Q,i}$ = 1.50: $\psi_{0,i}$ = 0.7)
Dead load including beam, excluding slab (kN/m²)	1.00	($\gamma_{G,j,sup}$ = 1.35)
Calculated slab weight including mesh (kN/m²)	2.63	($\gamma_{G,j,sup}$ = 1.35)
Fire (EN1990 Eqn 6.11)		
Combination factor for leading variable action, $\psi_{1,1}$	0.50	
Combination factor for accompanying variable action, $\psi_{2,i}$	0.50	

TSlab – Specify steel sections and steel grade



TSlab – Input fire resistance period and analyse

Parametric Fire	
Compartment length (m)	9.00
Compartment width (m)	9.00
Compartment height (m)	4.00
Window height (m)	1.00
Window length (m)	M
Percentage open window	90
Fire Load (MJ/m^2)	500
Wall lining factor (J/m^{2}s$^{1/2}$K)	720
Combustion factor	1.00
Growth rate, slow, medium,fast (S, M, F) [M]	M

Analyse using parametric fire

Standard temperature-time curve	
Fire resistance (minutes)	60

Analyse using Standard Fire

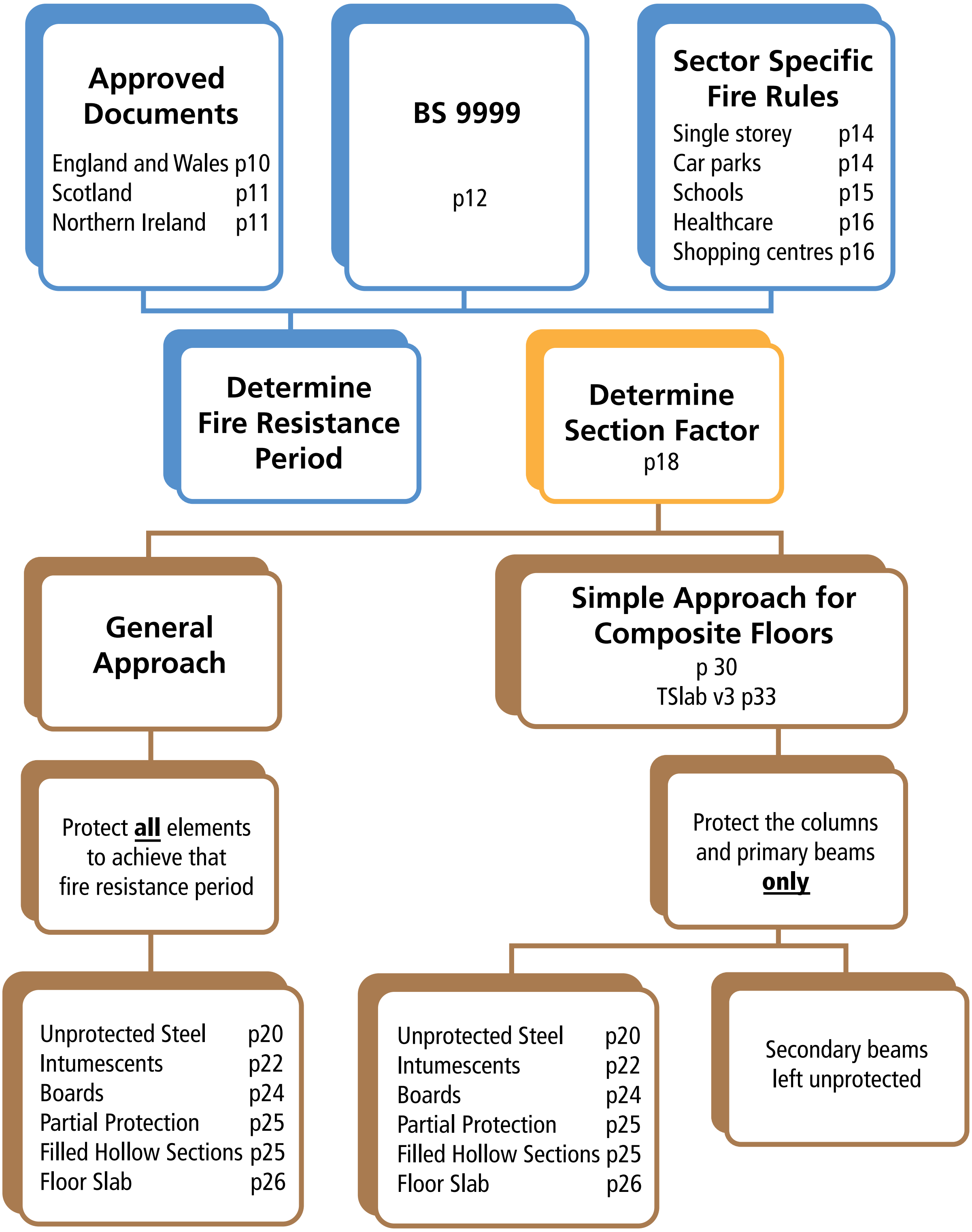
TSlab – Presentation of results

Results of slab resistance calculations

		Time	Beam	Mesh	Slab top	Slab bottom	Beam capacity	Displa-cement	Slab yield	Enhanc-ement	Slab capacity	Total capacity	Unity factor
			----------Temperatures---------										
		(mins)	(°C)	(°C)	(°C)	(°C)	(kN/m^2)	(mm)	(kN/m^2)		(kN/m^2)	(kN/m^2)	
Mesh area in long span	193												
Mesh area in short span	193												
		0	20	20	20	20	25.40	190	0.79	2.81	2.23	27.63	0.22
		5	144	25	20	138	25.40	250	0.79	3.41	2.70	28.10	0.22
		10	319	36	22	283	25.37	322	0.79	4.12	3.27	28.64	0.21
		15	486	52	26	419	20.81	389	0.79	4.78	3.79	24.60	0.25
		20	622	63	33	524	11.03	439	0.79	5.28	4.18	15.21	0.40
		25	719	78	39	600	5.56	474	0.79	5.63	4.46	10.02	0.61
		30	784	109	48	658	3.48	499	0.79	5.87	4.66	8.13	0.75
		35	828	125	58	703	2.60	516	0.79	6.05	4.79	7.39	0.83
		40	859	131	64	739	2.18	532	0.79	6.20	4.92	7.10	0.86
		45	883	135	68	770	1.86	546	0.79	6.34	5.02	6.89	0.89
		50	902	172	77	797	1.62	555	0.79	6.43	5.09	6.71	0.91
		55	919	204	80	820	1.53	564	0.79	6.52	5.17	6.70	0.92
		60	934	226	83	840	1.45	574	0.79	6.61	5.24	6.69	<0.92>

Maximum unity factor 0.92

Floor slab adequate


Approved Documents
England and Wales p10
Scotland p11
Northern Ireland p11
BS 9999
p12
Sector Specific Fire Rules
Single storey p14
Car parks p14
Schools p15
Healthcare p16
Shopping centres p16
Determine Fire Resistance Period
Determine Section Factor
p18
General Approach
Simple Approach for Composite Floors
p 30
TSlab v3 p33
Protect all elements to achieve that fire resistance period
Protect the columns and primary beams only
Unprotected Steel p20
Intumescents p22
Boards p24
Partial Protection p25
Filled Hollow Sections p25
Floor Slab p26
Unprotected Steel p20
Intumescents p22
Boards p24
Partial Protection p25
Filled Hollow Sections p25
Floor Slab p26
Secondary beams left unprotected

Summary

More is known about structural steelwork in fire than any other construction material. Its performance has been determined through a series of full-scale fire tests, which are unparalleled for other materials. There is certainty in how structural steelwork performs and certainty that finite element models and other simpler tools accurately reflect how it actually performs in fire.

Determining the fire protection requirements for the structural steelwork of a building is a simple and straightforward process, consistent across all types of common building types.

The first step is to determine the fire resistance period that the structure is required to withstand in order to ensure adequate time for the building to be evacuated in the event of a fire. The fire resistance period is determined by use of either the prescriptive approach of Approved Documents or through the risk based approach set out in BS 9999. Reference should also be made to sector specific fire rules that may supplement the requirements of the other documents.

The second step is to determine the section factor of the structural steelwork specified. The section factor (A/V or Hp/A) is used to describe the heating rate of a member, with lower numbers indicating stockier sections that are slower to heat than slender members with higher section factors. Section factors can be calculated but would normally be selected from *Advance* Section Property Tables or from the eBlue Book. It varies dependent on profile of fire protection (boarded or intumescent) and on exposure of the member to the fire (3 or 4 sided).

The final step is to derive the fire protection requirement based on the required fire resistance period and section factor.

Unprotected steelwork is usually deemed to have 15 minutes inherent fire resistance. For higher fire resistance periods, fire protection is usually required. In the UK, this will typically be provided by either intumescent coating or board.

Default temperatures for steelwork designed to BS 5950-8 are 550°C for members exposed to fire on 4 sides and 620°C for beams supporting a concrete floor, due to the heat sink effect of the slab. In both cases, the section factor should be used to determine the thickness of fire protection for that system from either manufacturer's literature or the ASFP's Yellow Book.

Cellular beams can display complex failure mechanisms in fire. They are normally protected using intumescent coatings and care should be taken to ensure specification of an appropriate product. It is recommended that designers consult both beam and coating manufacturers to ensure correct specification.

To determine fire performance of a floor slab, manufacturer's design tables should be used. Increased fire resistance periods will typically result in an increase in the reinforcement that must be provided. The ASFP's Yellow Book gives guidance on the filling of voids beneath different deck profiles. Beams forming part of a compartment wall will require the voids to be filled. Care should be taken when considering voids on floors supported by cellular beams.

The general approach is to fire protect all elements in a structure and demonstrate performance through standard fire test results. However, for composite floors, there is the option to use the simple modelling approach to leave secondary beams unprotected.

TSlab is a simple to use spreadsheet-based tool developed following the full-scale fire tests at Cardington. These tests demonstrated that a composite steel floor plays a crucial role in providing enhanced fire resistance not apparent by tests on single isolated elements of construction.

It provides a step-by-step approach for designers to ensure that a composite floor slab will develop tensile membrane action, allowing the secondary beams to be left unprotected. Critical to this design approach is the position and amount of reinforcement provided. TSlab can be downloaded from *www.tatasteelconstruction.com*

Assessment of Steelwork after a Fire

When considering whether steelwork that has been subject to fire can be re-used, a general rule of thumb is that if the steel is straight and there are no obvious distortions then it is probably still fit for purpose. At 600°C the yield strength and stiffness of steel is equal to about 40% and 30% respectively of their room temperature values. Any steel still remaining straight after the fire and which had been carrying an appreciable load was probably not heated beyond 600°C, will not have undergone any metallurgical changes and will therefore be fit for re-use.

Determining tensile strength from hardness test results

Grades	Brinell Hardness Number	Vickers Hardness Number	Ultimate Tensile Strength N/mm²
S355	187	197	637
S355	179	189	608
S355	170	179	559
S355 / S275	163	172	539
S355 / S275	156	165	530
S355 / S275	149	157	500
S275	143	150	481
S275	137	144	481
S275	131	138	461
S275	126	133	451
S275	121	127	431

However in practice it is recommended that, in all instances, some hardness tests should be carried out. For grade S275 steel, if the ultimate tensile strength resulting from the tests is within the range specified in the table, then the steel is probably reusable. For grade S355 steel additional tensile test coupons should be taken from fire affected high strength steel members when hardness tests show that:

- there is more than 10% difference in hardness compared to non-fire affected steelwork,

  or

- hardness test results indicate that the strength is within 10% of the specified minimum.

Where deflections are visible, general guidelines on the maximum permissible levels of deflection to ensure satisfactory performance are difficult to specify. The amount of deflection or distortion must be checked so that its effect under load can be calculated to ensure that the functioning of the structure is not impaired. Therefore every building should be considered as a separate case and the structural engineer involved in the reinstatement exercise must decide what level is acceptable to satisfy the relevant Codes.

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Article of interest:

- FIRE DAMAGE ASSESSMENT OF HOT ROLLED STRUCTURAL STEELWORK

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