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YELLOW BOOK

Fire protection for structural steel in buildings
5th Edition

(Volume 1 of 2)

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ASFP YELLOW BOOK

Amendments to Vol 1 (Amendments to Vol 2 included in the front of each product section)

DATE	SECTION	AMENDMENT SUMMARY	SOURCE
06/01/14	All	Fifth edition – major revision to include new EN test methods and revised procedures for intumescents and cellular beams	NR

Note:

Amendments may only be inserted by ASFP Secretariat with approval of the ASFP Technical Officer.

Volume 1: contains methodologies for the fire testing and assessment of structural fire protection
Volume 2: Parts 1 to 4 contain data for products according to the type of fire protection material

The Association was formed in 1976, and currently represents UK contractors and manufacturers of specialist passive fire protection products, with associate members representing regulatory, certification, testing and consulting bodies. It seeks to increase awareness and understanding of the nature of fire and the various forms, functions and benefits provided by passive fire protection. It is willing to make its specialist knowledge on all aspects of fire protection and can assist specifiers and main contractors in identifying products suitable for specific requirements, both in the UK and related overseas markets. The Association encourages experimental work related to passive fire protection and promotes consideration and discussion of all issues affecting the fire protection of structural steel and buildings.

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The Steel Construction Institute (SCI) develops and promotes the effective use of steel in construction. It is an independent, membership based organisation. SCI's research and development activities cover multi storey structures, industrial buildings, bridges, civil engineering and offshore engineering. Activities encompass guidance on structural design in carbon and stainless steels, dynamic performance, fire engineering, sustainable construction, architectural design, building physics (acoustic and thermal performance), value engineering, and information technology.

Membership is open to all organisations and individuals that are concerned with the use of steel in construction. Members have access to specialist advisory service, free issue of every new SCI publication and free access to Steelbiz, an online technical information system (www.steelbiz.org).

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The British Constructional Steelwork Association is the national organisation for the steelwork contractors in the UK and Ireland. 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.

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The Fire Test Study Group (UK) (FTSG) is a forum for technical discussions and liaison between consulting fire test laboratories involved in producing test and assessment information for the purposes of building control. The member laboratories are all UKAS Accredited. The primary objective of the group is to ensure common technical interpretations of the fire test standards and a common approach to technical appraisals or assessments of products made by FTSG members.

FTSG members participate on all relevant BSI committees, the equivalent ISO & CEN technical committees and are involved in European Commission technical discussions on harmonisation.

FTSG members strongly support the publication of this edition of the "Yellow Book" as it provides specifiers and regulatory bodies with independently validated data and a comprehensive guide to the performance of materials used to provide fire protection to structural steel.

Certification bodies allied to FTSG member laboratories have agreed to certificate structural fire protection products using the procedures defined in the Yellow Book.

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Acknowledgements

Permission to reproduce extracts from BS 5950-8: 2003, Structural use of steelwork in buildings – Part 8; Code of Practice for fire resistant design is granted by BSI. British Standards can be obtained from BSI Customer Services, 389 Chiswick High Road, London W4 4AL.

The publishers wish to express their appreciation of the work undertaken by the ASFP Technical Committee and Task Group 1 (Reactive Products) and Task Group 2 (Non-reactive Products) in the drafting of this 5th edition of the Yellow Book. Particular appreciation is expressed to the following individuals who served on an editing group from Task Groups 1 & 2:

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CERTIFIED
Construction CPD Certification Service

FIRE AND YOUR LEGAL LIABILITY

Fire losses in the UK were over £1bn in 2012. That's why we must all play our part.

Why is this of relevance to me?

If you are involved in provision of a fire protection package, at any level, then you share liability for its usefulness and its operation when it's needed in fire, and that liability will still be there in the event of a court case.

I place the order; it is not my responsibility to install the works!

If it is your responsibility to specify the materials and/or appoint the installation contractor, it is also your responsibility to ensure that they can prove competency for the fire protection materials used, or the works to be carried out. It's no longer simply a duty of care or voluntary – it's a legal obligation.

If you knowingly ignore advice that leads to a failure in the fire performance of any element of installed fire protection within a building, then you are likely to be found to be just as culpable as the deficient installer.
You share liability for the provision of information required under Building Regulation 38 that tells the user of the building about the fire prevention measures provided in the building. Otherwise, the user cannot make an effective risk assessment under the Regulatory Reform (Fire Safety) Order 2005, the Fire Scotland Act 2005, and the Fire & Rescue Services (Northern Ireland) Order 2006.

What is expected of me?

In the event of fire, and deaths, a court will want to know how every fire protection system was selected; the basis for selection of the installer, whether adequate time was provided for its installation, and whether there was adequate liaison between the different parties to ensure it was installed correctly. No ifs, no buts – it's all contained in the Construction, Design and Management Regulations 2007.

The CDM 2007 regulations, enforced by Health and Safety Executive concentrate on managing the risk, and the health and safety of all those who build, those that use the building, those who maintain it and those that demolish it – cradle to grave.

Be aware – the time to consider the above is before the event, not after it!

Fire protection for structural steel in buildings

Foreword

I am pleased to introduce the fifth edition of the ASFP 'Yellow Book' the original of which was introduced some 30 years ago. Throughout that period it has become the definitive reference to the provision of fire protection to structural steel in buildings, and a source of validated performance data about products for that purpose provided by ASFP members.

This edition incorporates a significant number of important changes including:

- A revised protocol for the evaluation of products that protect structural steel members in the absence of a specific British Standard for their fire testing and assessment. Data for this 'Yellow Book' assessment may be generated using British Standard fire test data and/or European fire test data.
- Restructuring to take into account major developments in European standardisation of the testing and assessment of products that protect structural steel members.
- A revised protocol for the testing and assessment of protected cellular beams which uses thermal data generated either from existing British Standard tests or the new prEN 13381-9 test (to be published in 2014).
- Reference to a default structural model, commissioned by the ASFP, to predict limiting temperatures for cellular beams with openings of various shapes which can then be used to generate appropriate thicknesses of fire protection.
- A revised section reflecting requirements for gaining CE Marking of products which is currently obtained by gaining a European Technical Approval (ETA).
- A requirement that all products included in Volume 2 will either be CE marked, or third party certificated by certification bodies accredited for this purpose by UKAS

In contrast to previous editions, the ASFP Technical Review Panel will no longer review test and assessment data supporting products included in this book. This will be undertaken by ensuring that all products are either CE marked and/or third party certificated and this will be checked with the appropriate certification body by the ASFP Technical Officer. Future data sheets will also reference this latest edition of the Yellow Book.

I commend the 'Yellow Book' to all, as an authoritative source of guidance, referenced in Approved Document B 2006, on the safe provision of fire resistance for structural steel frames in buildings.

Clive Newman
Chairman of the ASFP Technical Committee

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Scope

This publication defines the procedures for evaluating proprietary fire protection of structural steelwork, primarily to provide compliance with Building Regulations. It also provides a comprehensive guide to proprietary materials and systems all of which are manufactured, marketed or site applied by ASFP members.

The evaluation of proprietary fire protection may be undertaken essentially by two routes:

1. A traditional 'Yellow Book' assessment which may be based on thermal data derived from testing to BS 476 or EN 13381 test methods.
2. An assessment to EN 13381-4 (non-reactive products) or EN 13381-8 (reactive products) which can only be based on thermal data derived from testing to EN test methods.

Route 1 will most likely be used in the UK and in areas of the World where British Standards are still used. Route 2 can also be used in the UK and must be used in continental Europe where CE marking against a European Technical Assessment (ETA) is the route to the European Single Market. Increasingly, manufacturers will use Route 2 as they use European test standards to avoid duplication of testing to both British and European standards.

It should be noted that ETAs are not mandatory under the Construction Products Regulation which came into force in July 2013. Consequently the industry is in discussion with the European Commission to 'convert' the pre-existing standards (European Technical Approval Guidelines – ETAGs) used to generate European Technical Approvals under the CPD into harmonised European product standards (hENs). Once a hEN is published this will make CE marking of the products covered by it mandatory under the Construction Products Regulation. Once a hEN is published, manufacturers will only be able to use Route 1 for those countries that still accept British Standards e.g. some Middle East and Far East countries.

A new European standard for the evaluation of products protecting cellular beams (prEN 13381-9) is in an advanced state of development. This refers to the use of structural engineering models, which take into account the variety of failure modes of e.g. Vierendeel bending, to generate appropriate limiting temperatures. The ASFP commissioned a structural model which is referred to in this publication and is the default model to predict limiting temperatures for cellular beams with openings of various shapes.

Other developments in European standardisation include a new standard for concrete filled hollow columns (EN 13381-6) which has recently been published and new European standard for rods (prEN 13381-10) which is expected to be published in the next 5 years.

This document does not deal with the preparation requirements of steelwork and bolted connections; these are addressed in ASFP Technical Guidance Document 11. It should be noted, however, that the performance of some types of passive fire protection is dependent on the manner of substrate preparation. It is essential for specifiers to understand the preparation conditions within the scope of certification of a product, and to seek guidance where these conditions cannot be achieved.

Detailed information on the application methods and quality provisions for application is available in ASFP Technical Guidance Documents as follows:

TGD 8 Code of practice for junctions between different fire protection systems (structural steel elements)
TGD 11 Code of practice for the specification and on-site installation of intumescent coatings for the fire protection of structural steelwork
TGD 13 Code of practice for over cladding reactive coatings
TGD 14 Code of practice for the installation and inspection of board systems for the fire protection of structural steelwork
TGD 15 Code of practice for the installation and inspection of sprayed non-reactive coatings for the fire protection of structural steelwork
TGD 16 Code of Practice for off-site applied intumescent coatings

All these documents are available as free download documents from www.asfp.org.uk/publications.

Definitions

CEN

European Committee for Standardisation. This committee is responsible for the preparation of European Standards.

Composite beam

A beam comprising a hot rolled steel I or H section connected via shear connectors to a precast concrete or composite floor slab where the steel section and floor slab are designed to act together.

Composite floor

a floor comprising a concrete topping cast onto a profiled metal decking.
Note: The composite action of such floors is in the nature of the connection with the steel beams supporting them whereby studs (shear connecters) are fixed through the profiled floor into the beam.

Cellular beam

structural steel beams with circular or rectangular opening(s) in the web.

Castellated beam

a rolled steel beam the web of which is first divided by a lengthwise hexagonal cut, then welded together so as to join the peaks of both halves, thus increasing its depth

Critical temperature

The temperature at which failure of the structural steel element is expected to occur against a given load level (see also limiting temperature below).

Design temperature

The 'design temperature' is the temperature determined by calculation at which failure of the structural steel element is expected against a given load level at a particular location in a building

Fire load

The energy per square metre of floor area of the combustible material present within the internal bounding surfaces of a room, compartment or building.

Fire resistance period

The fire resistance period of each tested loaded steel section is the duration of the test until the specimen is no longer able to support the test load.

Intumescent coating / reactive coating

A coating which reacts to heat by swelling in a controlled manner to many times its original thickness to produce a carbonaceous char, which acts as an insulating layer to protect the steel substrate.

Limiting steel temperature

The maximum temperature of the critical element of a steel member prior to failure, under fire conditions. Limiting temperatures and critical temperatures are defined differently but they are effectively the same with the former being used in BS 5950-8 and the latter in the Eurocodes.

Orientation

Plane in which the exposed face of the test specimen is located, either vertically or horizontally during testing.

Passive (non-reactive) fire protection products (e.g. boards and sprays)

Products which do not change their physical form on heating, providing fire protection by virtue of their physical or thermal properties

Plate thermometer

A 100 x 100mm insulated thin steel plate to which a thermocouple is attached, used to measure the temperature in a fire test furnace.

Reactive fire protection products (e.g. intumescent coatings)

Products which are specifically formulated to provide a chemical reaction upon heating such that their physical form changes and in so doing provide fire protection by thermal insulating and cooling effects.; e.g. intumescent products

Section factor (A/V)

The rate of increase in temperature of a steel cross-section is determined by the ratio of the heated surface area (A) to the volume (V). This ratio, A/V, has units of m^{-1} and is known as the 'Section Factor'. Members with low section factors will heat up more slowly. In the UK, the term Hp/A has been used for many years to denote the section factor, but in the European fire test standards the section factor is referred to as A/V. It should be noted that the terms A/V and Hp/A have very similar meaning and consequently, in order to avoid confusion to the user of this publication, only the term A/V will be used.

In profiled protection: The ratio of the inner surface area of the fire protection material per unit length, to the cross sectional volume (area) of the steel member per unit length.

In boxed protection: The ratio of the inner surface area of the smallest possible rectangle or square encasement that can be measured round the steel member per unit length to the cross sectional volume (area) of the steel member per unit length.

Note that the section factor for cellular beams is calculated differently – see Section 4

Steel UB or UKB

Hot rolled universal beam manufactured to the dimensions in BS 4: Part 1: 2005

Steel UC or UKC

Hot rolled universal column manufactured to the dimensions in BS 4: Part 1: 2005

Stickability

Ability of a fire protection material to remain coherent and in position for a defined range of deformations, furnace and steel temperatures, such that its ability to provide fire protection is not impaired.

Structural Hollow Sections (SHS)

Hot formed/finished structural hollow sections manufactured to dimensions in BS EN 10210-2

UKAS

United Kingdom Accreditation Service

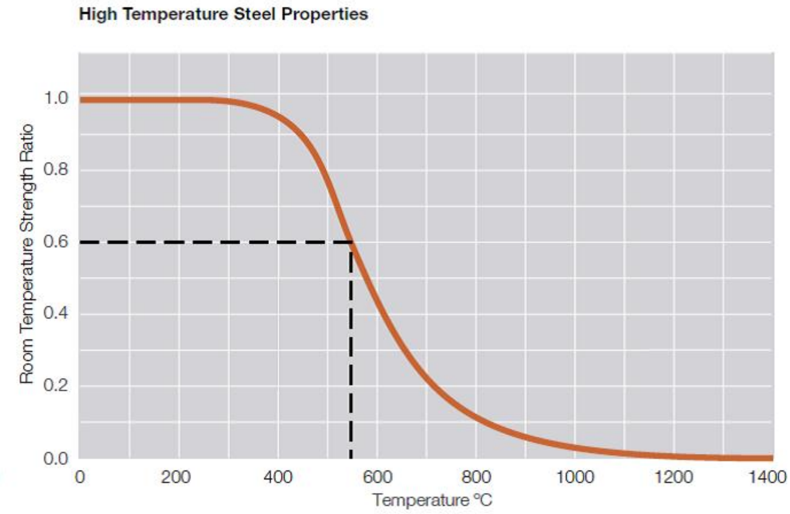
Note:

I or H (re-entrant) sections are commonly referred to as ‘open’ sections; and hollow sections are commonly referred to as ‘closed’ sections throughout Europe.

1 Introduction

In the event of fire, Building Regulations require that buildings shall be designed and constructed so that their ‘stability will be maintained for a reasonable period’. In other words, they should not collapse prematurely to provide time for the occupants to escape and for the fire service to obtain access. In most modern buildings, the loadbearing function is provided by a steel framework to which the rest of the building is attached. The extent to which an element requires fire resistance depends upon such factors as size, height, use and occupancy of the building and the function of the element.

Figure 1 – Reduction in steel strength with temperature



Fires in buildings regularly exceed 1000 degrees centigrade within a relatively short period of time (30 – 60 minutes), yet heavily loaded steel loses its design margin of safety, about 40% at temperatures around 550°C regardless of the grade and as its temperature rises further the loss of strength is rapid and significant see Figure 1. Consequently, it is necessary to limit the temperature rise of the steel so that sufficient strength remains for the structural frame to continue to be able to provide its loadbearing function.

The most practical way to limit the rise in steel temperature is to insulate it from the fire. Traditionally, ‘fire protection’ comprising non-combustible boards and cementitious sprays were applied to the structural frame on-site. These materials are still commonly used and are particularly suitable for harsh environments.

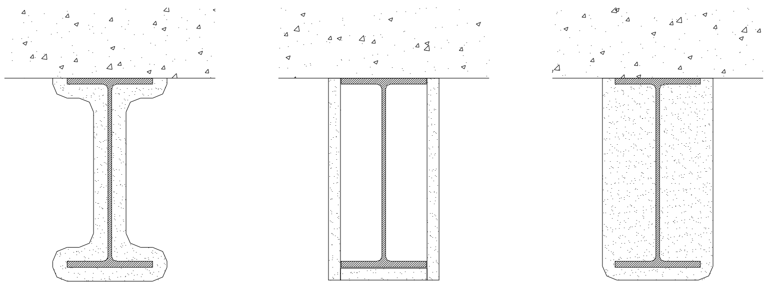
However, in recent years reactive coatings (intumescent paints) have become increasingly popular because they can be prepared offsite and they have good aesthetic properties, although they can be more sensitive to site (and end-use) conditions and good application.

Whatever type fire protection is used, it is evaluated by testing a variety of individual structural members in special ‘fire resistance’ furnaces. An analysis is then made of the temperatures reached by these members and predictions are made (by calculation and other methods) of the amount of material needed for the almost infinite number of sizes and shapes of steel sections available to designers.

1.1 Protection Methods

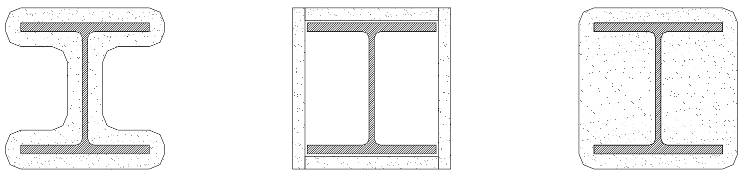
A wide range of materials is available to enhance the fire resistance of structural steel members. They can be applied in a variety of ways to meet specific site requirements. In considering any fire protection system it is important to distinguish between *profile*, *box* and *solid* methods of application (Figures 2 and 3). Sprayed materials would normally be applied to follow the *profile* of the section. Board materials would normally be used to form a *box* around the section and concrete can be used to form *solid* protection. Details of individual fire protection products/systems are given in Volume 2.

Figure 2 – Protection technique for three-sided protection



Profile | **Box (with or without gap over flanges)** | **Solid**

Figure 3 – Protection technique for four-sided protection



Profile | **Box (with or without gap over flanges)** | **Solid**

Specially designed and constructed suspended ceilings utilising lightweight metal support components, insulating tiles and panels, and sprayed or trowelled compounds on suspended lath, tested in accordance with BS 476-23 or EN 13381-1 may also be used for the protection of structural steel but they are outside the scope of this publication.

1.2 Fire Testing

Fire tests on elements of building construction have been carried out in accordance with a number of British and European test methods. The BS 476 series used in the UK and many other countries where British Standards are traditionally used is being gradually superseded by European fire testing standards which are used in the European Single Market and visible recognition of these is given in Approved Document B: 2006 and national equivalents in Scotland, Northern Ireland and the Republic of Ireland. The adoption of the European standard is intended to remove technical barriers to trade within Europe. The international fire testing standard, ISO 834, is similar to the other standards and is in the process of being revised to bring it more in line with the European standard.

The size and construction of a test specimen is ideally identical with the element in its intended orientation in a building. In the fire resistance test, loaded beams are tested horizontally with protection applied to three sides. Columns are tested vertically with the protection applied to all sides. It is therefore common to meet the terms “three sided” and “four sided” exposure when dealing with fire protection to steelwork.

Beams are tested horizontally in conjunction with a floor slab (Figure 4) and columns are tested vertically (Figure 5).

Figure 4 – General arrangement for fire tests on beams

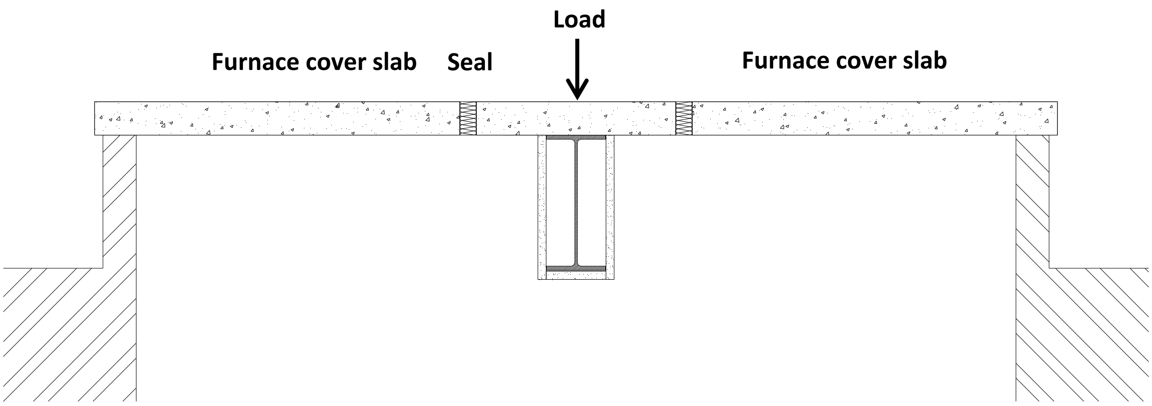
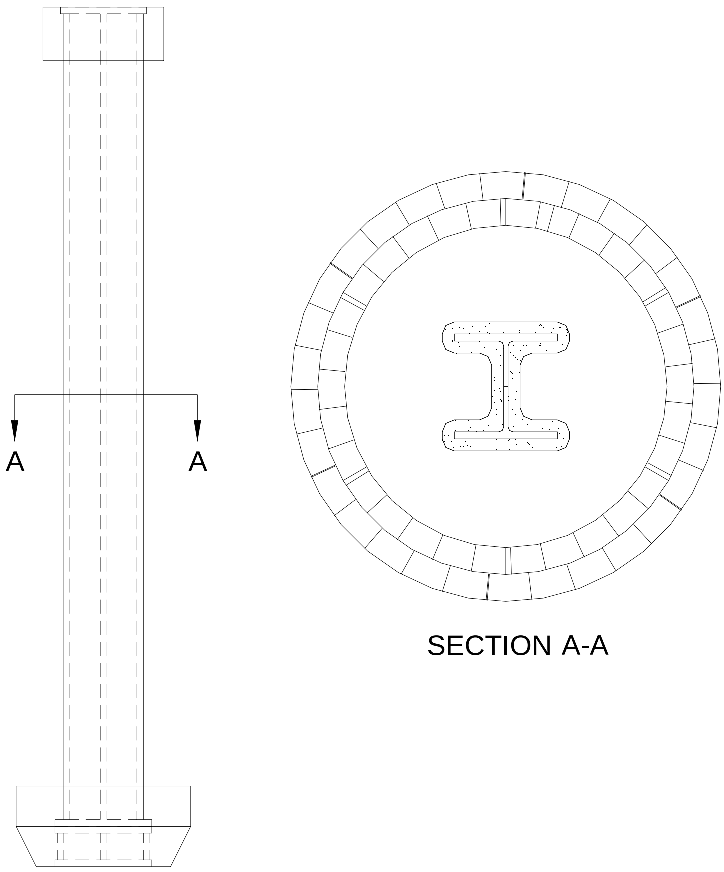


Figure 5 – General arrangement for fire tests on loaded columns



The results of a standard fire resistance test relate to the steel section size and loading, together with the thickness and performance of the protection system. To repeat the procedure to explore those important and numerous variables for all steel sections and protection parameters would be prohibitive. Consequently, assessment procedures have been developed which allow the performance of a range of steel sections to be estimated from the information gained from a limited number of tests.

1.3 Assessment of fire protection materials (general)

Methods of assessing the performance of fire protection materials have been developed which enable the thickness of protection for a wide range of situations to be predicted. The procedure is in two parts. Firstly, a carefully designed programme of fire tests is carried out on both loaded and unloaded specimens and, secondly, a mathematical or other procedure is applied to the results of the tests which enables predictions of required thickness to be made. These programmes of tests are designed to determine both the insulation characteristics of a fire protection material and its physical performance under fire conditions for a range of steel sizes (in terms of Section Factor, protection thicknesses and fire resistance periods). They generate the maximum amount of data from the minimum number of tests.

A method of assessing fire protection materials has been developed and used in the UK for a number of years. It was used to generate the data in the earlier editions of this publication and is one of the methods used in this edition. Further details are in section 2.

More recently, European methods of assessing fire protection materials have been developed. These methods have been formally standardised in EN 13381-4 (non-reactive products) and EN 13381-8 (reactive products). In a similar programme of tests to those already used in the UK, both loaded and unloaded specimens are tested and an appraisal of the fire protection material is derived. The method has a number of technical differences from the UK procedure which make an exact comparison difficult. Further details are in section 3.

1.4 Limiting temperatures

1.4.1 General

In this publication, the thicknesses of fire protection materials to maintain hot rolled and/or hot finished/formed steel sections below specified temperatures for specified periods of time are given in product data tables. These are either published in the appropriate volume of this publication, the manufacturer's literature or are hosted on certification body websites.

1.4.2 Codes used to derive critical/limiting temperatures for hot rolled structural steelwork

The standards which can be used for structural design in the UK are listed in Approved Document A. Prior to October 2013; this referenced the BS 5950 series of standards for steel design. However, at that time, a new edition of Approved Document A was published by the Government. In this, an action by the British Standards Institute in 2010 to withdraw the BS 5950 series of design standards was recognised and the codes, standards and other references deemed acceptable for structural design and construction referenced instead the relevant Eurocodes and their National Annexes. However, the new the Approved Document A also stated that "*There may be alternative ways to achieving compliance with the requirements and there might be cases where it can be demonstrated that the use of the withdrawn standards no longer maintained by the British Standards Institute continues to meet Part A requirements*". A similar approach has been adopted in Scotland and is outlined in Technical Handbook 1. This effectively means that, although structural design using the Eurocodes is set to dominate in the UK, the BS 5950 series of standards continue to be used and is reflected in this document.

This is important because, in early editions of this publication, data on the thickness of fire protection to provide a given period of fire resistance for hot rolled and finished/formed structural steelwork was provided on the basis of limiting (failure) temperatures derived from BS 5950 Structural use of steelwork in buildings: Part 8 Code of practice for fire resistant design. Default limiting temperatures were provided for columns and for beams supporting concrete floors. These assumed that the structural section was fully loaded at the time of a fire. Such temperatures must also now be provided for situations where design is carried out using the Eurocodes.

The fire Eurocodes are: BS EN 1991: Actions on Structures. General actions. Part 1.2 Actions on structures exposed to fire; BS EN 1993: Design of steel structures. General rules. Part 1.2 Structural fire design; and BS EN

1994: Design of composite steel and concrete structures. General rules. Part 1.2 Structural fire design. The overarching principles of the Eurocodes are similar to those of the British Standard, although limiting temperatures are referred to as critical temperatures.

Default critical/limiting temperatures to both codes are given in Section A.3.2. In general, critical temperatures are lower than limiting temperatures. Where standards or where legislation permits; if designed to Eurocodes, limiting temperatures should be derived using the Eurocode approach and if designing to BS 5950, one should use limiting temperatures from BS 5950.

The use of both the fire Eurocodes and BS 5950 Part 8 allows designers to calculate critical/limiting temperatures when the sections are not fully loaded. There are many instances when this occurs. For example, the critical case in the design of many beams is not strength but is allowable deflection or vibration. When this happens, there is often a reserve of strength available to the designer and this can be used to calculate alternative limiting/critical temperatures. Thus, it can be shown using BS EN 1993-1-2 that a fully loaded, non-composite beam carrying a concrete floor slab in an office has a critical temperature of 603^{o}C (See Section A.3.2), but where the beam is not fully loaded, this temperature can be increased considerably. This can have a significant impact in terms of reducing fire protection thicknesses and can be of great value when dealing with sections requiring a very high build-up of protection.

Section 2 – 'Yellow Book' assessment method (Route 1)

2.1 General

Methods of assessing the performance of fire protection materials have been developed in the UK which enables the thickness of protection for a wide range of sections to be derived. The assessment procedures have been developed by the ASFP in consultation with industry, with a view to:

- Making assessments more consistent from different sources.
- Establishing more consistent acceptance criteria.
- Providing guidance to manufacturers on testing requirements.
- Providing practical guidance for evaluation of constructions which are 'un-testable'
- Consolidating available information on the performance of fire protection materials.

Separate procedures are given for reactive coatings and passive (non-reactive) materials in recognition of the technical differences and physical performance characteristics of these materials.

Guidance on the test and assessment procedures of European Standard EN 13381-4 and 8 is given in Section 3.

2.2 Background information

The appropriate procedures detailed in this document have resulted from discussions of the ASFP Technical Committee and the appropriate task groups. The ASFP Technical Committee and technical task groups contain representatives from a broad section of the structural fire protection industry, test laboratories and certification bodies. Consequently the procedures given in this document are based on the best available knowledge at the time of writing and are considered to provide a reliable means of evaluating the performance of fire protection materials and coatings. The assessment procedures use data generated from tests on loaded beams and sometimes loaded columns in conjunction with tests on unloaded sections when exposed to the heating conditions specified in BS 476-20 or the relevant part of EN13381.

The scope of a product assessment need not cover all the shapes and orientations detailed in this document. For example, where a product is intended to be used only on beams, an assessment based on a loaded beam test and other data from unloaded short sections may be used. The programme of tests need not be restricted to one steelwork shape, but additional loaded tests may then be necessary. Similarly an assessment need not cover all the steelwork shapes. An assessment can be restricted to one or more shapes alone, e.g. 'I' sections only, but at least three loaded tests plus unloaded sections would be required to cover both orientations and a range of thicknesses.

The assessments will be primarily based on test information from 3rd party test laboratories accredited to EN ISO 17025; e.g. UKAS accredited laboratories or other laboratories similarly accredited by national accreditation bodies that have signed a Memorandum of Association with UKAS or Notified Bodies as defined under the Construction Products Regulation. Appropriate data from other independently validated sources may be used to supplement the assessment but will not be used as the main basis of the evaluation.

The potential fissuring, cracking or detachment of a fire protection material or coating may only become apparent during full scale loaded fire resistance tests. The loaded tests are therefore designed to provide information regarding the physical/mechanical performance of fire protection under the following conditions:

- Vertical and horizontal orientations (columns and beams) as appropriate.
- Maximum and minimum protection thicknesses.
- Maximum and minimum fire resistance periods under consideration.

To demonstrate the retention of the fire protection material, loaded beam tests should be continued until the deflection at mid-span reaches a minimum value of span/35. Loaded column tests should be continued until structural failure is imminent.

2.3 Test and assessment procedures – passive (non-reactive) fire protection systems

This Section presents guidance with respect to the evaluation of structural steel sections protected against fire by passive (non-reactive) fire protection systems such as, but not limited to boards, slabs and renderings. It is permissible to use an assessment to EN 13381-4 in its entirety. Where the assessment is based on test data generated in accordance with EN 13381-4 or BS 476: Parts 20/21 or a mixture of both, the assessment shall be carried out following the requirements of this Section.

2.3.1 Test procedures

2.3.1.1 BS 476: Parts 20/21

The test procedures given in BS 476: Parts 20/21 should be followed but may be varied by the following additional requirements:

a) The temperature of the steel elements should be measured by mineral insulated stainless steel sheathed thermocouples of Type K as specified in EN 60584-1 and have an overall diameter of 1.5mm.

b) The thermocouples should be attached to the steel sections by peening or other methods that do not affect the response or accuracy of the thermocouple.

c) Thermocouples for measurement and recording of steel temperatures shall be located according to Figures 11 to 14 (2.4.1.11).

Additional thermocouples may be fixed to the steel sections at other locations in accordance with the manufacturer's instructions.

2.3.1.2 EN 13381-4

It is acceptable to use test data generated using the test procedures given in accordance with EN 13381-4 to provide an assessment in accordance with 2.3.4 subject to the following rules:

a) The load bearing capacity must satisfy the requirements given in 2.3.4.3.
b) The average temperature of the steel beams (loaded and unloaded short beams) may be derived from the thermocouples referred to in Figures 11 and 12 in 2.4.1.11.
c) The test data must be used without modification i.e. not adjusted to take into account the difference in performance between BS and EN test conditions.
d) The EN test data can be used in whole or in part to supplement BS data but where a data set includes both BS and EN data the following should generally apply:

   i) EN data can be used to supplement BS data to extend the scope of the assessment where no BS data exists.
   ii) Where conflict occurs between BS and EN data, BS data take precedence over EN data points.

e) The assessment must comply with all requirements given in 2.3.4.

2.3.2 Test programme

2.3.2.1 General

The test programme must be designed to adequately demonstrate the ability of the protection system to maintain the maximum anticipated structural performance of the steel section and provide sufficient thermal data to cover the anticipated range of section types and sizes.

Consequently, the test programme will include loaded sections and unloaded sections.

2.3.2.2 Tests on Loaded Sections

Loaded beams and loaded columns shall be tested depending upon the scope of the assessment. The purpose of testing these sections is to demonstrate the stickability performance of the coating for up to the maximum required fire resistance period and to correct the thermal data generated by the short sections for stickability.

For assessments required to cover I-section beams and columns the following testing on loaded sections should be carried out:

Table 1 – Loaded section sizes

Section Type	Section Size mm x mm x kg/m	Protection Thickness
Loaded beam	406x178x60 or to suit scope of assessment	Minimum
Loaded beam	406x178x60 or to suit scope of assessment	Maximum

The magnitude of the load applied to loaded sections shall be in accordance with BS449: Part 2:1969

Testing a loaded column is not mandatory if loaded beams are tested, however in the case of an assessment relating to columns only, loaded columns of a size to suit the scope of the assessment should be carried out at minimum and maximum protection thickness in lieu of the loaded beams.

In the case of boards or slabs loaded columns should be tested in addition to the loaded beams if the fixing method for beams differs from that for columns.

If reinforcement e.g. in certain types of spray protection is used over part of the thickness range additional loaded tests will be required.

The protection of hollow columns by passive (non-reactive) fire protection systems may be evaluated by the modification of results given by the testing of I-sections using the equations given in 2.3.4.6 d) or by testing in accordance with the principles for reactive coatings given in 2.4.2. In this case the analysis of the test data should comply with assessment protocol given in 2.3.4.7

2.3.2.3 Short I or H Sections

The selection of the test specimens will be determined to suit the scope of the assessment required for the product. The selection will be on the basis of a prescribed section factor range and the thickness factor range (maximum and minimum) as given in Table 2.

Table 2 – Section range factor with thickness range factor

Section Range Factor (K_s)	Thickness Range factor (K_d)		
	0.0 (d_{min})	0.4-0.6	1.0 (d_{max})
0.0 (s_{min})	✓	✓	✓
0.4-0.6	✓	✓	✓
1.0 (s_{max})	✓	✓	✓

The table applies to beams and columns separately i.e. at least 9 short beam sections should be tested for a beam assessment and at least 9 short column sections should be tested for a column assessment.
The selection of the sections to be tested in accordance with Table 2 shall be based on the nominal section sizes as listed in Tables 3 to 5. For practical reasons, each section factor range e.g. 0.4-0.6 must be considered have a tolerance of ±15%.

For assessment purposes the dimensions and cross-sectional areas of the steel sections shall be measured, neglecting any internal and external radii. These values shall be used to determine the section factors, according to the equations given in Annex 4, Table A.1.

The range factor will be 1.0 for the maximum value and 0.0 for the minimum value in each case and the actual values will be determined by the manufacturer.

Actual thickness factors are calculated in accordance with the following equation:

$d_p = K_d\ (d_{max} - d_{min})\ ) + d_{min}$

Where
d_p is thickness at factor K_d
d_{max} is maximum thickness at K_d factor of 1
d_{min} is minimum thickness at K_d factor of 0

e.g. Thickness range 8 to 30mm

Then thickness for a K_s factor of 0.5 is ((30-8) x 0.5) + 8 = 19mm.

In the case of board systems the thickness range factors may be adjusted to suit the nominal board thickness.

2.3.3 Construction of the steel test specimens

2.3.3.1 General

The construction of the test specimens shall follow the requirements of BS 476: Parts 20/21 and or EN 13381-4 unless specifically modified in this document.

The steel grade required for the loaded sections shall be S275 or S355 in accordance with BS EN 10025.

2.3.3.2 Size of sections

Loaded beams shall have a total length exposed to heating of not less than 4000mm. The length of the specimen shall be the exposed length plus up to a maximum of 500mm at each end.

All loaded columns shall have a minimum height, exposed to heating, of 3000mm.

The short beams and columns shall have a length of 1000mm ±50mm. Short sections weighing more than 350kg/m may be reduced to 500mm in length.

2.3.3.3 Thickness measurement: Box Protection (Boards/Slabs).

For board or slab/mat fire protection materials, the nominal thickness of each material shall be measured in accordance with EN12467, EN 13162 or EN 823.

The measurement shall be carried out either on the actual materials during assembly of the test specimen or on a representative special test sample, the minimum linear dimensions of which shall be 300 mm x 300 mm. At least nine measurements shall be made including measurements around the perimeter and over the surface of the material.

The thickness of slab or board type fire protection materials should not deviate by more than 15 % of the mean value over the whole of its surface. The mean value shall be used in the assessment of the results and in the limits of applicability of the assessment. If the board thickness varies by more than 15 % then the maximum thickness recorded shall be used in the assessment.

2.3.3.4 Thickness measurement: Profile Protection (Renderings)

For sprayed passive (non-reactive) fire protection materials the thickness shall be measured using a 1 mm diameter probe or drill, which shall be inserted into the material at each measurement position until the tip of the probe or drill touches the surface of the building element. The probe or drill shall carry a circular steel plate of diameter 50 mm upon it, for accurate determination of the surface level.

The number and location of thickness measurement points shall be as given as follows:

Loaded beams:

A minimum number of 88 measurements should be taken on I-section beams spread over the measuring stations at locations in the proximity of:

- the measurement stations at which temperature measurements are made on the surface of the test beam;
- the positions at which temperature measurements are made on the upper surface of the bottom flange of the beam, halfway between each temperature measurement station;
- similar positions on the lower surface of the upper flange of the I-section beam to those of the lower flange indicated above;
- the positions halfway between the outermost temperature measurement stations and the outermost points on the upper surface of the bottom flange of the beam.

Unloaded beams:

A minimum number of 24 measurements at positions on beams at locations in the proximity of:

- the temperature measurement stations (between 50mm and 100mm away from) at which temperature measurements are made on the surface of the beam;
- similar positions on the lower surface of the upper flange of the I-section beam to those of the lower flange indicated above.

Loaded columns:

A minimum number of 50 measurements should be taken on H columns spread over the measuring stations at locations in the proximity of:

- the temperature measurement stations (between 50mm and 100mm away from) at which temperature measurements are made on the surface of the test column;
- the positions halfway between each temperature measurement station.

Unloaded short columns:

A minimum number of 20 measurements should be taken on Hcolumns spread over the measuring stations at locations in the proximity of:

- the temperature measurement stations (between 50mm and 100mm away from) at which temperature measurements are made on the surface of the test column.

The thickness of sprayed fire protection materials or renderings should not deviate by more than 20% of the mean value. The mean value shall be used in the assessment of the results and in the limits of applicability of the assessment. If it deviates by more than 20% then the maximum thickness recorded shall be used in the assessment.

The mean thickness (or maximum thickness according to the above criteria for permitted deviation in thickness) of fire protection material applied to each loaded beam and to the loaded steel column section, where used, shall be the same as that applied to its reference beam or short steel column section. The difference between the thicknesses in each case shall not be greater than 10 % of the maximum value or ± 5 mm, whichever is the lesser.

2.3.3.5 Properties of Protection Systems

Density

The density of each fire protection material shall be determined from measurements of mass and dimensions using the following:

For board or panel passive (non-reactive) fire protection materials, the density can be obtained from values of mass, mean thickness (from nine measurements) and area measured either on the actual materials during assembly or on a representative special test sample, the minimum linear dimensions of which shall be 300 mm x 300 mm.

The mass of the board shall be obtained using a balance having an accuracy equivalent to 0.1 % of the total mass of the sample being weighed or 0.1 g (the sample size shall be sufficient such that the minimum sample mass is 100 g) whichever is the greater.

The density of fibrous or similar compressible fire protection material shall be related to the nominal thickness.

For spray applied fire protection materials the density of the material shall be determined from samples sprayed, from beneath, into metal trays, horizontally orientated, at the same time as the fire protection system is applied to the steel test specimens. These trays shall be of size 300mm x 300mm and made from 1mm thick steel plate.

The depth of the trays shall be the same as the design thickness of the fire protection material.
For each thickness of material two such trays shall be prepared with the material applied to the same thickness as that applied to the steel. One of these trays is dried to provide a reference for dry density and moisture content. The second tray shall be used to determine the density at the time of test.

The thickness of the specimen within the trays shall be determined at nine positions over the surface of the trays according to:

- one at the centre (one total);
- two along each centre to corner axis, equidistant from each other, the centre and the corner (eight in total).

The mass of the fire protection within the tray shall be obtained using a balance having an accuracy equivalent to 0.1 % of the total mass of the sample being weighed or 0.1 g (the sample size shall be sufficient such that the minimum sample mass is 100 g) whichever is the greater.

At each thickness of fire protection material, the density of each should not deviate by more than 15 % of the mean value. The mean value shall be used in the assessment of the results and in the limits of applicability of the assessment. If it deviates by more than 15 % then the maximum density recorded shall be used.

The mean density of fire protection material (or maximum density according to the above criteria for permitted deviation in density) applied to each loaded beam and to the loaded steel column section, where used shall be the same as that applied to its equivalent unloaded beam or short steel column section.

The difference between the densities in each case shall not be greater than 10 % of the maximum mean value at that thickness. The test laboratory shall confirm equilibrium values of loaded and reference sections are within 10% of each other

Moisture content

The samples and materials used to measure moisture content shall be stored together with and under the same conditions as the test specimens. The measurement of final moisture content shall be made on the day that fire testing takes place.

For board or slab passive (non-reactive) fire protection materials, special test samples shall be taken measuring minimum 300 mm x 300 mm and of each thickness of the material used. They shall be weighed and dried in a ventilated oven, using the temperatures and techniques specified in EN 1363-1.

The moisture content of the specimen shall be calculated as a percentage of its moisture equilibrium weight.

For spray applied passive (non-reactive) fire protection materials, the moisture content of the material shall be determined from oven drying of one of the sample trays referred to above., for each thickness tested.

They shall be weighed and dried in a ventilated oven, using the temperatures and techniques specified in EN 1363-1. The moisture content of the specimen shall be calculated as a percentage of its moisture equilibrium weight.

2.3.3.6 Conditioning of the test specimens

Test specimens shall be conditioned in such a manner that they correspond as closely as possible, in temperature and state of cure to the expected state of a similar element in service or as specified by the manufacturer.

2.3.4 Assessment procedures

2.3.4.1 General

The assessment is carried out using a multiple linear regression method using the thermal data generated by the testing of the short unloaded sections, relates to a range of design temperatures and covers both beams and columns.

2.3.4.2 Assessment parameters

The following parameters are used in the assessment protocol:

a) The average thickness of the rendering or board/slab.
b) The section factor calculated on the basis of Annex 4, Table A.1 using actual measured dimensions.
c) The mean steel temperature calculated as follows:

I-section beams

the average of the temperatures recorded by the thermocouples attached to the lower flange plus the average of the temperatures recorded by the thermocouples attached to the web divided by 2.

I-section columns

the average of the temperatures recorded by the thermocouples attached to the flanges plus the average of the temperatures recorded by the thermocouples attached to the web divided by 2.

d) At least the minimum data set in accordance with Table 2.

e) The maximum fire resistance period.

2.3.4.3 Maximum fire resistance period

The maximum fire resistance period is determined by the performance of the loaded sections.

If, during a loaded test, load-bearing capacity failure of the specimen occurs before the maximum required fire resistance period is achieved, (e.g. 115 min rather than 120 min or more) the result may still be acceptable provided that, for beams, the load is removed after a deflection of at least span/35 has occurred or, for columns, the load is removed when structural failure is imminent and the test is run-on until the full period is completed.

The protection system should remain intact during the over-run period for the extrapolation to be considered. The time extrapolation will be limited to 10% of the achieved maximum load-bearing capacity for any particular specimen shape or orientation.

2.3.4.4 Criteria for acceptability

The acceptability of the analysis within the range of steel section temperature and duration of the test shall be judged up to the maximum temperature tested on the following basis:

a) For each short section the predicted time in minutes to reach the design temperature calculated to one decimal place shall not exceed the corrected time by more than 15 %;

b) The mean value of all percentage differences as calculated in a) shall be less than zero;

c) A maximum of 30 % of individual values of all percentage differences as calculated in a) shall be more than zero;

d) The results of the analysis which satisfy a) to c) above must also comply with the following rules provided all other parameters remain constant:

   i. The thickness of fire protection material increases with fire resistance time

   ii. As the section factor increases the fire resistance time decreases

   iii. As fire resistance time increases the temperature increases

   iv. As thickness increases temperature decreases

   v. As section factor increases the temperature increases

   vi. As section factor increases thickness increases

e) Using the regression coefficients derived from the short section data the predicted time to reach the design temperature for each loaded section shall not be greater than the measured time.

2.3.4.5 Assessment design temperatures

The assessment shall be carried out at steel temperatures between 350°C and 800°C in 50°C intervals, provided that the protection system has proved to be effective and intact at those temperatures, fire resistance periods and section factors.

An analysis relating to a steel design temperature other than those given above can be undertaken subject to the requirement of the manufacturer.

2.3.4.6 Permitted Extensions

a) Section factor

I or H Section beams and columns

Maximum permitted section factor: up to 10% above the maximum section factor of any section tested.

Minimum permitted section factor: up to 10% below the minimum tested on any section subject to the minimum permitted thickness being applied. For section factors below the extended minimum, the same thickness as that applied to the extended minimum section factor must be applied.

b) Protection thickness

Beams

Maximum permitted thickness: up to 10% above the maximum thickness tested on a loaded beam.

Minimum permitted thickness: up to 10% below the minimum tested on a loaded beam.

Columns

Maximum permitted thickness: up to 10% above the maximum thickness tested on a loaded column.

Minimum permitted thickness: up to 10% below the minimum tested on any section.

c) Other sections with re-entrant details

Results of the assessment for I or H sections are directly applicable to angles, channels and T-sections for the same section factor.

d) Protection Thickness for Hollow Columns (SHS)

Boxed systems

Where thicknesses of the fire protection material have been assessed from I or H sections with boxed protection, no change in thickness is required, i.e. the thickness for a SHS of a given A/V value is equal to that for the I or H section of the same 'box' A/V value.

Profiled systems

Where thicknesses of the fire protection material have been assessed from I or H sections with profiled protection, a correction to the thickness is required based on the A/V value of the section as follows:

i) establish the A/V value of the structural hollow section.

ii) determine the thickness d_p, in mm of the fire protection material based on the I or H section data in accordance with the following equations:

for A/V values up to 250 m^{-1} increase the thickness as follows:

$$Modified\ thickness = d_p\left(1 + \frac{A_p/V}{1000}\right)$$

for A/V values higher than 250 m^{-1} increase the thickness as follows;

Modified thickness = 1.25 d_p

e) Method of fixing and support

The assessment only applies to the method of fixing and support for the protection system used for the tested sections. General guidance for alternative fixing methods and support particularly for board and slab systems will be published in a separate ASFP Technical Guidance Document.

f) Reinforcement

If a reinforcing mesh was included as part of the protection system then the assessment only applies to sections protected by the protection system if it includes the same type of mesh and same method of installation as used for the tested sections. General guidance on the use of mesh reinforcement will be published in a separate ASFP Technical Guidance Document.

g) Surface preparation and primers

The surface preparation for the steel is limited to the method used for the tested sections and includes the use of primers and surface treatments as tested. General guidance on the surface treatment methods and use of primers will be published in a separate ASFP Technical Guidance Document.

h) Deep web sections

The maximum beam web depth shall be limited to the maximum web depth of the loaded beam tested plus 50%.

The maximum depth of a column shall be limited to the depth of the loaded beam or loaded column plus 100%. This is subject to a maximum permitted depth of 600mm for boxed fire protection systems.

i) Beams with Protection on all Sides

The results of the analysis for columns can be applied to beams exposed on all four sides up to the maximum protection thickness predicted from the appropriate loaded beam test.

2.3.4.7 Assessment protocol: Multiple linear regression method

The following stepwise methodology shall be performed:

Steps 1 to 5: Use of input data from test results.

Input Data

- the design temperatures as defined in 2.3.4.5
- the times to reach the mean design temperatures
- the calculated section factor for the steel members
- the thickness of the protection material only

Basic Equation

The multiple linear numerical regression analysis is conducted at each design temperature using the equation:

Fire resistance time (minutes) $t = a_o + a_1 d_p V/A + a_2 d_p$

Where a_o, a_1, a_2 = constants applicable to the material,
d_p = thickness of fire protection material (mm), and A/V = Section Factor (m^{-1}).

Steps 1 to 5: Use of input data from test results

step 1

Determine the regression coefficients a_0, a_1, and a_2 by solving the regression equation using all the test data for each design temperatures from the minimum to the maximum temperature appropriate for which the analysis is requested.

step 2

Using the regression coefficients, calculate the time required to reach each design temperature for various thicknesses of the fire protection system and various section factors.

step 3

Compare the predicted times to reach each design temperature with the corrected measured times and determine whether the results meet the criteria of 2.3.4.4 b), c) and d).

step 4

If necessary, determine for each of the acceptance criteria b), c) and d) a simple modification factor 'x', where 'x' ≤ 1.0, which, when applied to all the regression constants, causes the predicted times to just meet these acceptance criteria.

step 5

Use the modified regression coefficients to determine the thickness required for a given section factor for each required fire resistance period and for each steel temperature. The thickness is determined using the following equation:

$$d_p = \frac{t - a_0}{(a_1 V/A + a_2)}$$

2.3.4.8 Assessment report

The assessment report will fully detail the scope and limits of approval, basis of the assessment and justification for any deviations from the procedures detailed in this document.

All test data used in the preparation of the assessment should be fully referenced by test number, test standard and type of test (beam/column, loaded/unloaded, full scale/small scale, etc).

The format of the assessment report shall provide the following minimum details:

a) Brief description of fire protection material /product/system - generic types.
b) Details of test specimens, number of specimens and sizes used in the analysis.
c) Details of method of analysis adopted.
d) Details of the correction of the data for stickability.
e) Predictive analyses at each critical temperature with a summary of test results and summary of analysis data.
f) Compliance with criteria of acceptability, details of any constraints and permitted extensions.
g) Predicted thicknesses for various section factors and design temperatures.
h) The reference of each test report used for the assessment.
i) Maximum fire resistance period defined by 2.3.4.3.
j) Surface preparation of the steel substrate and if applicable use of mesh reinforcement.
k) Method of fixing and support.
l) Reasons for the omission of any test data.

2.4 TEST AND ASSESSMENT PROCEDURES – REACTIVE FIRE PROTECTION SYSTEMS

This Section presents guidance with respect to the evaluation of structural steel sections protected against fire by reactive coatings. It is permissible to use an assessment to EN 13381-8 in its entirety. Where the assessment is based on test data generated in accordance with EN 13381-8 or BS 476: Parts 20/21 or a mixture of both the assessment shall be carried out following the requirements of this Section.

2.4.1 Test procedures

2.4.1.1 BS 476: Parts 20/21

The test procedures given in BS 476: Parts 20/21 should be followed but may be varied by the following additional requirements:

a) The temperature of the steel elements should be measured by mineral insulated stainless steel sheathed thermocouples of Type K as specified in EN 60584-1 and have an overall diameter of 1.5mm.

b) The thermocouples should be attached to the steel sections by peening or other methods that do not affect the response or accuracy of the thermocouple.

c) Thermocouples for measurement and recording of steel temperatures shall be located according to the Figures 11 to 14 (2.4.4.11).

   Additional thermocouples may be fixed to the steel sections at other locations in accordance with the manufacturer's instructions.

2.4.1.2 EN 13381-8

It is acceptable to use test data generated using the test procedures given in accordance with EN 13381-8 to provide an assessment in accordance with 2.4.4 subject to the following rules:

a) The load bearing capacity must satisfy the requirements given in 2.4.4.4

b) The average temperature of the steel beams (loaded and unloaded short beams) may be derived from the thermocouples referred to in Figures 11 and 12 (2.4.4.1.11).

c) The test data must be used without modification i.e. not adjusted to take into account the difference in performance between BS and EN test conditions.

d) The EN test data can be used in whole or in part to supplement BS data but where a data set includes both BS and EN data the following should generally apply:

   i) If EN data is used to provide an additional thickness line then all the data points in the line must be used.
   ii) EN data points can be used to supplement BS data points to extend the scope of the assessment where no BS data exists. For example an EN data point which has the same nominal thickness as a BS line may be used provided the section factor is not covered by the BS data.
   iii) Where conflict occurs between BS and EN data points BS data points take precedence over EN data points

e) The assessment must comply with all requirements given in 2.4.4.

2.4.2 Test programme

2.4.2.1 General

The test programme must be designed to adequately demonstrate the ability of the coating to maintain the maximum anticipated structural performance of the steel section and provide sufficient thermal data to cover the anticipated range of section types and sizes.

Consequently, the test programme will include loaded sections and unloaded sections.

2.4.2.2 Tests on Loaded and Tall Sections

Loaded beams and loaded columns and tall columns shall be tested depending upon the scope of the assessment. The purpose of testing these sections is to demonstrate the stickability performance of the coating for up to the maximum required fire resistance period and to correct the thermal data generated by the short sections for stickability.

For assessments required to cover I-section beams and columns the following testing should be carried out:

Table 3 – Loaded/tall section sizes

Section Type	Section Size mm x mm x kg/m	Protection Thickness
Loaded beam	406x178x60 or to suit scope of assessment	Minimum
Loaded beam	406x178x60 or to suit scope of assessment	Maximum
Loaded column	203x203x52 or to suit scope of assessment	Maximum
Tall column*	203x203x52 or to suit scope of assessment	Maximum

* may be tested as an alternative to the loaded column.

The testing requirements for hollow columns (SHS) may be adjusted if it is shown that one particular shape performs worse than the other. In this case only the most onerous performing shape need be tested.

Testing of circular and rectangular hollow columns protected with intumescent coatings does not conclusively demonstrate that one particular shape is more onerous than another.

To demonstrate which particular shape is more onerous, prior to assessing both circular and rectangular hollow shapes on the basis of testing one shape only the following process shall be followed:

a) Test a tall column of each type with the same nominal section factor, protected with the same coating thickness that relates to the nominal maximum thickness.

b) Determine the most onerous performance, by comparing the steel temperature profiles of each type of column with respect to time, and include this in the product assessment.

c) Once the determination of the most onerous type of hollow section has been made, the short sections may be selected accordingly.

Alternatively fire tests on both circular and rectangular hollow sections may be conducted and assessed separately.

For assessments required to cover hollow columns the following testing should be carried out:

Table 4 – Loaded/tall hollow section sizes

Section Type	Section Size mm x mm x mm or dia (mm) x mm	Protection Thickness
Loaded column	200x200x6.3 or to suit scope of assessment	Maximum
Loaded column	219.3x6.3 or to suit scope of assessment	Maximum
Tall column*	Either 219.3x6.3 for circular columns or 200x200x6.3 for rectangular columns or to suit scope of assessment	Maximum

* may be tested as an alternative to the loaded columns only if loaded I-section or hollow section beams are tested.

For assessments required to cover rectangular hollow beams the following testing should be carried out:

Table 5 – Loaded section sizes to cover rectangular hollow sections

Section Type	Section Size mm x mm x mm	Protection Thickness
Loaded beam	300x200x6.3 or to suit scope of assessment	Maximum

The magnitude of the load applied to loaded sections shall be in accordance with BS449: Part 2:1969.

2.4.2.3 Short Sections

The selection of the test specimens will be determined to suit the scope of the assessment required for the product. The selection will be on the basis of the section factor range (maximum and minimum) and the thickness factor range (maximum and minimum).

The range factors will be 1.0 for the maximum value and 0.0 for the minimum value in each case and the actual values will be determined by the manufacturer.

For short sections of all shapes the minimum required data sets depending upon the required protection thickness range are given in Tables 6 to 8.

Table 6 – Section range factor v. thickness range factor (<3mm)

Section Range Factor (K_s)	Thickness Range factor (K_d)		
	0.0 (d_{min})	0.4-0.6	1.0 (d_{max})
0.0 (s_{min})	✓	✓	✓
0.4-0.6	✓	✓	✓
1.0 (s_{max})	✓	✓	✓

This table applies where the maximum protection thickness minus the minimum protection thickness equals 3mm or less.

Table 6 applies to beams and columns separately i.e. at least 9 short beam sections should be tested for a beam assessment and at least 9 short column sections should be tested for a column assessment.

The selection of the sections to be tested in accordance with Tables 6 to 8 shall be based on the nominal section factor as listed in Tables 3 to 5. For practical reasons each section factor range e.g. 0.4-0.6 must be considered have a tolerance of ±15%.

Table 7 – Section range factor v. thickness range factor (3mm – 4.5mm)

This table applies where the maximum protection thickness minus the minimum protection thickness is greater than 3mm and less than or equal to 4.5mm.

Section Range Factor (K_s)	Thickness Range factor (K_d)			
	0.0 (d_{min})	0.23-0.43	0.56-0.76	1.0 (d_{max})
0.0 (s_{min})	✓	✓	✓	✓
0.4-0.6	✓	✓	✓	✓
1.0 (s_{max})	✓	✓	✓	✓

Table 7 applies to beams and columns separately i.e. at least 12 short beam sections should be tested for a beam assessment and at least 12 short column sections should be tested for a column assessment.

Table 8 – Section range factor v. thickness range factor (>4.5mm)

This table applies where the maximum protection thickness minus the minimum protection thickness is greater than 4.5mm.

Section Range Factor (K_s)	Thickness Range factor (K_d)				
	0.0 (d_{min})	0.15 – 0.35	0.40 – 0.60	0.65 – 0.85	1.0 (d_{max})
0.0 (s_{min})	✓	✓	✓	✓	✓
0.4-0.6	✓	✓	✓	✓	✓
1.0 (s_{max})	✓	✓	✓	✓	✓

Table 8 applies to beams and columns separately i.e. at least 15 short beam sections should be tested for a beam assessment and at least 15 short column sections should be tested for a column assessment.

It is recognised the above tables are intended for new product testing. Extension testing of existing products may result in thickness bands not compliant with the tables. In such cases the requirement for the minimum number of thickness bands appropriate to the maximum protection thickness shall be complied with, and the bands shall have a minimum separation no less than 0.15(d_{max}) and a maximum separation no greater than 0.4(d_{max})

It is acceptable to increase the scope by testing additional thickness bands beyond the number given in Table 8. In this case the additional bands should lie between the bands given in the table.

For assessment purposes the dimensions and cross-sectional areas of the steel sections shall be measured, neglecting any internal and external radii. These values shall be used to determine the section factors, according to the equations given in Annex 4, Table A.1.

To allow for data correction a short equivalent reference section (similar section factor and protection thickness) must be tested in the same furnace as the loaded or tall sections and at the same time where possible. This reference section may be included in Tables 6 to 8.

Additional sections may be tested to increase the scope of the assessment and at least one short beam section should have a minimum web depth of 600mm.

If the increase in scope relates to an increase in the maximum protection thickness the additional sections selected must include an appropriate loaded section or tall section together with the equivalent reference section.

Actual thickness and section factor are calculated in accordance with the following equations:

For thickness

$d_p = K_d (d_{max} – d_{min)}) + d_{min}$

Where

d_p is thickness at factor K_d

d_{max} is maximum thickness at K_d factor of 1

d_{min} is minimum thickness at K_d factor of 0

e.g. Thickness range 0.2 to 1.2mm

Then thickness for a K_s factor of 0.5 is ((1.2-0.2)x0.5)+0.2 = 0.7mm

For section factor

$s_p = K_s (s_{max} – s_{min)}) + s_{min}$

Where

s_p is section factor at factor K_s

s_{max} is maximum section factor at K_s factor of 1

s_{min} is minimum section factor at K_s factor of 0

e.g. Section Factor range 60 to 300m^{-1}

Then section factor for a K_s factor of 0.5 is ((300-60) x 0.5) + 60 = 180m^{-1}

2.4.3 Construction of the Steel Test Specimens

2.4.3.1 General

The construction of the test specimens shall follow the requirements of BS 476: Parts 20/21 and or EN 13381-8 unless specifically modified in this document.

The steel grade required for the loaded sections shall be S275 or S355 in accordance with BS EN 10025.

2.4.3.2 Size of sections

Loaded beams shall have a total length exposed to heating of not less than 4000mm. The length of the specimen shall be the exposed length plus up to a maximum of 500mm at each end.

All loaded columns shall have a minimum height, exposed to heating, of 3000mm.

The short beams and columns shall have a length of 1000mm ±50mm. Short sections weighing more than 350kg/m may be reduced to 500mm in length.

The tall column sections shall have a height of 2000mm ±50mm.

2.4.3.3 Upper plate for columns

In order that the thermal insulation performance of a reactive coating applied to a column may be accurately determined, the top edge of the column undergoing test is required to be adequately insulated to prevent inappropriate heat transfer to the section at this position.

A 6mm thick steel plate shall be fixed directly to the top edge of unloaded columns and at a distance of 3m from the base of the loaded column. The plate will be welded to the section and will be coated with the reactive material to all exposed areas (except the top face) at a thickness similar to that applied to the main section.

The upper edge of the plate will be protected with insulation board or similar which at elevated temperatures is capable of providing equivalent or greater insulation than that of the fire protection.

This arrangement should allow the char to form in a more realistic manner and prevent false temperature data being recorded in this critical area.

This arrangement may also be applied to the loaded column except that the plate may be positioned below the top edge to avoid interference with the loading equipment. In this case the minimum exposed height shall be maintained.

2.4.3.4 Dry film thickness measurement

The thickness shall be measured using an instrument employing either the electromagnetic induction or eddy current principle, with a minimum probe contact diameter of 2.5mm. The instrument shall be operated in accordance with the manufacturer's instructions for use.

Calibration shall be carried out immediately prior to any series of measurements being taken utilising calibration shims above the anticipated thickness being measured. Calibration shims shall be no more than 50% greater than the thickness being measured. The instrument shall be set to zero on the flat plate supplied.

The instrument shall satisfy the following criteria:

a. Possess a total range greater than the highest thickness to be measured.

b. Provide a digital display of coating thicknesses.

In addition, the following properties are advantageous:

c. Capable of storing measured values

d. Capable of calculating statistical parameters – maximum, minimum and mean value and standard deviation.

e. Capable of providing a hard copy of the data and possess the ability to be linked to a computer.

If c) to e) are not available, readings will need to be written down by hand as taken to enable items in d) to be calculated if required.

Thickness shall be measured on allocated surfaces other than edges and web/flange joins. Measurements shall be evenly distributed over all the coated surfaces and there shall be minimally one reading per 200 cm² of coated surface.

No readings shall normally be taken within 25mm of edges, web/flange joins or web stiffeners but it may be necessary to waive this requirement for narrow flange beams.

In the case of a primer being employed, primer thickness shall be determined prior to application of the intumescent coating and subsequently subtracted from the measured total thickness of primer and intumescent coating.

2.4.3.5 Dry film thickness distribution

Loaded beams:

A minimum number of 88 measurements should be taken on I-section beams and 66 measurements for hollow beams spread over the measuring stations at locations in the proximity of:

- the measurement stations at which temperature measurements are made on the surface of the test beam;
- the positions at which temperature measurements are made on the upper surface of the bottom flange of the beam or the bottom surface of hollow beams, halfway between each temperature measurement station;
- similar positions on the lower surface of the upper flange of the I-section beam to those of the lower flange indicated above;
- the positions halfway between the outermost temperature measurement stations and the outermost points on the upper surface of the bottom flange of the beam or the bottom surface of hollow beams.

Unloaded beams:

A minimum number of 24 measurements at positions on beams and 18 measurements on hollow beams (web and flanges or faces of hollow beams at locations in the proximity of:

- the temperature measurement stations (between 50mm and 100mm away from) at which temperature measurements are made on the surface of the beam;
- similar positions on the lower surface of the upper flange of the I-section beam to those of the lower flange indicated above.

Loaded or tall columns:

A minimum number of 50 measurements should be taken on H columns and 20 measurements on hollow columns spread over the measuring stations at locations in the proximity of:

- the temperature measurement stations (between 50mm and 100mm away from) at which temperature measurements are made on the surface of the test column;
- the positions halfway between each temperature measurement station.

Unloaded short columns:

A minimum number of 20 measurements should be taken on H columns and 8 on hollow columns spread over the measuring stations at locations in the proximity of:

- the temperature measurement stations (between 50mm and 100mm away from) at which temperature measurements are made on the surface of the test column.

In addition to the above measurements at least 1 measurement should be taken at 5 random positions over the general area of each specimen. These positions should not be within 200mm of each other but spread as evenly as practical.

The average primer thickness should be measured first and subtracted from the total average primer and reactive coating thickness. The resulting permitted thickness tolerances excluding primer and topcoat (assuming normal distribution of measured thickness) shall be as follows:

a) at the temperature measuring stations:

A minimum of 68 % of readings shall be within ± 20 % of the mean.
A minimum of 95 % of readings shall be within ± 30 % of the mean.
All readings shall be within ± 45 % of the mean.

b) overall:

A minimum of 68 % of readings shall be within ± 20 % of the mean at the temperature measurement stations.
A minimum of 95 % of readings shall be within ± 30 % of the mean at the temperature measurement stations.
All readings shall be within ± 45 % of the mean at the temperature measurement stations.

If measurement shows that the readings are not in accordance with this distribution it will be necessary to make adjustments by removing or adding to the coating to ensure conformity.

2.4.3.6 Conditioning of the test specimens

Test specimens shall be conditioned in such a manner that they correspond as closely as possible, in temperature, solvent content and state of cure to the expected state of a similar element in service or as specified by the manufacturer.

2.4.4 Assessment procedures

2.4.4.1 General

The assessment relates to a range of design temperatures.

Generally, only beam data points should be used for the assessment of beams and only column data points should be used for the assessment of columns.

In situations where all equivalent beams and columns, i.e. those of the very similar section factor and thickness, produce fire resistance times, within 5%, it is acceptable to use all data points for both beams and columns. The performance may be adjusted to accommodate small differences in section factor and thickness of up to 15% using a similar technique to that used to correct the data (section 2.4.4.5). The equivalent sections must cover the range of section factors and thickness.

For the assessment of I-section and rectangular hollow beams it is acceptable to use data generated by the testing of short columns of the same shape providing the required loaded beams have been tested. Alternatively separate testing of short sections of the same shape may be also be used for the assessment.

2.4.4.2 Section shape

Steel section shapes will be divided into the following groups and each is treated separately for the purpose of assessment:

<u>I-section (section shape providing a re-entrant profile)</u>

a) Horizontal
b) Vertical

<u>Circular/rectangular section</u>

a) Horizontal
b) Vertical

2.4.4.3 Assessment parameters

The following parameters are used in the assessment protocol:

a) The average dry film thickness of the coating only i.e. excluding primer and topcoat thickness.
b) The section factor calculated on the basis of Annex 4, Table A.1 using actual measured dimensions.
c) The mean steel temperature calculated as follows:

I-section beams

the average of the temperatures recorded by the thermocouples attached to the lower flange plus the average of the temperatures recorded by the thermocouples attached to the web divided by 2.

H-section columns

the average of the temperatures recorded by the thermocouples attached to the flanges plus the average of the temperatures recorded by the thermocouples attached to the web divided by 2.

Hollow sections

the average of the temperatures recorded by all thermocouples.

d) The corrected times for the mean steel temperature of the steel sections to reach the specified temperatures. In the case of loaded or tall sections only times adjusted for nominal thickness are used.
e) At least the minimum data set in accordance with Tables 6 to 8.
f) The maximum fire resistance period.

The data from the short reference section is not used in the analysis but replaced by data from the equivalent loaded or tall section instead. However, to satisfy the test matrix requirements the short reference sections may be included as part of the test matrix in Tables 6 to 8.

2.4.4.4 Maximum fire resistance period

The maximum fire resistance period is determined by the performance of the loaded and tall sections.

If, during a loaded test, load-bearing capacity failure of the specimen occurs before the maximum required fire resistance period is achieved, (e.g. 115min rather than 120min or more) the result may still be acceptable provided that, for beams, the load is removed after a deflection of at least span/35 has occurred or, for columns, the load is removed when structural failure is imminent and the test is run-on until the full period is completed.

The coating should remain intact during the over-run period for the extrapolation to be considered. The time extrapolation will be limited to 10% of the achieved maximum load-bearing capacity for any particular specimen shape or orientation.

In the case of testing tall columns these sections must achieve a time to an appropriate temperature given that is at least 90% of the maximum required fire resistance period. The coating should remain intact for at least the maximum required fire resistance period.

Appropriate temperatures for tall columns are 520^{o}C for hollow sections and 550^{o}C for I or H sections.

2.4.4.5 Correction for Stickability

2.4.4.5.1 Principles

To take into account the stickability performance of the product the temperature data for the short sections is to be corrected against the loaded beams, loaded columns and tall columns depending upon the selected test programme.

Correction of the test data should be in accordance with the following principles:

I-section beams:

correct using the loaded beams at maximum and minimum protection thickness and their equivalent reference sections. Obtain correction factors for intermediate thicknesses by linear interpolation.

I-section columns:

correct using the loaded column or the tall column at maximum protection thickness and the equivalent reference section.

Hollow columns (SHS):

Correct using the loaded column or the tall column at maximum protection thickness and the equivalent reference section. The correction must be based on the most onerous shape unless both shapes are tested in accordance with the minimum the test package given in Tables 6 to 8.

Hollow beams (SHS):

Correct using the loaded beam at maximum protection thickness and the equivalent reference section.

2.4.4.5.2 Correction Procedures

The loaded or tall section and its equivalent short reference section may not have identical section factors and protection thickness, in which case the times for the short section to reach each of the design temperatures are adjusted to the same section factor and thickness as the loaded or tall section using the following equation.

$t_c = t_1 \times (S_1/S) \times (D/D_1)$
Where
t_c is corrected time
t_1 is time for the reference section to reach the design temperature
S is the section factor of the loaded or tall section
S_1 is the section factor of the reference section
D is the protection thickness for the loaded or tall section
D_1 is the protection thickness for the reference section

The correction factor k is calculated using the following equation.

Correction factor $k = t_l / t_c$
t_l is time for the loaded or tall section to reach the design temperature.

Where the correction factor is greater than one a correction factor of one is used.

The times for the short sections to reach the specified temperatures are corrected using the appropriate correction factor and the corrected times are used as input data in the analysis.

An example is given in Table 9.

Table 9 – Example of the determination of a Correction Factor

Section Type	Thickness mm	Section Factor m^{-1}	Time to reach design temp minutes	Corrected time for thickness and section factor for reference section minutes t_c	Correction factor ($k=t_l/t_c$)
Loaded Beam	2.50 (D)	158 (S)	67 (t_l)	75.6	0.88
Reference Beam	2.56 (D_1)	161 (S_1)	76 (t_1)		

Where the selected test package includes loaded sections with minimum and maximum thickness the correction factor for the short sections is calculated by linear interpolation between the correction factors derived at minimum and maximum protection thickness.

The correction factor for short sections with thicknesses within the range is obtained by linear interpolation using the following equation:

$$k_i = \left[\frac{k_{max} - k_{min}}{d_{max} - d_{min}}\right](d_i - d_{min}) + k_{min}$$

k_i is correction factor for the short section at thickness di
k_{imax} is correction factor at maximum protection thickness
$k_{imin}$is correction factor at minimum protection thickness
d_i is protection thickness of the short section in mm
d_{min} is the minimum protection thickness of the loaded or tall section in mm
d_{max} is the maximum protection thickness of the loaded or tall section in mm
Corrected time for the short section = k_i x time to the design temperature

An example calculation relating to correction using loaded and reference beams is given in Table 10.

Table 10 – Determination of Correction Factors using Loaded and Reference Beams

Section Type	Thickness mm	Section Factor m^{-1}	Time to reach design temp minutes	Corrected time for thickness and section factor for reference section minutes t_c	Correction factor k
LB d_{max}	2.50	158	67	75.6*	0.88 (k_{max})
Ref B d_{max}	2.56	161	76		
LB d_{min}	0.38	155	40	40.7*	0.98 (k_{min})
Ref B d_{min}	0.39	154	42		

LB loaded beam. Ref B equivalent short beam. d_{max} maximum thickness. d_{min} minimum thickness.

*this is the time that the short beam would have achieved if its protection thickness and section factor were the same as that of the equivalent loaded beam. An example is given in Table 11.

Table 11 – Correction of Short Section Data

Short section	Thickness (d_i) mm	Time to design temperature minutes	Factor k_i	Modified time minutes
short beam	1.25	75	0.939	70.4

Factor k_i is obtained by linear interpolation between k_{max} and $k_{min.}$

The correction factors for all design temperatures above the temperature at which the loaded section fails loadbearing capacity as defined in BS 476: Part 20 will be based on a lowest value derived as follows:

a) determine the factor at a temperature equal to 100 °C below that at which loadbearing capacity failure occurred as above;

b) determine factors for intermediate temperatures at intervals of 10 °C in the same way;
c) select the lowest value and use for data correction for design temperatures above that at which loadbearing capacity failure occurred.

In the case where the scope of the assessment is to be increased by the testing of additional loaded or tall sections ie related to an increase in maximum protection thickness it is acceptable to determine the correction factor for the additional short sections by linear interpolation between the correction factors derived at previous maximum and new maximum protection thickness.

2.4.4.6 Criteria for acceptability

The acceptability of the analysis within the range of steel section temperature and duration of the test shall be judged up to the maximum temperature tested on the following basis:

a) For each short section the predicted time in minutes to reach the design temperature calculated to one decimal place shall not exceed the corrected time by more than 15%;

b) The mean value of all percentage differences as calculated in a) shall be less than zero;

c) A maximum of 30% of individual values of all percentage differences as calculated in a) shall be more than zero;

d) The results of the analysis which satisfy a) to c) above must also comply with the following rules provided all other parameters remain constant:

   i. The thickness of fire protection material increases with fire resistance time

   ii. As the section factor increases the fire resistance time decreases

   iii. As fire resistance time increases the temperature increases

   iv. As thickness increases temperature decreases

   v. As section factor increases the temperature increases

   vi. As section factor increases thickness increases

e) Modification of the analysis should be made until the criteria of acceptability are met

2.4.4.7 Assessment design temperatures

The assessment shall be carried out at steel temperatures between 350°C and 800°C in 50°C intervals, provided that the protection system has proved to be effective and intact at those temperatures, fire resistance periods and section factors.

An analysis relating to a steel design temperature other than those given above can be undertaken subject to the requirement of the manufacturer.

2.4.4.8 Permitted Extensions

a) Section factor

Beams

Maximum permitted section factor: up to 10% above the maximum section factor of any section tested.

Minimum permitted section factor: up to 10% below the minimum tested on any beam section subject to the minimum permitted beam thickness being applied. For section factors below the extended minimum the same thickness as that applied to the extended minimum section factor must be applied.

Columns

Maximum permitted section factor: up to 10% above the maximum section factor of any column section tested.

Minimum permitted section factor: up to 10% below the minimum tested on any column section subject to the minimum permitted column thickness being applied. For section factors below the extended minimum the same thickness as that applied to the extended minimum section factor must be applied.

The above extensions are confined to each section type i.e. the permitted extensions for beams are not appropriate for columns and vice versa. Similarly those extensions applied to I or H sections may not be applied to hollow sections and vice versa.

b) Protection thickness

Beams

Maximum permitted thickness: up to 10% above the maximum thickness tested on a loaded beam.

Minimum permitted thickness: up to 10% below the minimum tested on a loaded beam.

Columns

Maximum permitted thickness: up to 10% above the maximum thickness tested on a loaded column or tall column.

Minimum permitted thickness: up to 10% below the minimum tested on a loaded column where such a test has been carried out. Where this is not the case the permitted minimum will be limited to 10% below the minimum tested on a short unloaded column.

c) Other sections with re-entrant details

Results of the assessment for I or H sections are directly applicable to angles, channels and T-sections for the same section factor.

d) Method of application

For water-based coatings the method of application does not significantly affect the performance of the coating therefore the assessment applies to all application methods (generally spraying or brushing).

For solvent based coatings the method of application is more sensitive and may affect the performance of the coating. If the application method used for the tested sections is by spraying the assessment applies to both spraying and brushing.

If the application method used for the tested sections is not by spraying the assessment is limited to the application method used for the tested sections.

e) Primer Compatibility

The assessment of the coating is limited to the primer type and thickness used for the loaded tests and tall columns. General guidance on the use of primers is given in prEN 16623 6.2.3.

f) Surface Preparation

The adhesion of the coating system, including the primer, will depend on satisfactory preparation of the steel substrate therefore the assessment is limited to the surface treatment used for the tested sections.

g) Deep Web Beam Sections

If the tested sections providing data for the assessment included a 610mm deep web unloaded beam and a 120mm wide flange unloaded beam the assessment applies beam sections up to 914mm in depth.

Where such sections have not been tested the assessment is limited to the maximum depth of any beam tested plus 50%.

2.4.4.9 Assessment protocol: Graphical method

The following stepwise methodology shall be performed:
Step 1 : Determination of nominal thickness
Step 2 : Preparation of graphs
Step 3 : Methods for plotting lines or curves
Step 4 : Application of criteria for acceptability
Step 5 : Derivation of intercepts
Step 6 : Linear interpolation
Step 7 : Reporting of results

Input Data

- the design temperatures as defined in 2.4.4.7
- the times to reach the mean design temperatures
- the calculated section factor for the steel members
- the thickness of the protection material only

Step 1: Adjust corrected times on the basis of a nominal protection thickness
For each data point adjust the corrected time to reach the specified design temperature on a pro-rata basis of nominal and actual thickness. An example follows:

Assuming linear behaviour and a plot of nominal thickness 0.500 mm and a data point of 0.523 mm actual thickness with a time to reach a specified design temperature of 64 minutes use $0.500/0.523 \times 64$, i.e. 61 minutes for this data point.

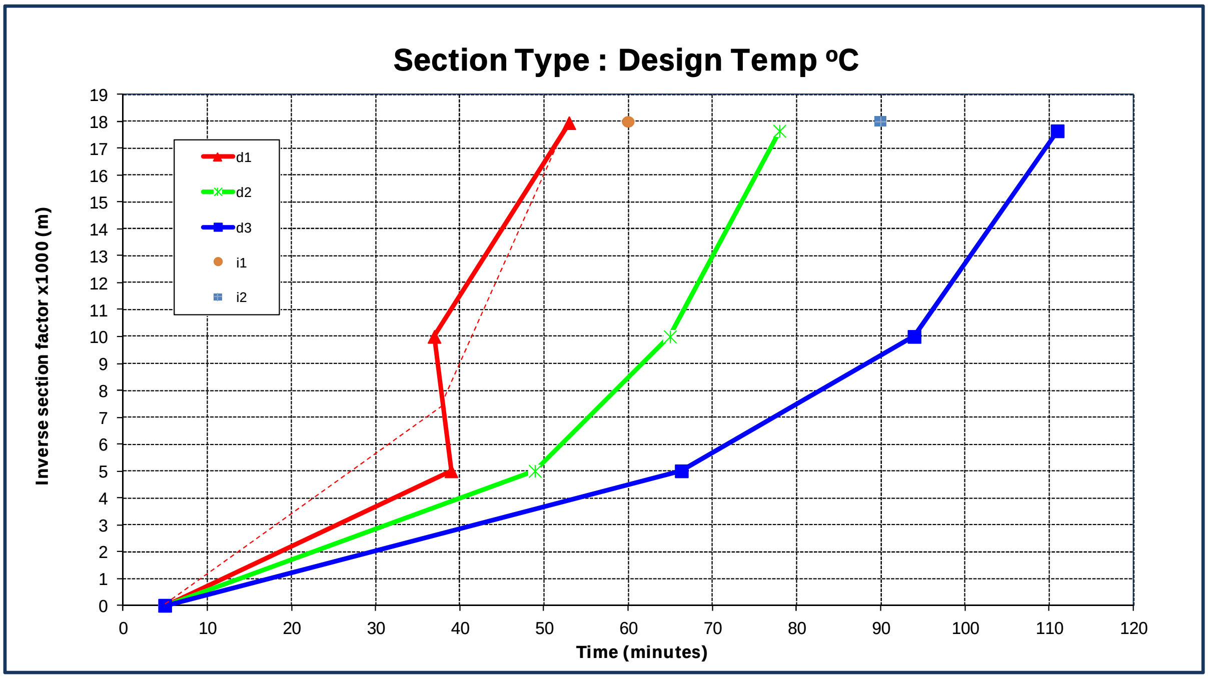
The nominal protection thickness is calculated as the mean of the individual thicknesses in the nominal range.

Adjustments using this approach should be limited to ± 10 % of the nominal thickness considered

Step 2: Graph

For each section tested within each nominal thickness range and for each design temperature, plot the inverse section factor against the adjusted corrected time to reach the steel design temperature as shown in Figure 6.

Figure 6 – inverse section factor v. time



An additional conservative 'virtual' data point'(vdp), represented by the coordinates inverse section factor of 0.0m and the time to reach each design temperature as specified from the standard heating curve in BS 476: Part 20 or EN 1363-1 may be used for all design temperatures and each nominal dry film thickness.

Step 3 - Line Plotting
The plots may be drawn as a simple point to point line construction or curves and may or may not include the virtual data point.

It is acceptable to include both straight line point to point plots and curved plots in any graph, further data points may be added to a straight line plot to allow a curve to be drawn and curves may be redrawn as straight line point to point plots.

Each plot shall satisfy the following requirements.

Point to point

For any nominal thickness requiring a point to point plot a minimum of three data points will be required. Additional data points may be accommodated within the minimum data set given in Table 6 to 8 in between each pair of consecutive section factors that have been tested.

Where there are data points that show contradiction as shown in line d1 in Figure 6 a conservative line shall be used. This line may be drawn to the most conservative data point (the higher inverse section factor value) or by giving equal credence to each data point i.e. by selecting a point mid-way between each point as shown by the dotted line in Figure 6.

A straight line may be drawn from the virtual data point to the lowest real data point if necessary and where data points do not show contradiction as shown for lines d2 and d3 of Figure 6.

In all cases the slope of any line used to derive intercepts shall be positive.

Curved Line

For any nominal thickness requiring a curve fit plot a minimum of five actual data points will be required. This means that additional data points are required above the minimum data set given in Tables 6 to 8. These additional data points must be accommodated in between pairs of consecutive section factors referred to in Tables 6 to 8.

The curve must be a mathematical least squares fit and may pass through the virtual data point if required.

In the case where the virtual data point is included in the curve and any part of the curve dips below the virtual data point a straight line must be drawn between the virtual data point and the first actual data point.

If this straight line does not intersect with the curve then an additional straight line must be drawn between the two actual data points to ensure this additional line crosses the curve. See Figure 7.

If the curve is not drawn using the virtual data point a straight line must be drawn between the virtual data point and the next actual data point. See Figure 8.

Similarly if this straight line does not intersect with the curve an additional line must be drawn as Figure 7.

Figure 7 – inverse section factor v. time including the vdp in the curve

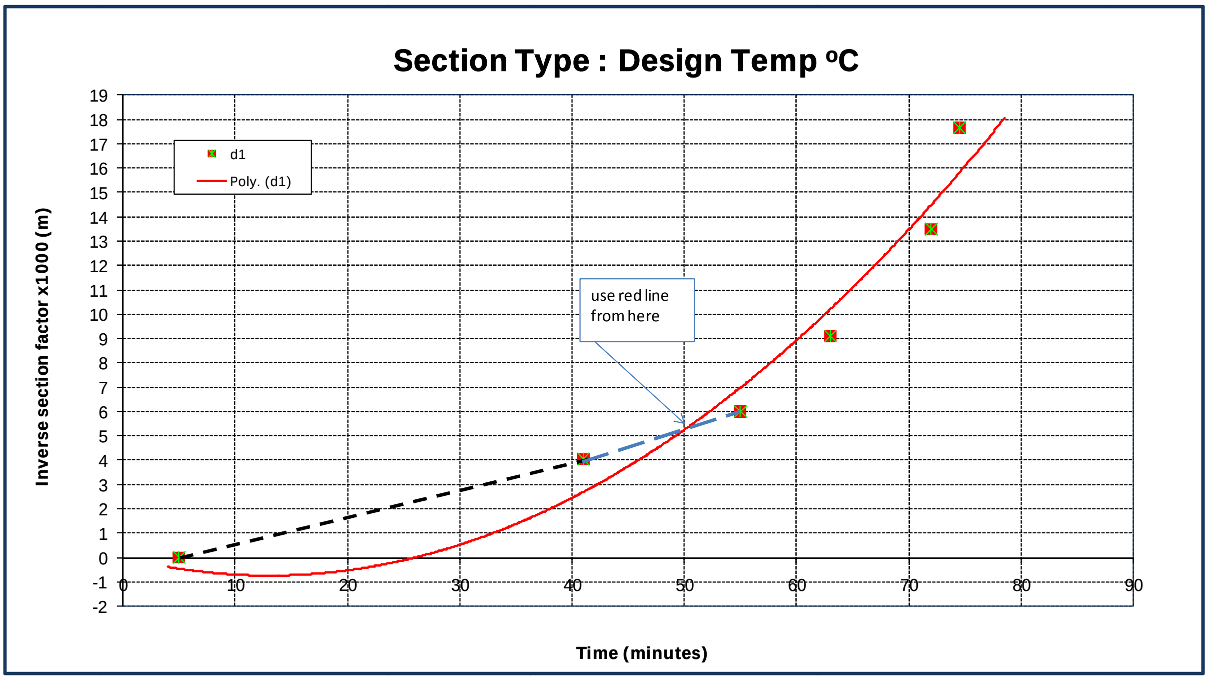
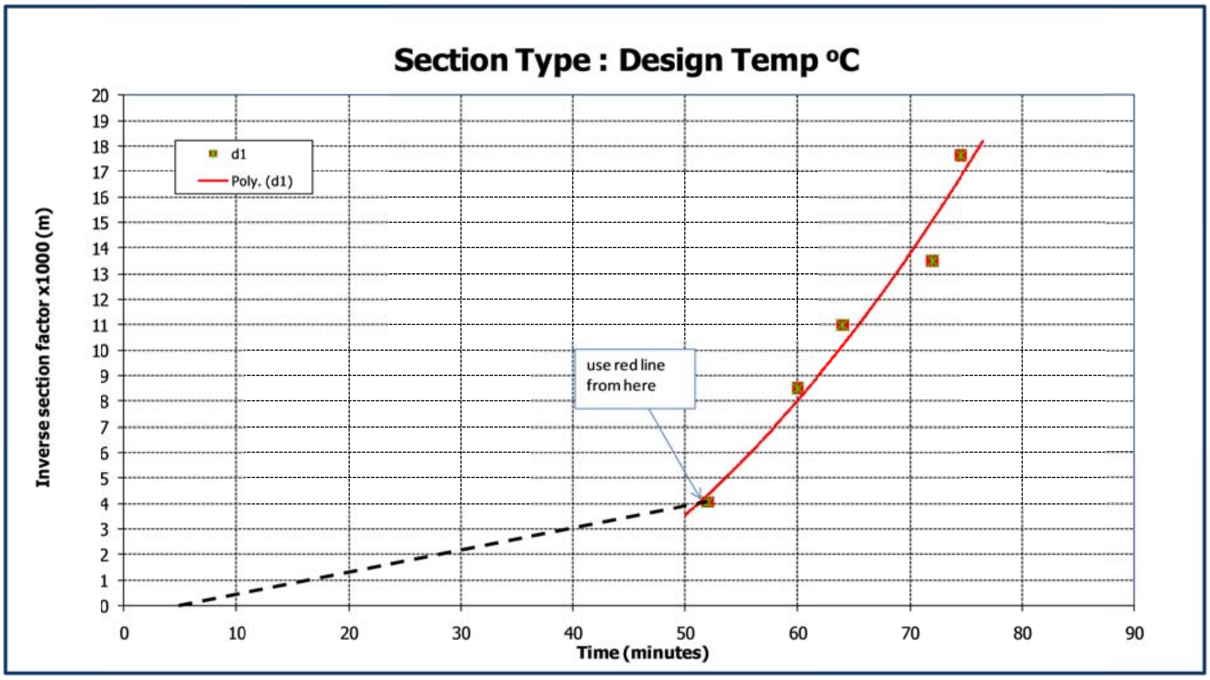


Figure 8 – inverse section factor v. time not including the vdp in the curve



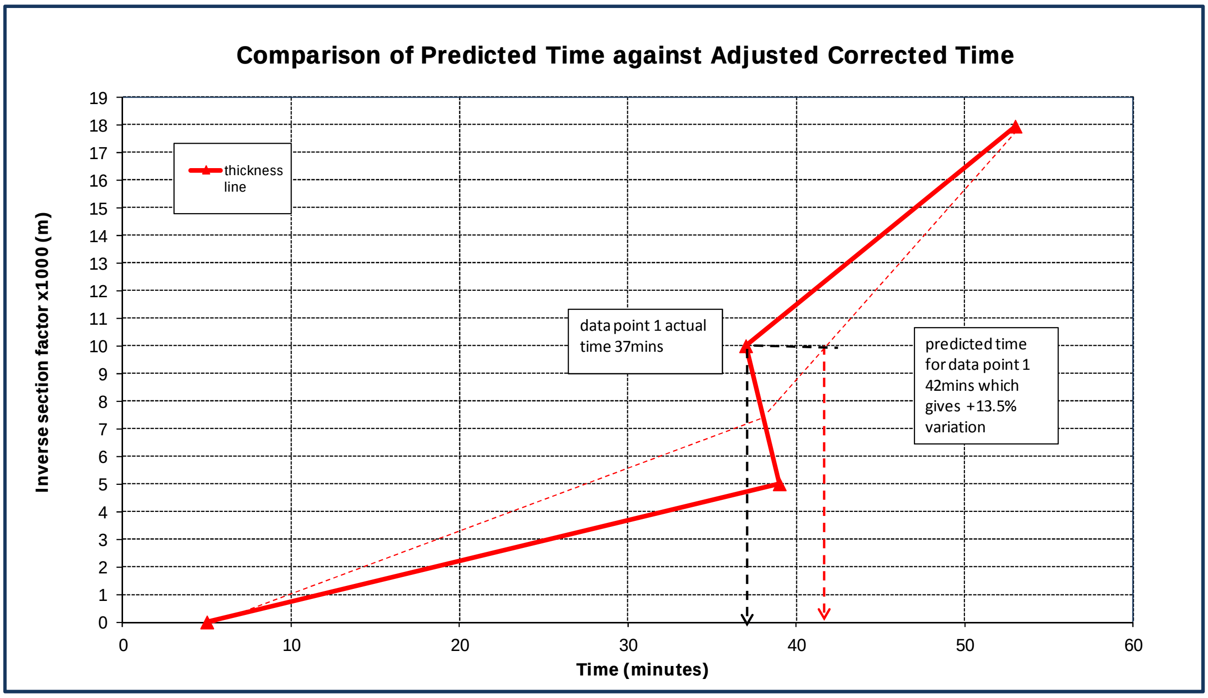
In all cases of curve fitting the following rules shall be applied:

a) The line must be a smooth curve without inflections.
b) All data points must be included in the curve fitting.
c) The line to the virtual data point must be a straight line.

Step 4: Compliance with acceptability criteria

Apply the three criteria given in 2.4.5.6 a), b) and c) for each design temperature as shown in the example given in Figure 9 (based on Figure 6) which shows a plot of inverse section factor against the predicted time and corrected time for a nominal thickness at a particular design temperature using a straight line plot. This principle also applies to curved plots.

Figure 9 – inverse section factor v. time – comparison of predicted against adjusted corrected



If for any line criteria a) is not met then the line in question must be moved towards the 'Y' axis maintaining the slope of a straight line or the curvature of a curve until it is met.

Where criteria b) or c) is not met for a particular design temperature then the lines should be moved as described above starting with the line containing the smallest unconservative prediction i.e. nearest to the actual data point.

After each move of a line the smallest unconservative prediction is redetermined and the process is repeated until the criteria are met.

Step 5: Deriving intercepts

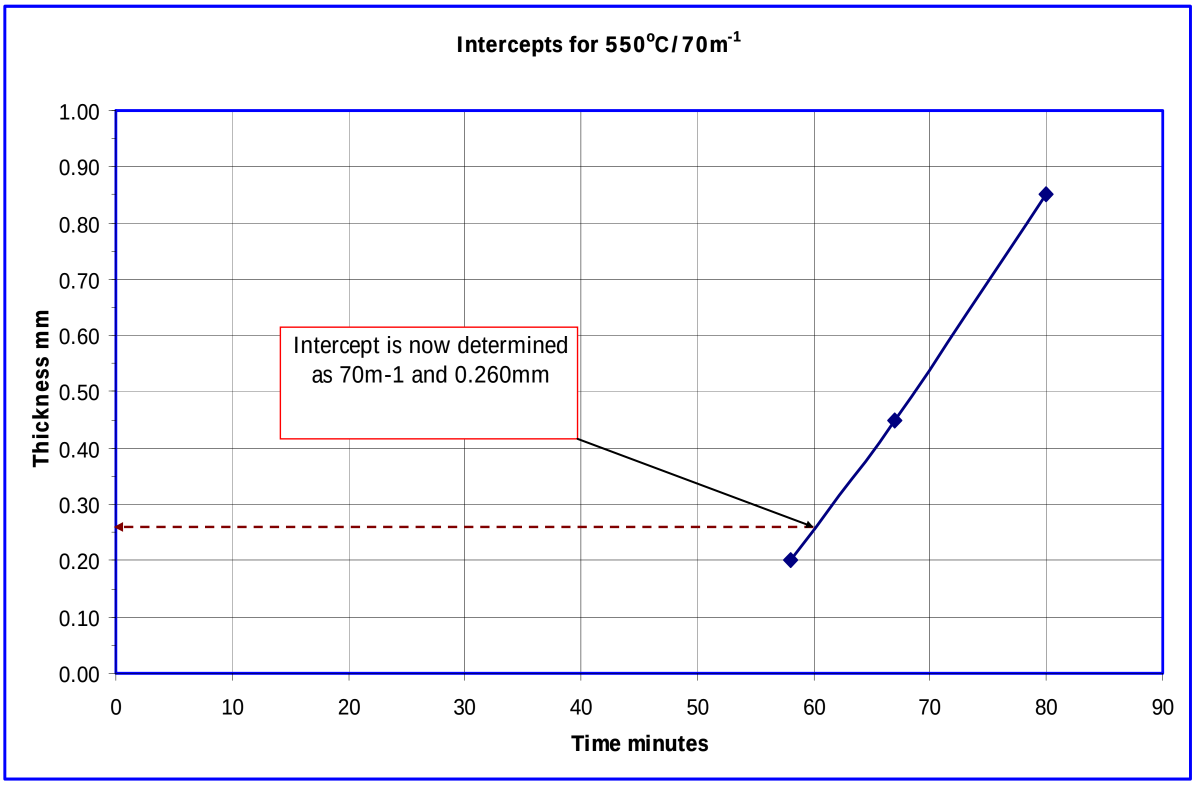
For each design temperature and each nominal dry film thickness plot, establish the inverse section factor at the intercept for each required period of fire resistance. The intercept is derived using the line that satisfies the criteria for acceptability. The intercept is then converted to a limiting section factor for that nominal thickness and that period.

Where a nominal thickness line does not intersect a fire resistance period but is within 10% of this period the line may be extrapolated to derive an intercept.

Where a nominal thickness line is not within 10% of this period an intercept may be derived by interpolation by plotting an additional graph of nominal thickness against adjusted corrected time for a common section factor. This will allow an appropriate thickness to be determined for the common section factor at a particular fire resistance period.

An example of this type of plot is shown in Figure 10 which is based on a hypothetical minimum thickness of 0.200mm, intermediate thicknesses of 0.450mm and 0.850mm and a common section factor of $70m^{-1}$.

Figure 10 – thickness v time for 550°C/$70m^{-1}$



The determination of the appropriate thickness for a common section factor shall be calculated by linear interpolation between adjacent nominal thicknesses that cover the particular fire resistance period, in this case 60 minutes.

In this case the data is summarised as follows:

Nominal Thickness mm	Time to Reach the Design Temperature (550°C) minutes
0.200	58
0.450	67

Linear interpolation to 60 minutes gives a calculated thickness of 0.260mm for a common section factor of 70m-1. Therefore in this case a calculated intercept of 0.260mm and 70m-1 may used in the assessment. The above procedures may be adopted in all cases were common section factors are available. Figure 6 also shows examples of the use of these intercepts represented by i1 and i2.

Where a thickness line crosses over another thickness line then the intercept shall be that associated with the higher thickness except where the crossover occurs because of the use of the virtual data point. In this case the crossing line to the virtual data point may be omitted and the intercept derived form the lower thickness line.

Step 6: Linear interpolation

For each design temperature and each fire resistance period determine the section factor for each nominal dry film thickness, using the data from the predicted straight line or curved line, obtained in steps 3 to 5.

Determine intermediate thicknesses and section factors by linear interpolation. In order to apply linear interpolation it is necessary to ensure that there are sufficient steps in the thickness range to avoid unconservative predictions.

2.4.4.10 Assessment report

The Assessment Report will fully detail the scope and limits of approval, basis of the assessment and justification for any deviations from the procedures detailed in this document.

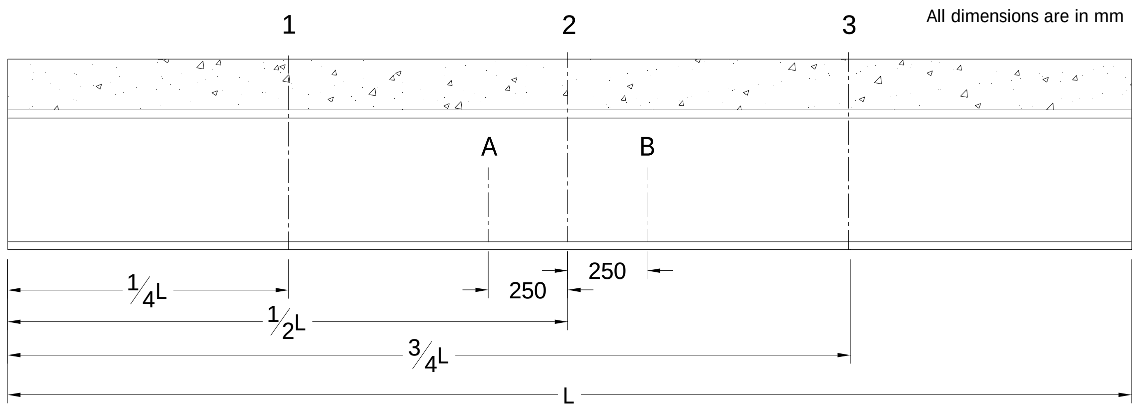
All test data used in the preparation of the assessment should be fully referenced by test number, test standard and type of test (beam/column, loaded/unloaded, full scale/small scale, etc).

The format of the assessment report shall provide the following minimum details:

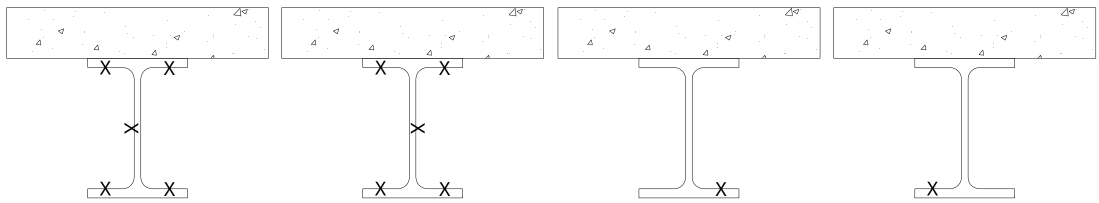
a) Brief description of fire protection material /product/system - generic types
b) Details of test specimens, number of specimens and sizes used in the analysis.
c) Details of method of analysis adopted.
d) Details of the correction of the data for stickability.
e) Predictive analyses at each critical temperature with a summary of test results and summary of analysis data.
f) Compliance with criteria of acceptability, details of any constraints and permitted extensions.
g) Predicted thicknesses for various section factors and critical temperatures.
h) The reference of each test report used for the assessment.
i) Maximum fire resistance period defined by Clause 2.4.4.4. Surface preparation of the steel substrate and primer details and if applicable top coat details.
j) Method of application.
k) Reasons for the omission of any test data.

2.4.4.11 Thermocouple locations

Figure 11 - Thermocouple Locations for Loaded Beams

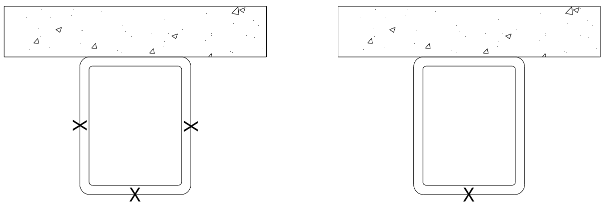


Loaded beam side elevation



Positions 1 and 3 | Position 2 | Position A | Position B

Thermocouple locations applicable to loaded 'I' and 'H' beams (17 total)



Positions 1 to 3 | Positions A and B

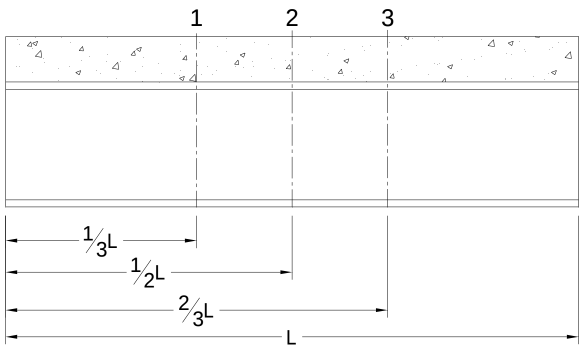
Thermocouple locations applicable to loaded hollow section beams (11 total)

Key

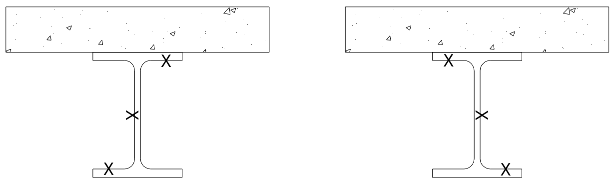
1	Position 1	A	Position A
2	Position 2	B	Position B
3	Position 3	L	Span of beam

Figure 12 - Thermocouple Locations for Short Unloaded Beams

All dimensions are in mm

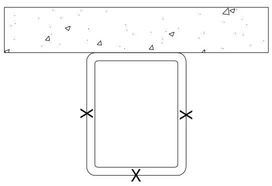


Short beam side elevation



Positions 1 and 3 Position 2

Thermocouple locations applicable to short 'I' and 'H' beams (9 total)



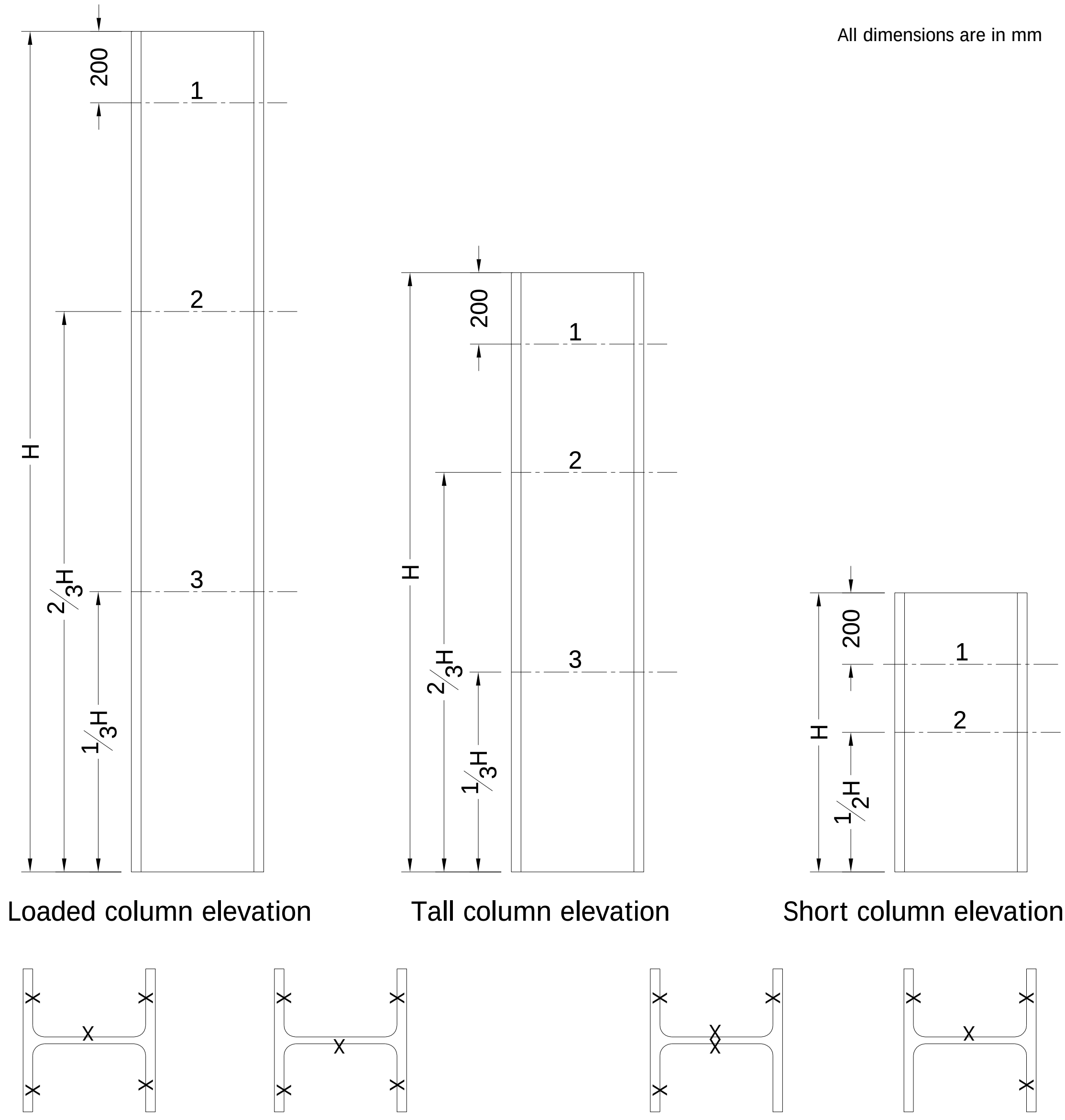
Positions 1 to 3

Thermocouple locations applicable to short hollow section beams (9 total)

Key

1	Position 1	L	Length
2	Position 2		
3	Position 3		

Figure 13 - Thermocouple Locations for Loaded, Tall and Short I or H Shaped Columns



Thermocouple locations applicable to loaded and tall columns (15 total)

Thermocouple locations applicable to short columns (9 total)

Key

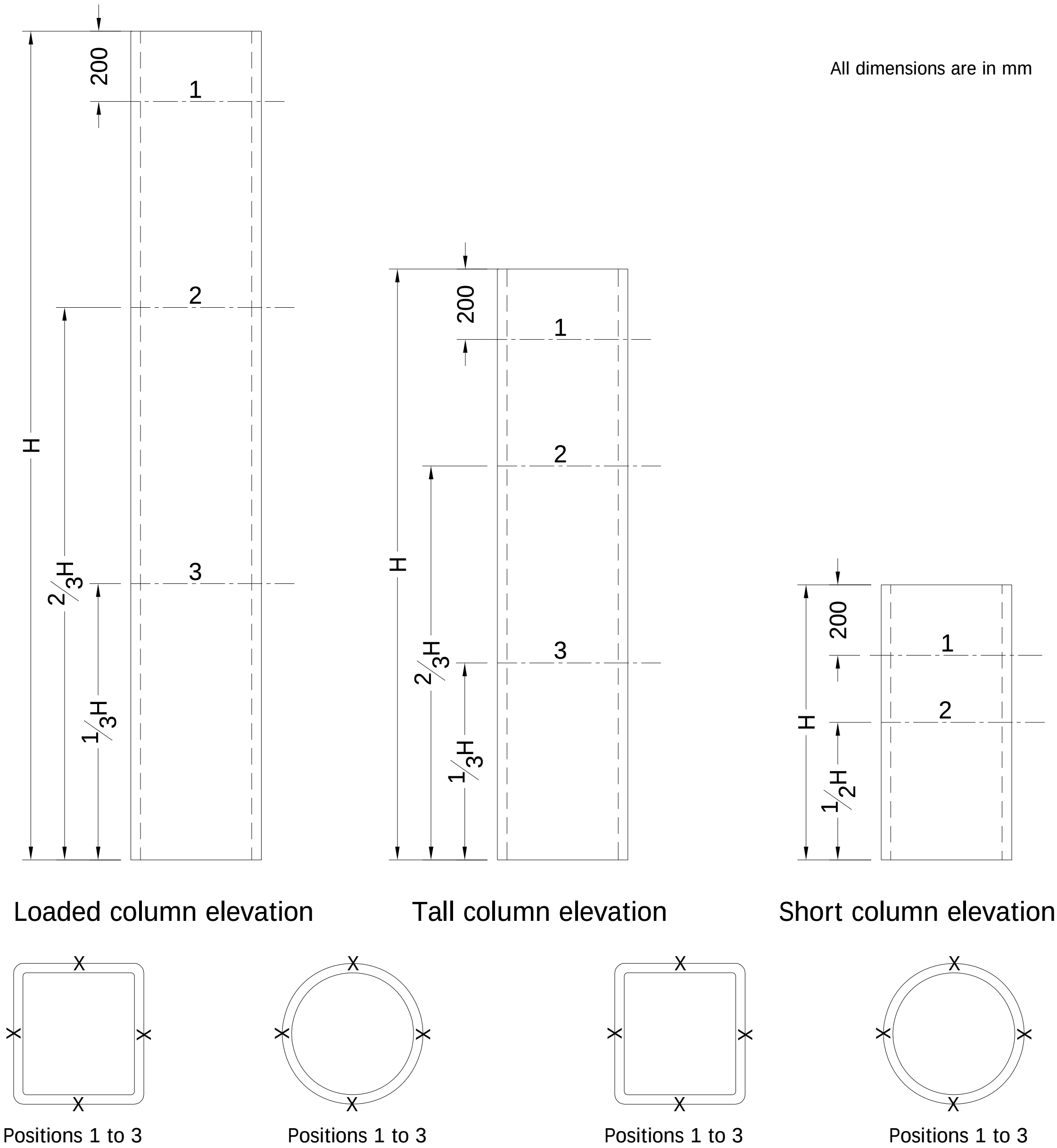
1 Position 1

2 Position 2

3 Position 3

H Height

Figure 14 – Thermocouple Locations for Loaded, Tall and Short Hollow Columns



Thermocouple locations applicable to loaded and tall columns (12 total)

Thermocouple locations applicable to short columns (8 total)

Key

1	Position 1
2	Position 2
3	Position 3
H	Height

3. European test and assessment procedures (Route 2)

3.1 Introduction

The procedures used for determining the contribution to the fire resistance of load-bearing elements of structure are given in the following standards:

- EN 13381-4: 2013: Test methods for determining the contribution to the fire resistance of structural members - Part 4: Applied passive protection to steel members
- EN 13381-8: 2013: Test methods for determining the contribution to the fire resistance of structural members - Part 8: Applied reactive protection to steel members

Products to be evaluated are subject to the test and appraisal processes detailed in these standards.

Primary test evidence must be obtained from 3rd party test laboratories accredited to ISO 17025; e.g. UKAS accredited laboratories or other laboratories similarly accredited by national accreditation bodies that have signed a Memorandum of Association with UKAS or Notified Bodies as defined under the Construction Products Regulation.

3.2 General

It is well documented that the ability of structural steel components to support load varies with temperature, consequently the individual components of the steel frame of a building can be designed such that they are able to support the applied load at temperatures other than that related to the maximum permissible loading.

The European approach given in the EN 13381-4 & 8 allows for a wide range of steel design temperatures, generally 350^{0}C to 700^{0}C, to be used, consequently the thickness of applied fire protection may be varied in accordance with the load carried by the individual steel member.

The standard is designed to cover a range of thicknesses of applied protection material, a range of steel sizes, a range of design temperatures and a range of fire protection periods. The evaluation consists of a test and a subsequent assessment protocol based on the data obtained from the tested sections.

A number of methods of analysing the test data are defined since there is unlikely to be a single method which is suitable for all protection materials. The methods include: a) graphical, b) differential formula analysis based on thermal conductivity (variable and constant) and c) numerical regression analysis.

The fire test methodology makes provision for the collection and presentation of data, which can be used as direct input to the calculation of fire resistance of steel structural members in accordance with the procedures given in EN 1993-1-2 and EN 1994-1-2.

3.3 Testing Protocol

The test sections are chosen to suit the scope of the assessment and include both loaded and unloaded sections. The minimum number of short I-sections required to be tested is 13 and the minimum number of short hollow sections required to be tested is 6.

The test sections are chosen from a series of test packages which are designed to provide specific assessments dependent on the manufacturer's requirements.

The selection of test sections is in accordance with a specific matrix which lists the section factor range and the thickness range in a similar manner to the UK approach given in 2.3 and 2.4. The manufacturer decides the minimum and maximum values for these ranges.

In the case of reactive coatings a tall unloaded I-section column may be tested in lieu of a loaded column. For hollow columns protected with a reactive coating it is necessary to test a loaded hollow column protected with the nominal maximum protection thickness. Both circular and rectangular hollow columns can be covered by testing the most onerous shape under load and generating thermal data by testing short hollow columns of the more onerous shape. The most onerous shape is determined by testing tall columns of each shape with a similar section factor and nominal maximum protection thickness.

For passive (non-reactive) fire protection systems it is not necessary to test either loaded or tall or short hollow columns of either shape since these sections can be protected using I-section data. In the case of board systems this is carried out using the same results as for the I-section columns. For renderings the modification factors listed in 2.3.4.6 are also used in EN 13381-4 for determining the thickness required for both rectangular and circular shaped columns.

For each test involving a loaded beam or column or tall column, an equivalent unloaded reference beam or column section respectively is included. Whenever possible, it should be tested in the furnace at the same time as the loaded beam/column.

For both the maximum and the minimum thickness of the fire protection system, a loaded beam is tested to examine stickability during maximum deflection of the steel section when the lower flange is at a temperature of approximately 575^{0}C, up to a maximum anticipated steel temperature.

The data from the loaded or tall sections and equivalent unloaded reference sections is used to determine the correction factors for stickability correction to be applied to the thermal data generated from the unloaded short sections.

The loading is calculated using either the measured yield strength of the steel or that given in the mill sheet rather than using the nominal value.

3.4 Test Conditions

The furnace pressure and heating conditions are specified in EN 1363-1 and are similar to those given in BS 476-20. However, the temperature of the furnace is controlled using plate thermometers rather than the thermocouples specified by the British standard. The plate thermometer is designed to harmonise the exposure of furnaces across the EU and results in a higher thermal exposure compared to the British Standard. It is partly for this reason that 'EN' derived data can be used in a 'Yellow Book' assessment because it is obtained under a more onerous heating regime. The converse, using BS derived data in an EN assessment is not permitted.

Another difference between the British and European methods is that for the loaded beam test, a layer of insulation is placed between the top flange of the beam and the floor slab. This serves to reduce the heat sink effect of the slab and to minimise the effects of composite action. British Standard beam tests use a segmented dense concrete slab in intimate contact with the top flange of the beam. The ENs allow either heavy density concrete slabs or lightweight concrete slabs to be installed on the upper edge of the beam. The use of heavy concrete slabs means that the load is applied to the slab rather than directly to the beam and is similar to current UK practice.

3.5 Assessment Methods

3.5.1 Graphical Approach

At each design temperature the corrected time from each short section within a nominal thickness band is used to provide plots of time to reach the particular design temperature against inverse section factor which is a similar approach to that described in 2.4.

The thickness lines are related to nominal thicknesses and the corrected time for each data point within the band is adjusted to take into account the difference in actual thickness.

The plots can be best fit straight lines where a minimum data set of 3 data points for each nominal thickness line is available. The plots can also be curves or 'point to point' however an increased number of data points for these plots is required. For each curve or 'point to point' a minimum of 6 data points is required. Different plots can be used on the graphs i.e. there can be a mixture of straight lines, curves or 'point to point' lines depending upon the data set.

This method is similar to the graphical method given in 2.4.4.9 and there is also a 'virtual data point' that may be used to allow the plots to extend to lower time periods. This point is based on co-ordinates 0 inverse section factor and the time taken for the furnace to reach the design temperature.

All plots are subject to the criteria for acceptability and therefore straight lines and curves could be moved to a conservative position to satisfy the criteria. In the case of 'point to point' line the criteria are automatically satisfied. Should drawing to data points cause a reverse slope to the line the most optimistic data point is moved back to a line that connects the two data points above and below the optimistic one.

Limiting section factors are obtained from intercepts of the nominal thickness lines with the required time period and intermediate values are derived by linear interpolation between intercepts. Additional intercepts can be obtained by linear interpolation between nominal thickness lines for a constant section factor.

The results are presented to give the thickness of protection material required to provide specified fire resistance periods to various section factors for various design temperatures.

3.5.2 Differential Equation

The two methods using the differential equation are based on a one dimensional heat flow equation and assume the predominant heat flow is conduction through the protection material with the outer face assumed to be at the standard fire temperature. The protection material is described using its thermal conductivity, specific heat and density and the moisture content is also taken into account.

The differential equation is solved to give thermal conductivity as a function of time. The thermal conductivity is then adjusted until the criteria for acceptability given in the document are just satisfied. The results are presented to give the thickness of protection material required to provide specified fire resistance periods to various section factors for various design temperatures.

3.5.3 Numerical Regression Analysis

The numerical regression analysis is a statistical approach which has time to reach a specified design temperature, steel temperature, section factor and protection thickness as variables.

Using the corrected data from the short sections, the regression coefficients are determined and modified if necessary to satisfy the criteria for acceptability. The coefficients are used to predict the thickness of protection material required to provide specified fire resistance periods to various section factors for various design temperatures.

3.6 Criteria for Acceptability

For the assessment to be valid, the following criteria for acceptability must be met:

a) For each short section the predicted time to reach each design temperature shall not exceed the time for the corrected temperature to reach the design temperature by more than 15%.

b) The mean value of all percentage differences as calculated in a) shall be less than zero.

c) A maximum of 30% of individual values of all percentage differences in time shall be more than zero

d) The results of the analysis which satisfy a) to c) above must also comply with the following rules provided all other parameters remain constant:

i. The thickness of fire protection material increases with fire resistance time.
ii. As the section factor increases the fire resistance time decreases.

iii. As fire resistance time increases the temperature increases.
iv. As thickness increases temperature decreases.
v. As section factor increases the temperature increases.
vi. As section factor increases thickness increases.

e) Modification of the analysis should be made until the criteria of acceptability are met

3.7 Report of assessment

The report of the assessment will include:

a) Brief description of fire protection material /product/system - generic types.
b) Details of test specimens, number of specimens and sizes used in the analysis.
c) Details of method of analysis adopted.
d) Details of the correction of the data for stickability.
e) Predictive analyses at each critical temperature with a summary of test results and summary of analysis data.
f) Compliance with criteria of acceptability, details of any constraints and permitted extensions.
g) Predicted thicknesses for various section factors and critical temperatures.
h) The reference of each test report used for the assessment.
i) Maximum fire resistance period.
j) If appropriate surface preparation of the steel substrate and primer details and if applicable top coat details.
k) If appropriate method of application.

4 The fire protection of beams with web openings (cellular beams)

Long span beams with web openings are commonly known as "cellular beams" and have numerous, openings in the web to accommodate service items such as pipes and ducts. The provision of the openings for the service items allows longer spans and a reduced storey height for more economic building construction. The openings can be circular, square, or rectangular, although circular openings are most commonly used.

Cellular beams can be manufactured by cutting shaped apertures of an appropriate pattern in the web of the parent sections and re-welding the parts together to form a deeper web beam with openings in the web. They can also be manufactured by welding three plates together, with holes pre-cut in the plate forming the web.

The beams may be asymmetrical i.e. have different sized upper and lower portions or flanges.

The introduction of openings in the web of the steel beam means the structural capability of the beam differs from that of a solid beam in that the failure mode in fire is related to the closeness of holes and the web slenderness in addition to section factor. Structural failure can be through Vierendeel bending above the opening or buckling of the web post. These failure modes generally occur at lower temperatures than a plain beam of the same size.

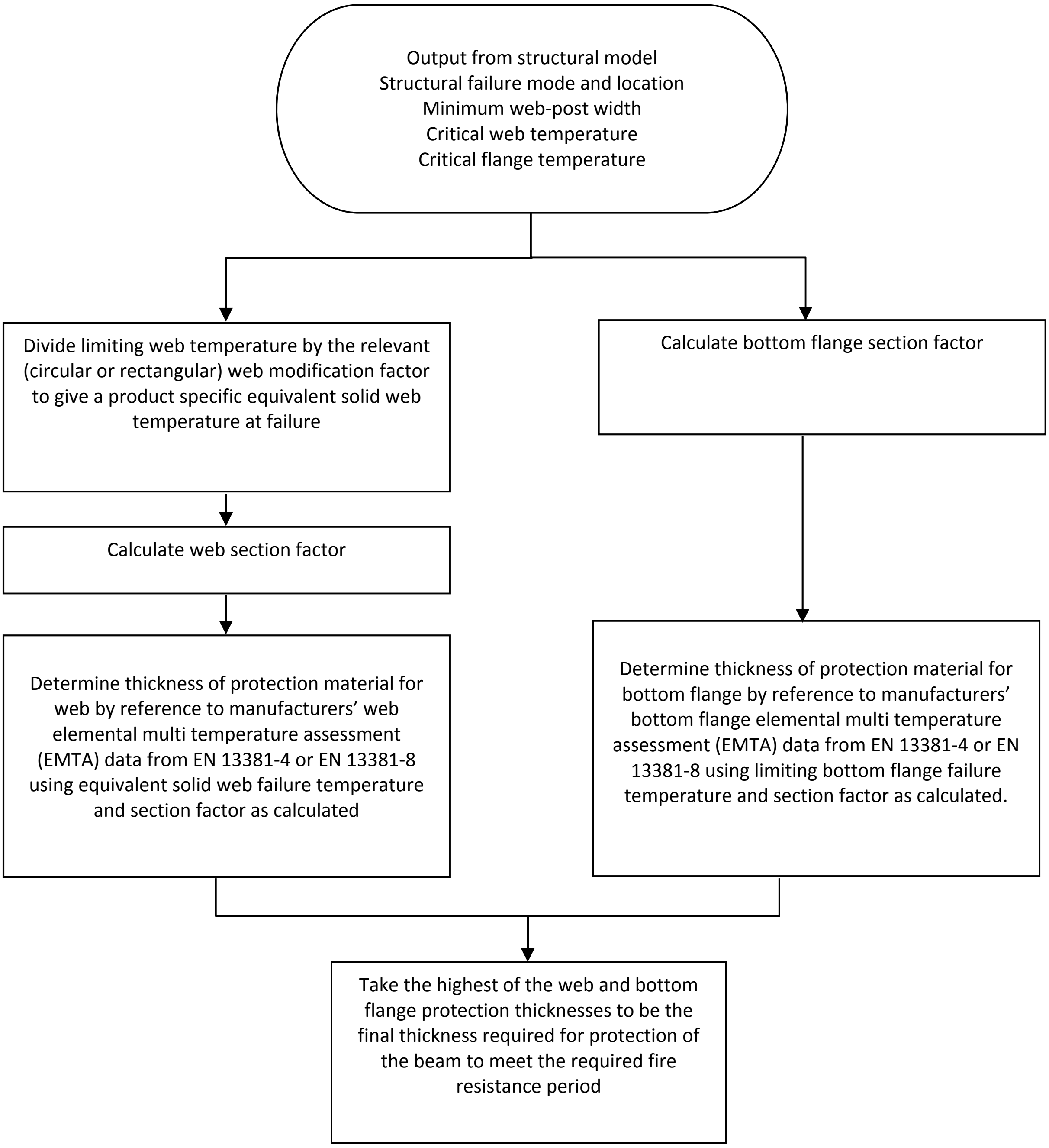
Therefore it is necessary that such beams are structurally evaluated taking into account all possible modes of structural failure under both ambient and fire conditions.

Due to the different behaviour of cellular beams it is necessary for additional thermal data to be measured around the web openings and on the web posts. The additional thermal data to be used in conjunction with a structural model to determine limiting temperatures of beams with web openings.

There are currently a number of structural models that can be used to determine the structural capability of beams with openings in the web. The Steel Construction Institute (SCI) published a number of structural models over a period of time based on progressive improvements which uses data derived from tests on products supplied by ASFP members to an agreed test programme.

The flow charts given in Figures 15, 16 and 17 show how to determine protection thickness for a number of scenarios.

Figure 15 – Flow chart to determine a product thickness of fire protection for a beam with web openings when outputs are provided to a manufacturer by a structural engineer



If the output of the structural model does not differentiate between web and bottom flange limiting steel temperatures then any temperature output must be assumed to be the limiting web temperature.
In the absence of further information on the failure modes along the beam, the smallest web-post width must be assumed to get the web modification ratio to determine the product specific equivalent solid web temperature at failure.

Figure 16 – Flow chart to determine a product thickness of fire protection for a beam with web openings using an iterative thickness analysis

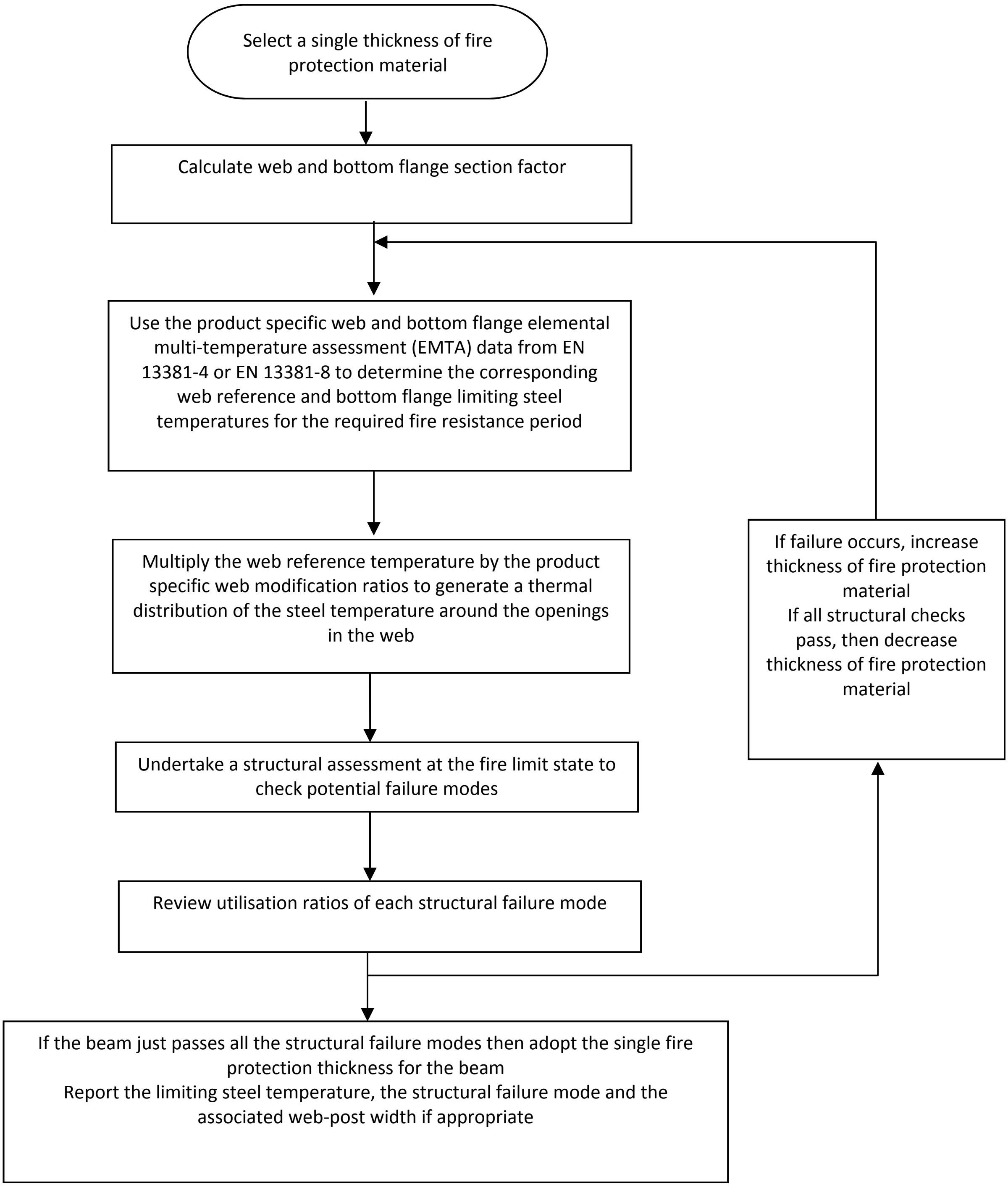
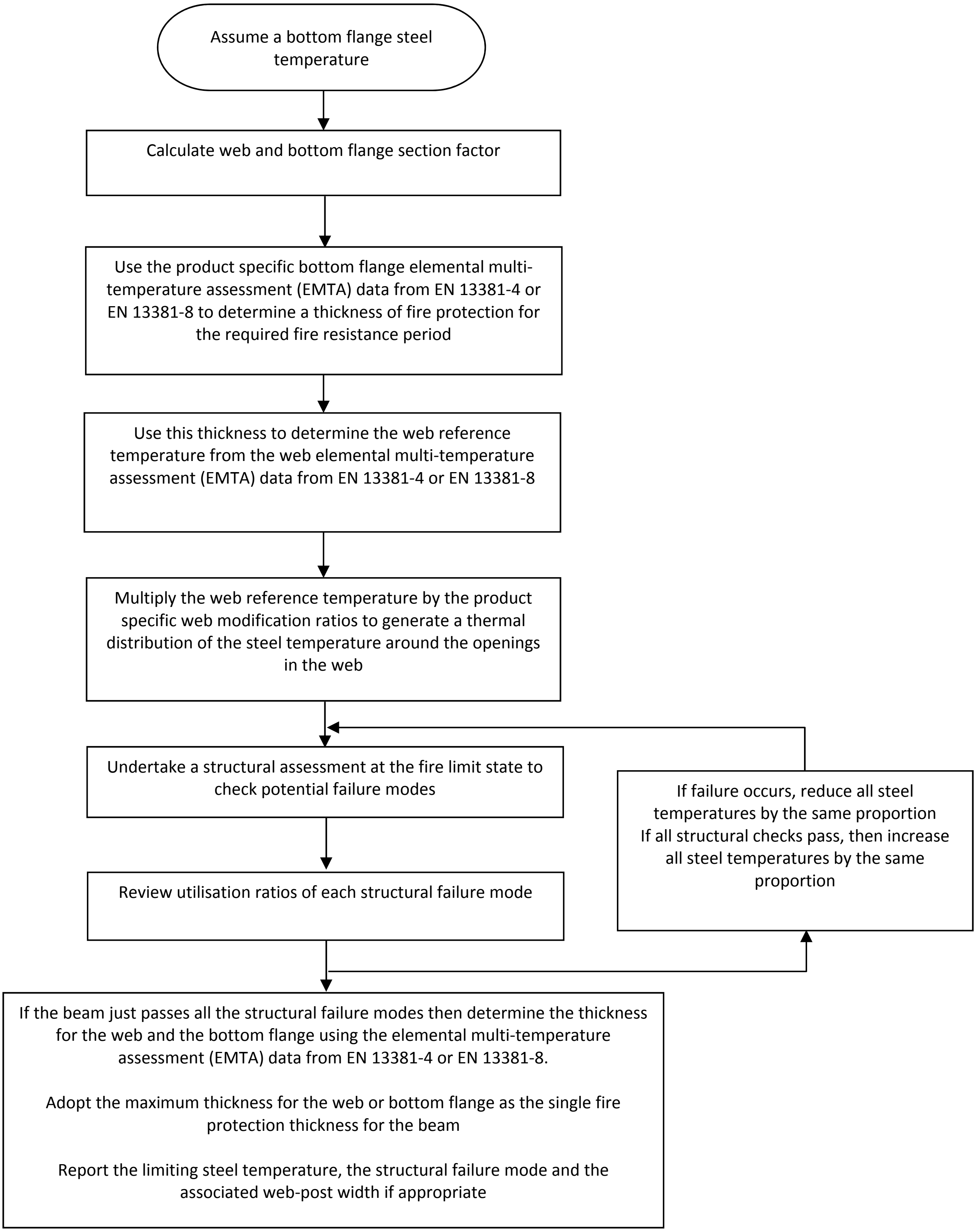


Figure 17 – Flow chart to determine a product thickness of fire protection for a beam with web openings using an iterative steel temperature analysis



To provide a consistent structural approach for these beams, the ASFP sponsored the SCI to produce a model capable of considering a wide range of beam designs and opening shapes and spacing. The SCI have published this method under their reference RT 1356. The latest version can be found on www.steelbiz.org.

The method of RT 1356 determines the limiting temperature at which structural failure will occur for all variations of beam sizes, opening shapes and spacing between openings. Once the limiting temperature is known it is necessary to determine the required fire protection thickness for the particular beam design.

To obtain the required thickness for a particular fire protection material it is necessary to generate the additional specific temperature information by testing a range of various designs of cellular beams protected with the fire protection material.

Using this test data it is possible to use the data provided by the testing and assessment of solid beams following the principles given in Section 2.3 and 2.4 to give an appropriate thickness of fire protection.

In order to use the principles of RT 1356 it is necessary for the assessment of solid beams to take the form of an elemental multiple temperature analysis (EMTA) that considers the assessment of the webs and lower flange separately.

Therefore the EMTA is carried out in the same manner as given in Sections 2.3 or 2.4 but the section factor is derived for the individual web or lower flange separately. This means for each product there will be two separate assessments, one for the web and one for the lower flange.

Cellular beams are usually designed for specific applications and as such will have a limiting temperature calculated from a structural model (as above) by a structural engineer recognised by the Engineering Council. If such a calculated limiting temperature is not available, a limiting temperature of 450^{o}C can be used based on a reduction in strength of 40% (web post buckling failure mode) under normal utilisation. Consideration of other failure modes or utilisation rates may result in a lower limiting temperature

The ASFP draws attention to the fact that it is claimed that compliance with this methodology may potentially involve working within the scope of certain patent rights (EP 1483 458) which concern the method of designing a fire resistant structural beam. ASFP takes no position concerning the evidence, validity and scope of these patent rights. The holder of these patent rights has assured the ASFP that, through an appropriate declaration, he/she agrees not to assert their patent rights against any person who carries out this methodology. In this respect, the statement of the holder of this patent right is held by ASFP. Further information may be obtained from: FABSEC Ltd., 1st Floor, Unit 3 Calder Close, Calder Business Park, Wakefield.

4.1 Test And Assessment Procedures – Cellular Beams Protected With Reactive Coatings

This Section presents guidance with respect to the evaluation of the fire resistance performance of structural steel beams with openings in the web and protected against fire by reactive fire protection coatings.

Testing is carried out adopting the principles of BS 476: Part 20:1987 or EN 1363-1.

4.1.1 Test protocol

The test protocol given in the previous edition was based on determining temperature ratios relating the temperature of the web post to that of lower flange for a given width of web post. This was known as the assessment of the web post line and was used together with the solid beam assessment to give an appropriate protection thickness.

However, there is under preparation a European test and assessment method that considers applied fire protection to steel beams with web openings. This is referenced prEN 13381-9 and although not yet published provides a more relevant approach to generating thermal data. In particular, the temperature ratios now relate the temperature of the web post to that of the solid web for a given width of web post.

Consequently, the test protocol and the calculation of specific temperature modification factors and web post lines referred to in prEN 13381-9 have been adopted by the ASFP as the basis of this protocol.

4.1.2 Test specimens

4.1.2.1 Selection of sections

The scope of the assessment will determine the selection of the test specimens. Tables 12, 13 and 14 provide specific section details for fire performance periods up to and including 240 minutes.

Where the scope of the assessment is required to include web posts narrower than those listed in Tables 12, 13 and 14 then additional sections shall be tested or the 130mm web posts can be replaced by 100mm web posts.

Table 12 – Up to and including 60 minutes fire protection

Beam Ref	Plate Girder dimensions (mm)	Web post width (mm)	Cell Opening Type
1	600x170x12x8	130	Circular
		160	Circular
2	600x170x12x8	160	Circular
		225	Circular
3	600x170x12x8	160	Circular
		225	Circular
4	600x170x12x8	500	Rectangular
5	600x170x12x8	130	Rectangular
		160	Rectangular

Table 13 – Up to and including 90 minutes fire protection

Beam Ref	Plate Girder	Web post width (mm)	Cell Opening Type
6	600x170x15x10	130	Circular
		160	Circular
7	600x170x15x10	160	Circular
		225	Circular
8	600x170x15x10	130	Circular
		225	Circular
9	600x170x15x10	500	Rectangular
10	600x170x15x10	130	Rectangular
		225	Rectangular

Table 14 – Up to and including 240 minutes fire protection

Beam Ref	Plate Girder	Web post width (mm)	Cell Opening Type
11	600x170x20x12	130	Circular
		160	Circular
12	600x170x20x12	160	Circular
		225	Circular
13	600x170x20x12	130	Circular
		225	Circular
14	600x170x20x12	500	Rectangular
15	600x170x20x12	130	Rectangular
		225	Rectangular

4.1.2.2 Steel sections

The grade of steel used shall be any structural grade (S designation) to EN 10025 (excluding S 185). Engineering grades (E designation) shall not be used.

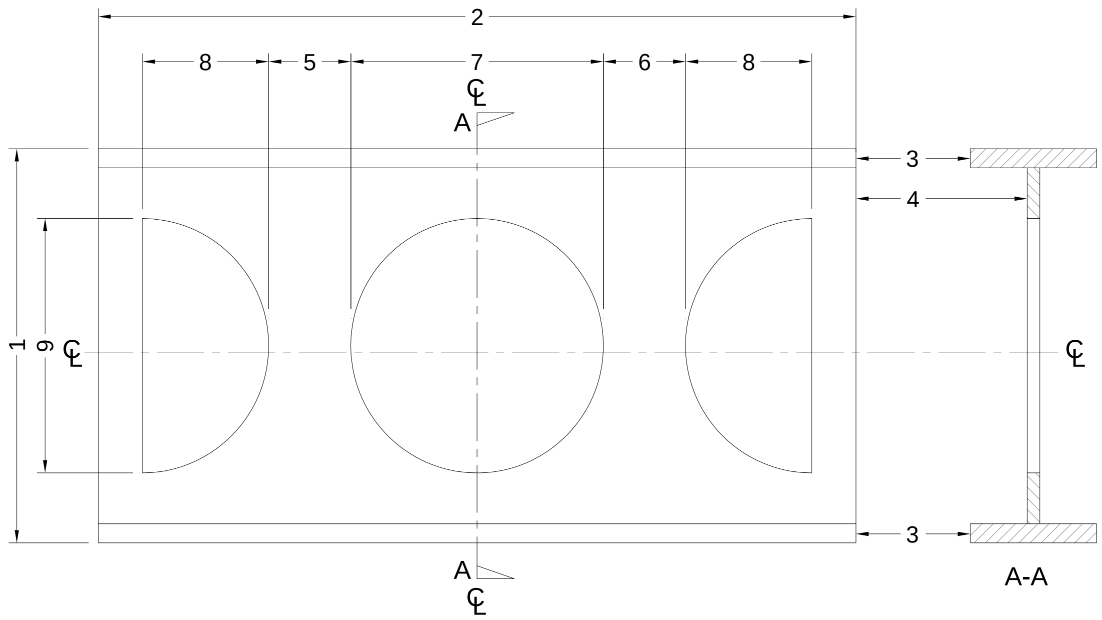
The beam sections shall be fabricated from welded steel plate to ensure that flange and web steel thicknesses are consistent, however the thermal data used for the assessment may be applied to beams manufactured from both steel plate and from hot rolled section.

The short beams shall have a length of 1200 ± 50 mm and will have circular or rectangular openings cut out of the webs. The short beams shall be constructed according to Figures 18, 19 and 20.

4.1.2.3 Instrumentation for measurement and determination of steel temperatures

Thermocouples for measurement and recording of steel temperatures shall be of the type and fixed as given in Section 2.3. The location of thermocouples attached to the beams shall be as given in Figure 22.

Figure 18 – Test Specimens with Circular Holes

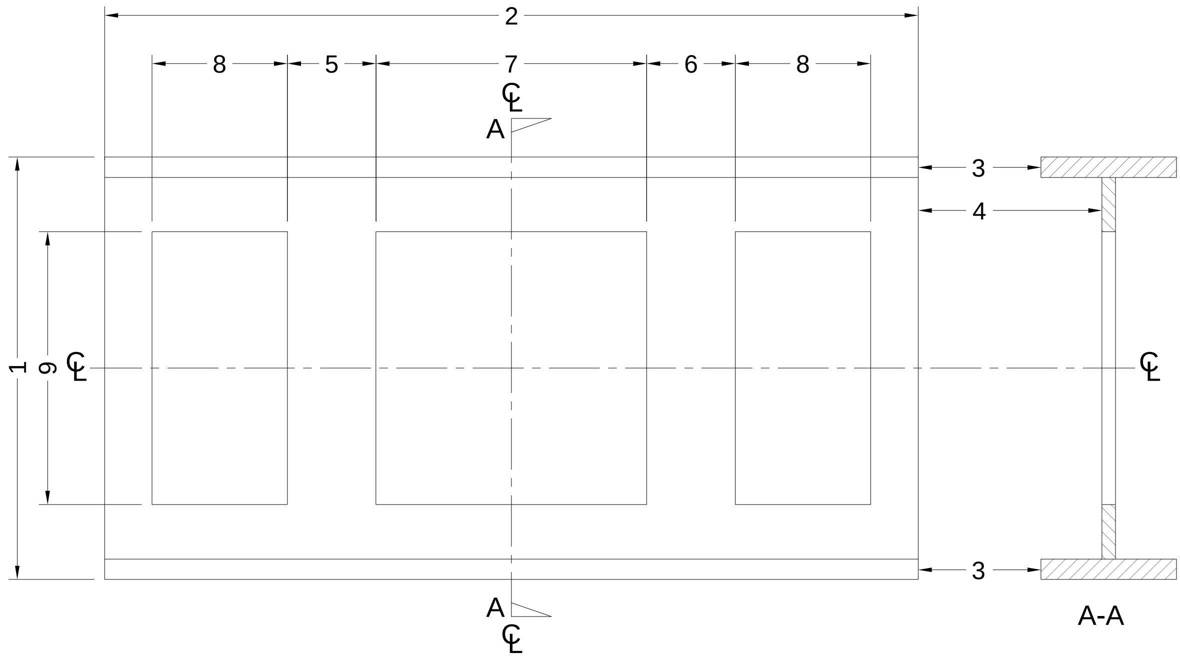


KEY to Figure 18

Specimen (Tables 12 - 14)	1	2	3	4	5	6	7	8	9
1	600	1200±50	170x12	8 thick	130	160	400	200	400
2	600	1200±50	170x12	8 thick	160	225	400	200	400
3	600	1200±50	170x12	8 thick	130	225	400	200	400
6	600	1200±50	170x15	10 thick	130	160	400	200	400
7	600	1200±50	170x15	10 thick	160	225	400	200	400
8	600	1200±50	170x15	10 thick	130	225	400	200	400
11	600	1200±50	170x20	12 thick	130	160	400	200	400
12	600	1200±50	170x20	12 thick	160	225	400	200	400
13	600	1200±50	170x20	12 thick	130	225	400	200	400

Dimensions in mm

Figure 19 – Test Specimens with Rectangular Holes

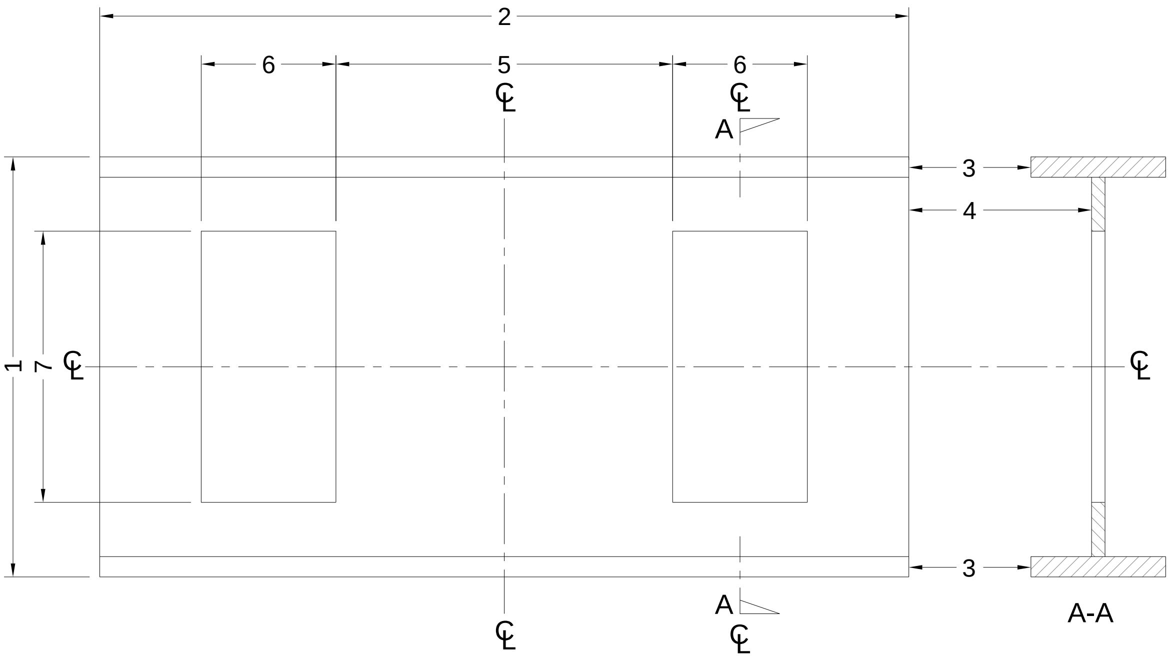


KEY to Figure 19

Specimen (Tables 12 - 14)	1	2	3	4	5	6	7	8	9
5	600	1200±50	170x12	8 thick	130	225	400	200	400
10	600	1200±50	170x15	10 thick	130	225	400	200	400
15	600	1200±50	170x20	12 thick	130	225	400	200	400

Dimensions in mm

Figure 20 – Test Specimens with Rectangular Holes



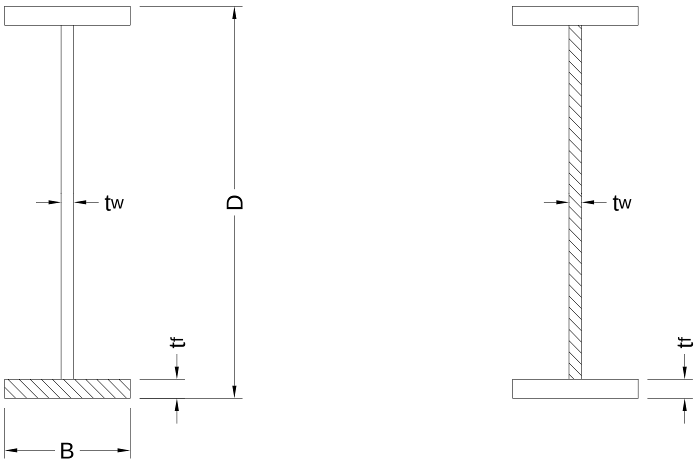
KEY to Figure 20

Specimen (Tables 12 to 14)	1	2	3	4	5	6	7
4	600	1200±50	170x12	8 thick	500	200	400
9	600	1200±50	170x15	10 thick	500	200	400
14	600	1200±50	170x20	12 thick	500	200	400

Dimensions in mm

The dimensions of the web and the lower flange shall be measured and these values shall be used to determine the elemental section factors. The elemental section factors shall be calculated in accordance with Figure 21.

Figure 21 Elemental Section Factor



	Lower Flange	Web
Heated perimeter (A)m	$(2B + 2t_f) - t_w$	$2D – 4t_f$
Area (V) m^2	$B \times t_f$	$(D-2t_f) \times t_w$

Section factor = A/V(m^{-1})

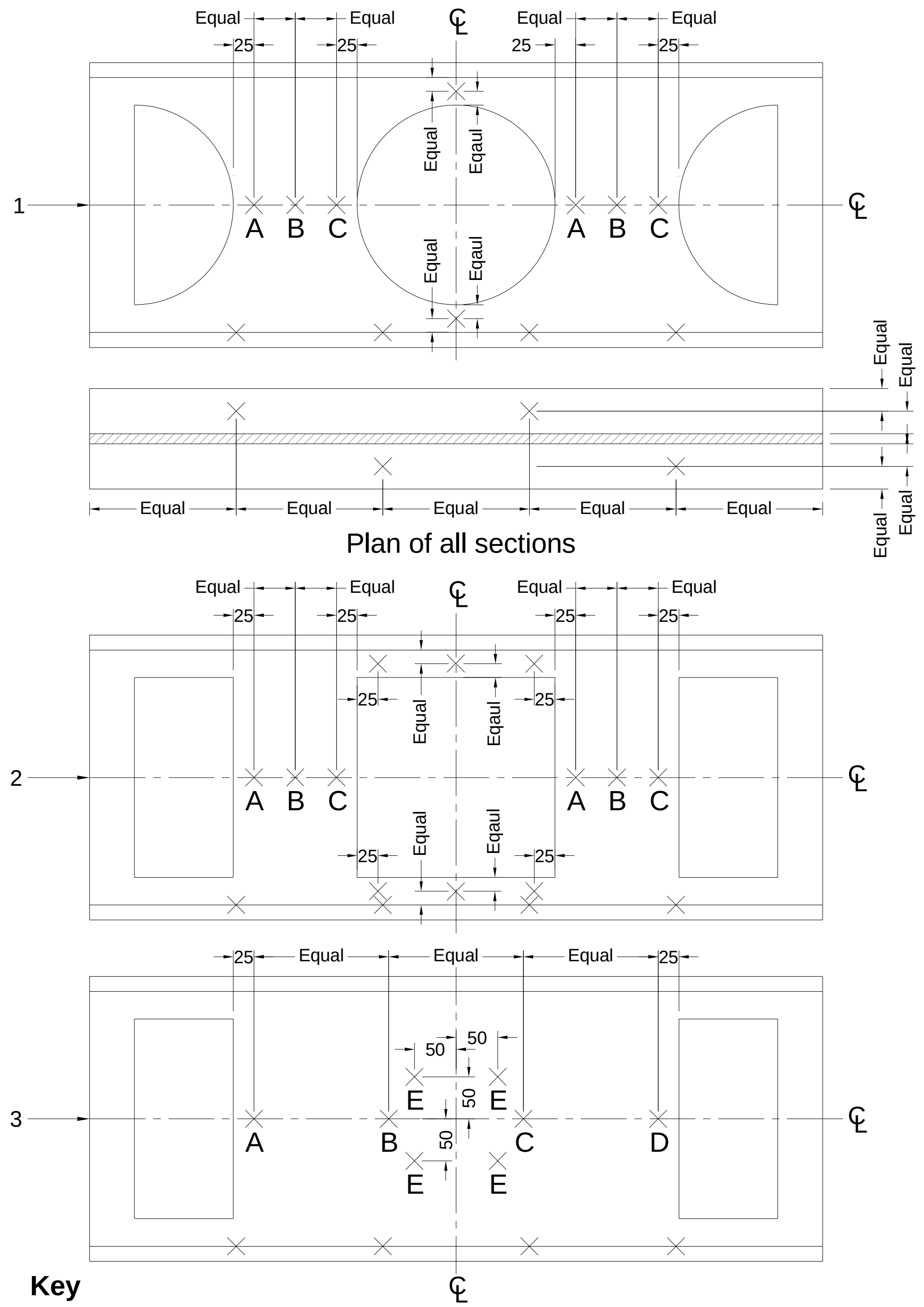
Key to Figure 21

B Width of beam flange
D Depth of beam
t_w Thickness of web
t_f Thickness of lower flange

4.1.2.3 Instrumentation for measurement and determination of steel temperatures

Thermocouples for measurement and recording of steel temperatures shall be of the type and fixed as given in Section 2.3.1.1. The location of thermocouples attached to the beams shall be as given in Figure 22.

Figure 22 – Thermocouple Positions



Key

1 Beam with circular openings

2 Beam with rectangular openings - web posts equal to or less than 225

3 Beam with rectangular openings - web posts greater than 225

A,B,C,D Web post thermocouples for web post average temperature

E Web post thermocouples for web reference temperature

Dimensions in mm

4.1.2.4 Fire protection thickness requirements

Thickness measurements shall be evenly distributed and shall be taken in order to provide an overall mean for each section, each bottom flange and each web post as follows;

Ten thickness measurements shall be taken on each face of each web post within an area 125mm above and below the web centreline.

The mean fire protection thickness on each web post is determined as the sum of the means of each web post side divided by two.

In the case of the 500mm web post the thickness measurements are taken in an area within a 250mm x 250mm square around the four thermocouples used for the web reference (see Figure 22 key item E).

Twenty thickness measurements shall be taken on the underside bottom flange of each section and the mean thickness of fire protection material on the bottom flange is then determined.

The mean thickness of the fire protection material on each face of each web post and the underside of the bottom flange shall be within 15% of each other and the overall mean i.e. the range of mean thicknesses shall not vary by more than 15% from the minimum mean to the maximum mean.

If any area does not meet this requirement, physical adjustments shall be made to ensure compliance.

In the case of reactive coatings thickness measurements shall be taken at a minimum of 20mm from the edge of any opening as electronic gauges are not reliable at less than this distance. Refer to gauge manufacturers for details.

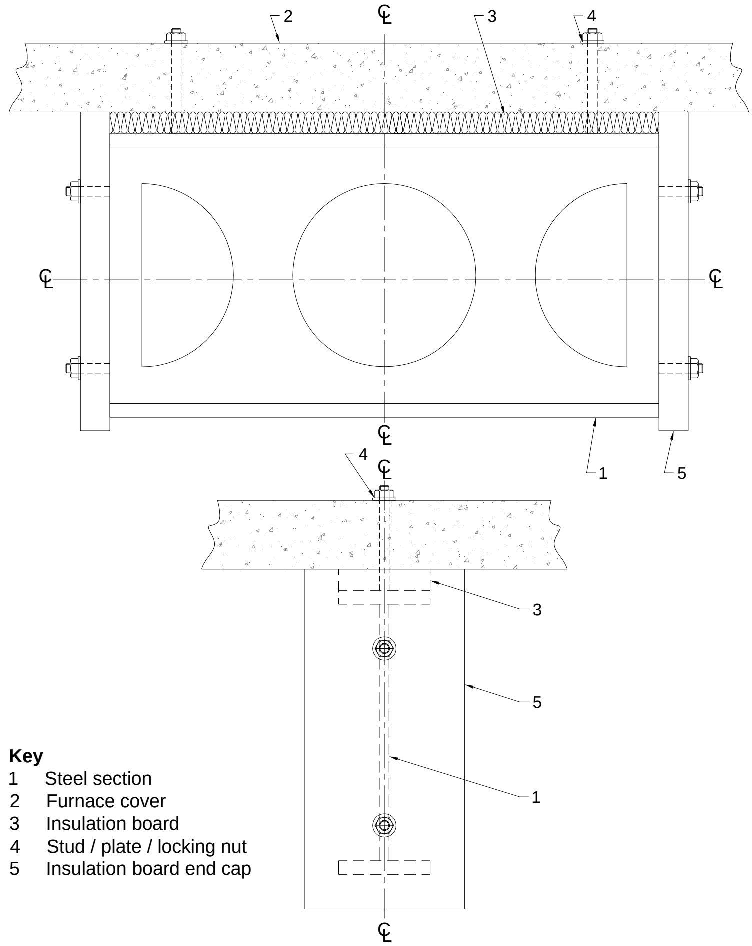
4.1.3 Installation of the test specimens

Each unloaded beam test specimen shall be bolted to the soffit of the furnace cover slabs using appropriate diameter studs welded to the beam. There shall be a suitable steel plate beneath the locking nut.

Each specimen shall be provided with a layer of ceramic fibre insulation board placed between the soffit of the furnace cover slabs and the top flange of the beam. This insulation material shall have an uncompressed thickness of (30 ± 5) mm and a nominal density of (125 ± 25) kg/m³. This insulation shall have a width equal to the width of the top flange of the steel beam (see Figure 23).

Alternative insulation materials of Class A1 complying with the requirements of EN 13501-1 may be used provided they have similar thermal properties and thickness to the specified ceramic fibre insulation.

Figure 23 Unloaded Beams- Typical Construction- Circular Holes (Rectangular Holes Similar)



4.1.4 Assessment

4.1.4.1 General

The temperature data obtained from the steel sections is used as the basis for relating each web post temperature and the temperatures recorded by the additional thermocouples to the web reference temperature at the required fire performance period.

4.1.4.2 Determination of mean temperatures

Web post temperatures are dependent upon the web post width and the mean web post temperatures are calculated as follows:

a) for web post width 100mm

$$\text{Web post temperature} = \frac{(\text{Temp at Position A}) + (\text{Temp at Position B}) + (\text{Temp at Position C})}{3}$$

b) for web post width 130mm

$$\text{Web post temp} = \frac{(\text{Temp at Position Ax45}) + (\text{Temp at Position Cx45}) + (\text{Temp at Position Bx40})}{130}$$

c) for web post width 160mm

$$\text{Webpost temp} = \frac{(\text{Temp at PositionA x 50}) + (\text{Tempat PositionC x 50}) + ((\text{Tempat PositionB x60})}{160}$$

d) for web post width 225mm

$$\text{Web post temp} = \frac{(\text{Temp at PositionA x 50}) + (\text{Temp at PositionC x 50}) + (\text{Temp at PositionB x 125})}{225}$$

e) for web post width 500mm

$$\text{Web post temp} = \frac{(\text{Temp at PositionA x 50}) + (\text{Temp at PositionD x 50}) + (\text{Temp at PositionB x 200}) + (\text{Temp at PositionC x 200})}{500}$$

f) For web reference.

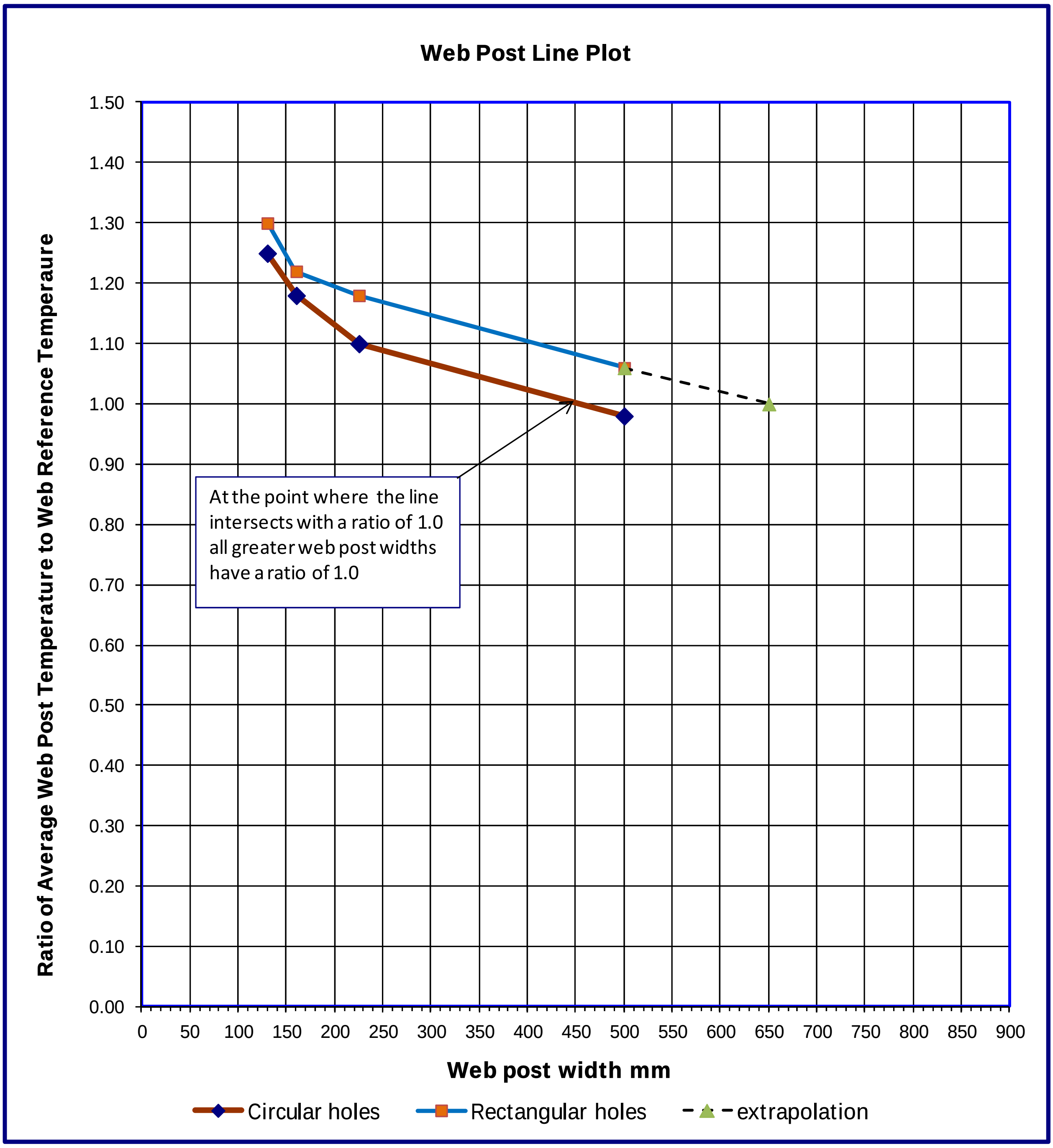
The web reference temperature is calculated as the average of the four thermocouples referred to as E in Figure 22.

4.1.4.3 Web post line assessment

The web post line assessment shall be based on the ratio of the mean web post temperature to the web reference temperature; for the maximum required fire performance period.

Where there is more than one web post of the same width then the mean of the individual ratios shall be determined. This ratio is then plotted against web post width (see Figure 24).

Figure 24 – Example Plot of Web Post Lines



If the web post line crosses a web post ratio of 1 then the web post ratio for web posts greater than this shall equal 1.0. The web post ratio shall increase with a decrease in web post width. If any point does not satisfy this criteria then it shall be replaced by the ratio of the next highest web post width.

For each shaped hole, if the ratio is above 1.0 for a web post width of 500mm as shown in Figure 24 as extrapolation the ratio can be extrapolated to a web post width which gives a ratio of 1.0. Then all greater web post widths shall have a ratio of 1.0 subject to a maximum web post width of 800mm for rectangular holes and 500mm for circular holes.

There shall be a separate web post line plot for both circular and rectangular web posts.

As a minimum requirement, the average bottom flange temperature shall not reach 575°C before it is in within 15% of the required period of fire performance.

No upper limit has been set in this respect, as the web post to web reference temperatures will be taken when the bottom flange has reached 575°C and not when the predicted period of fire performance has been reached. This will ensure that no benefit will be gained from over-application of the protection system.

A single fire test at maximum fire resistance period may be used to determine a web post line assessment for all fire resistance periods below. In this case for fire resistance periods below the maximum, the worst case ratio derived from the maximum period and that derived from the specified period shall be used for the specified period.

4.1.4.4 Additional thermal modification factors

In order to carry out some types of structural analysis the temperature measurement at a number of locations on the steel section around the web openings is required.

Therefore in addition to the web post and web reference thermocouples additional optional thermocouples situated at the top and bottom of the web posts and also underneath openings may be installed. For each of these additional positions the temperatures at the same position on each section should be averaged.

These mean values should then be used to calculate further modification factors as the ratio of the mean values to the web reference value so that each additional thermocouple position shall have associated with it a modification factor which shall be used as additional thermal information for the structural model.

4.1.4.5 Use of Limiting Temperatures

It is also acceptable to adopt the limiting temperature approach given in 4 except that the section factor and thickness of protection shall be derived using the EMTA and the modification factors referred to above.

4.1.5 General guidance of utilising cell beam test data generated in accordance with previous editions of the Yellow Book

a) The web reference temperature is generated from the loaded beam;
b) The web post temperature is generated from loaded beam and all the available short sections (weighted average temperature is calculated as described in section 4.1.5.2);
c) At the required time period, the web post line is based on the ratio of the web post temperatures to web reference temperature with necessary adjustment according to DFT and elemental section factors of each individual section. The average web post ratio will be taken if there is more than one test available for a web post width;
d) The web post ratio shall increase with a decrease in web post width (if this is not satisfied, then the more optimistic ratio should be replaced by the adjacent worst case. This process should be repeated until satisfied);
e) the web post line beyond the widest tested web post width is generated by linearly extrapolating the web post line slope between the last two web post ratios in the plot, until it intersects with a ratio of 1.0, after which point 1.0 will be used for the web posts with greater width. However the web post line will be anchored at 800mm for rectangular openings and 500mm for circular openings. If the linear extrapolation intersects with a ratio of 1.0 beyond the anchoring point, a straight line will be drawn between the last web post ratio and the anchoring point;
f) for above and below the opening temperature ratios, actual ratio using the web reference is used where temperature data is available. If test data is not available, then a ratio of 1.1 will be used. If the data from above the opening is missing, then it is acceptable to use the data from below the opening or 1.1, whichever is lower;
g) Web post ratio cannot be less than 1.0 in any case.

4.2 Assessment Procedures – Cellular Beams Protected with Passive (non-reactive)Fire Protection Systems

This Section presents guidance with respect to the evaluation of the fire resistance performance of structural steel beams with openings in the web and protected against fire by passive fire protection systems (typically boards, slabs and renderings).

It is acceptable to follow the test and assessment protocol for reactive coatings given in 4.1. However it is also acceptable to adopt the principle of using a thickness modification factor for passive (non-reactive) fire protection systems.

Where a limiting temperature of 450^{o}C has been provided or one associated with a particular design of cellular beam provided by a qualified structural engineer in accordance with the principles given in 4, the section factor for that beam shall be determined as the highest value derived from the following:

a) The section factor of the 'T' section above the opening
b) The section factor of the 'T' section below the opening
c) The section factor derived from $1400/t_w$ where t_w is the thickness of the web in mm.

In all cases the thickness of protection obtained based on the section factor and temperature as derived above shall be increased by 20%. The applied thickness shall not exceed the maximum assessed for the product for beam protection.

In order to adopt either of the above approaches, the testing and assessment of the solid beam sections must be carried out in accordance with 2.3.

4.2.1 Determination of the Acceptability of the Thickness Modification Factor

In order to apply the thickness modification factor of +20% it is necessary to ascertain that the factor is appropriate or conservative. In order to determine this, testing shall be carried out in accordance with the following test protocol:

4.2.2 Principle

The principle of testing is to compare the thermal performance of a solid beam with identical beams but with openings in the webs. The testing may include beams with both rectangular and circular openings or if required only one shaped hole may be tested. In this case the evaluation is confined to the tested shape.

4.2.3 Test Specimens

For the beams with openings, Beam 6 for circular openings and Beam 10 for rectangular opening as defined in Table 13 shall be selected. The solid beam shall have the same dimensions as those for the beams with openings.

To determine the steel temperature for the beams with openings the specimens shall be instrumented in accordance with 4.1.2.3 except that thermocouples shall be attached to the web post only.

To determine the steel temperature for the solid beam the specimen shall be instrumented in accordance with Figure 12 of 2.4.4.11 except that thermocouples shall be attached to the web only.

4.2.4 Test Procedures

The specimens shall be subject to testing in accordance with the heating and pressure conditions given in BS 476: Part 20: 1987 or EN 1363-1. In each case the specimens shall be mounted in the furnace roof as shown in Figure 4 and exposed on three sides.

4.2.5 Thickness of Protection

The solid beam shall be protected with the thickness of protection material appropriate to the section factor and maximum fire resistance period determined in accordance with the test and assessment procedures for I-section beams exposed on three sides given in Section 2. The thickness to be applied to the solid beam shall be determined based on the ability of the solid section to reach a specified temperature of 700°C within 15% of the maximum assessed fire resistance period.

The beams with openings shall be protected with a thickness of material equal to that applied to the solid beam plus 20%. When applying protection material around the openings any additional fixing measures or application techniques intended to be used in practice shall included.

The thickness of protection material shall be determined in accordance 2.3.3.3 or 2.3.3.4 as appropriate to the protection type (board or rendering).

4.2.6 Thermal Data Required for Analysis

For beams with openings, the mean temperature of the web post is dependent upon the width of the web post shall be derived in accordance with 4.1.4.2.

For the solid beam the mean temperature of the web shall be derived as the average of the thermocouples attached to the web.

4.2.7 Analysis of Thermal Data

It is necessary to compare the mean temperature of each web post with the mean web temperature within a temperature range of 350°C to 700°C as follows:

Determine the time (t_{ref}) at which the mean web temperature of the solid beam reaches each of the specified temperatures (T).

Determine the mean web temperature of each web post (T_w) at time $t_{ref.}$

Adjust T_w to take into account any discrepancy in mean thickness between that applied the solid beam and that applied to the web post. This is carried out as follows:

$T_{wa} = T_W \times (d_w/d_s)$

Where T_{wa} is the adjusted mean temperature of the web post

T_W is the mean temperature of the web post

d_S is the mean thickness applied to the solid beam x 1.20

d_W is the mean thickness applied to the web post.

An example calculation for T_{wa} is given as follows:

Specified temperature is 500°C. Time for mean temperature of web of the solid beam to reach 500°C is 89 minutes. At this time the mean temperature of the 130mm web post of Beam 6 is 485°C.

If mean thickness of solid beam protection is 20mm and that of the web post is 24.2mm then d_s = 20 x 1.20 =24mm and d_w = 24.2mm. Therefore T_{wa} = 485 x (24.2/24) = 489°C.

The following rules shall apply to the results of the testing:

a) If T_{wa} is equal to or less than T for any web post within the temperature range it is acceptable to apply the thickness modification factor to all web post widths.

b) If T_{wa} is greater than T for any web post within the temperature range it is not acceptable to apply the thickness modification factor and the test and assessment protocol given in 4.1 shall be followed.

c) If T_{wa} is greater than T for any web post within the temperature range it is not allowed to increase the factor of 1.2 and retest i.e. in all cases if the factor of 1.2 is proven inadequate the test and assessment protocol given in 4.1 shall be followed.

5 – CE marking and ETAs

5.1 - Product testing and assessment

Almost all fire protection products for the protection of structural steel in buildings are covered by European Technical Assessments (ETAs) prepared by an Approval Body against a European Technical Assessment Guideline (ETAG) http://www.eota.eu/en-GB/content/etags-used-as-ead/26/ (ETAGS will become European Assessment Documents (EADS) under the CPR). The ETAG relevant to fire protection for structural steelwork is ETAG 018 Fire protective products. It is split into four parts:

- Part 1: General Requirements
- Part 2: Reactive coatings for fire protection of steel elements
- part 3: Renderings and rendering kits intended for fire resisting applications
- Part 4: Fire protective board, slab and mat products and kits

Each ETAG addresses the Basic Works Requirement as applicable to the product and contains the testing and other procedures necessary to demonstrate its fitness for purpose as indicated below.

5.1.1 – Contents of ETAG 018-2 Reactive coatings for fire protection of steel elements

Basic Works Requirement (Essential Requirements under CPD)	**How Basic Works Requirement (Essential Requirements under CPD) are addressed in ETAG**
Safety in case of fire	Reaction to Fire and Resistance to Fire performance
Hygiene, health and environment	Release of dangerous substances
Energy economy and heat retention	Adhesion, Durability, Serviceability Corrosion resistance, Behaviour under different environmental conditions, Resistance to chemicals, Resistance to biological attack. Identification.

Note: ETAG 018-2 also contains an annex on the use of data obtained according to the obsolete ENV 13381-4:2002 for an assessment according to EN 13381-8:2010.

5.1.2 – Contents of ETAG 018-3 Renderings and rendering kits intended for fire resisting applications

Basic Works Requirement (Essential Requirements under CPD)	**How Basic Works Requirement (Essential Requirements under CPD) are addressed in ETAG**
Safety in case of fire	Reaction to Fire and Resistance to Fire performance
Hygiene, health and environment	Release of dangerous substances, Water vapour permeability
Safety in use	Mechanical resistance and stability, Resistance to impact/movement, Adhesion
Energy economy and heat retention	Thermal insulation, Durability, Serviceability: Thermal insulation, Resistance to UV exposure, Deterioration cause by: heat, rain, high humidity, heat and cold, freezing and thawing. Resistance to corrosion of a steel substrate/fixings induced by the rendering. Mechanical resistance and serviceability, resistance to impact/movement, air erosion, water vapour

	permeability, water absorption, adhesion (bond strength). Identification.

5.1.3 – Contents of ETAG 018-4 Fire protective board, slab and mat products and kits

Basic Works Requirement (Essential Requirements under CPD)	**How Basic Works Requirement (Essential Requirements under CPD) are addressed in ETAG**
Safety in case of fire	Reaction to Fire and Resistance to Fire performance
Hygiene, health and environment	Release of dangerous substances, Water vapour permeability
Safety in use	Mechanical resistance and stability, Pull-through resistance of mechanical fasteners, Resistance to hard body impact. Resistance to soft and/hard body impact. Resistance to eccentric load, Adhesion
Energy economy and heat retention	Thermal resistance, water vapour transmission coefficient, Durability and serviceability. Identification.

5.2 – What manufacturers must do

Most products are covered under the CPR and consequently manufacturers will need to find out how it affects them by undertaking the following:

- Determine if the product is covered by a European Technical Assessment Guideline (ETAG). ETAGs will become European Assessment Documents (EADs) under the CPR
- Determine the status of the ETAG. Many are still being drafted
- Determine how many products can be grouped together into families to reduce the amount of testing and other procedures
- Approach an ETA Issuing Body (for products covered by an ETAG/EAD)
- An ETA issuing Body will organise the testing and issue a Certificate of Conformity. The manufacturer can then make a Declaration of Performance and CE mark the product accordingly

The most important step is to choose a suitable ETA issuing body. Manufacturers should look for those who are members of EGOLF (European Organisation for fire testing, inspection and certification) and find out if they regularly participate in the Group of Notified Bodies Fire Sector Group.

6 – Fire protection system data sheets and their application

6.1 General

For a manufacturer to include his products in an ASFP colour book, they must either have the product CE marked under the Construction Products Directive/Construction Products Regulation, or must hold third party certification for the product from a certification body under a scheme accredited to EN 45011 (to become ISO 17065). Certification shall be carried out by a UKAS accredited (or nationally equivalent) certification body. Data will include the following elements:

- List of products and their properties
- A/V tables (at least for default limiting temperatures) to be accessed electronically from appropriate certification body website. Manufacturer's loadings will be clearly differentiated as to whether they are generated from CE marking or Yellow Book assessment
- This will require a common format for the data e.g. as per that in Figure 25 agreed at ASFP Council.

6.2 Presentation and use of certificated product data

Manufacturers wishing to place products in this publication shall request the certification body that they use for third party product certification/CE marking to present their product performance data (whether to national or European requirements) in the form of a multi-temperature assessment in tabular format as illustrated in Figure 25 i.e. for each fire resistance period (30min, 60min, 90min, etc.). The required product thickness is presented as a function of temperature and at increments of steel section factor of 5 over the range of the assessment.

Where the scope of the product test and assessment is such that data is not available at any coordinate within a Multi Temperature Analysis (MTA), that coordinate cell shall be completed with 'N/A', indicating not available - except that for any single section factor row in the table, the minimum derived thickness related to any temperature in that row can be used to complete the row for higher temperatures.

In application of the certificated data, interpolation of the various tabulated values may be used between adjacent values of temperatures and/or section factors.

6.3 Tendering for projects and the use of limiting temperatures

To be able to tender for projects, manufacturers shall be provided with not only the required fire resistance performance but also the associated limiting temperature (i.e. the temperature determined at the fire limit state for any/all structural members). This temperature shall be calculated and specified by a chartered structural engineer. When it is not provided, manufacturers may utilise an appropriate characteristic temperature(s) related to the building occupancy type connected to national design code requirements. These temperatures shall be given by a competent authority (e.g. the ASFP in the UK) or by national approvals or by regulation. Irrespective, the actual or characteristic temperature related to a product thickness shall be explicitly stated in the tender offering. For more information on the selection and use of limiting temperatures, see 1.4 and A 3.2.

Figure 25 – Common presentation of data

Fire Resistance Period – 30 Minutes									
Design Temperature °C	350	400	450	500	550	600	650	700	750
Section factor m^{-1}	Thickness of fire protection to maintain steel temperature below limiting temperature								
40	N/A	N/A	N/A	N/A	0.25	0.25	0.25	0.25	0.25
50	N/A	N/A	N/A	N/A	0.28	0.28	0.28	0.28	0.28
60	N/A	N/A	N/A	N/A	0.31	0.31	0.31	0.31	0.31
70	N/A	N/A	N/A	N/A	0.34	0.34	0.34	0.34	0.34
80	N/A	N/A	N/A	N/A	0.38	0.38	0.38	0.38	0.38
90	N/A	N/A	N/A	N/A	0.41	0.41	0.41	0.41	0.41
100	N/A	N/A	N/A	N/A	0.44	0.44	0.44	0.44	0.44
110	N/A	N/A	N/A	N/A	0.47	0.47	0.47	0.47	0.47
120	N/A	N/A	N/A	N/A	0.50	0.50	0.50	0.50	0.50
130	N/A	N/A	N/A	N/A	0.53	0.53	0.53	0.53	0.53
140	N/A	N/A	N/A	N/A	0.57	0.57	0.57	0.57	0.57
150	N/A	N/A	N/A	N/A	0.60	0.60	0.60	0.60	0.60
160	N/A	N/A	N/A	N/A	0.63	0.63	0.63	0.63	0.63
170	N/A	N/A	N/A	N/A	0.66	0.66	0.66	0.66	0.66
180	N/A	N/A	N/A	N/A	0.69	0.69	0.69	0.69	0.69
190	N/A	N/A	N/A	N/A	0.73	0.73	0.73	0.73	0.73
200	N/A	N/A	N/A	N/A	0.77	0.77	0.77	0.77	0.77
210	N/A	N/A	N/A	N/A	0.81	0.81	0.81	0.81	0.81
220	N/A	N/A	N/A	N/A	0.85	0.85	0.85	0.85	0.85
230	N/A	N/A	N/A	N/A	0.90	0.90	0.90	0.90	0.90
240	N/A	N/A	N/A	N/A	0.94	0.94	0.94	0.94	0.94
250	N/A	N/A	N/A	N/A	0.98	0.98	0.98	0.98	0.98
260	N/A	N/A	N/A	N/A	1.03	1.03	1.03	1.03	1.03
270	N/A	N/A	N/A	N/A	1.07	1.07	1.07	1.07	1.07
280	N/A	N/A	N/A	N/A	1.11	1.11	1.11	1.11	1.11
290	N/A	N/A	N/A	N/A	1.16	1.16	1.16	1.16	1.16
300	N/A	N/A	N/A	N/A	1.20	1.20	1.20	1.20	1.20

Annexes

A.1 Fire test standards – specific information

A.1.1 British Standard test standards

The general procedures used for determining the fire resistance of load-bearing elements of structure are specified in BS476 series. In assessing the performance of fire protection materials the relevant parts are:

- Part 20 Method of determination of the fire resistance of elements of construction (general principles)
- Part 21 Method of determination of the fire resistance of load-bearing elements of construction

Whilst BS 476 Part 20 is concerned with general principles and covers requirements which are common to the other Parts of BS 476, the BS 476 Part 21 fire resistance testing covers load-bearing elements of construction, such as steel beams, columns or walls, whilst BS 476 Part 22 fire resistance tests are intended for non-loadbearing elements of construction. The British standards will gradually be replaced by the European Standards as manufacturers seek to export products to mainland Europe and to develop new products to the more superior European standards. However, for those products that do not have to be CE marked and for those markets outside of Europe currently using British Standards; the need the British Standard remains and consequently it is included in this publication.

A.1.2 Description of fire tests to BS 476

Traditionally in the UK, loaded beam tests are carried out on a nominal span of 4.25 metres using a 305x127x42 Universal Beam for passive (non-reactive) insulating materials and a 406x178x60 Universal Beam for intumescent coatings.

Loaded column tests are normally carried out on a 203 x 203 x 52 kg/m Universal Column with an exposed length of at least 3 metres (Figure 5). The specimen is initially held vertically and, although it has freedom to expand longitudinally, its ends are rotationally fixed so that, structurally, an effective length factor of 0.7 can be assumed. It is then axially loaded to develop the required stress which is normally the maximum permitted by design.

The level of the applied load traditionally used in the UK is slightly lower than that specified in the European standard. The higher EN load could make the test more onerous in that the ability of the fire protection to maintain its stickability could be affected. However, any difference in the final assessed thickness of protection required to keep a steel member below a specified temperature is likely to be insignificant.

It is usual to include information on the fire insulating properties of fire protection materials obtained from tests performed on unloaded exploratory specimens (about 1m in length). This information is used in both the UK and European methods of assessing fire protection materials, and is often combined with loaded tests to form a complete ‘test package’.

The procedures used in UK fire testing laboratories have been agreed and standardised through the Fire Test Study Group, which are all UKAS approved fire testing laboratories, to ensure that consistent techniques are adopted in the generation of data for appraisal purposes. It is recognised that varying results can be obtained on identical specimens tested in different furnaces. To reduce the effect of such variations, the UK laboratories use common preparation, testing and measuring techniques.

A.1.3 European Standard test standards

The relevant European standards for assessing the performance of fire protection materials and systems are:

- EN 13381 Test methods for determining the contribution to the fire resistance of structural members Part 4: Applied passive protection to steel members
- EN 13381 Test methods for determining the contribution to the fire resistance of structural members Part 8: Applied reactive protection to steel members

These standards make reference to the EN 1363 series of standards which contain general information about conducting fire resistance tests. However, as all the procedures for assessing fire protection are currently specified in EN13381-4 & 8, it is these standards which are mainly referred to in this document.

EN 13381-4 and 8 have no equivalent British Standards. In the UK, it is generally accepted that the procedures for determining the contribution of applied protection to the fire resistance of steel members are covered by this ASFP publication.

A.1.4 Description of fire tests to EN 13381-4 & 8

The testing programme for the assessment of a fire protection material to EN 13381-4 or 8 differs in a number of respects from the BS 476 programme. The main difference is that the European standard presents a number of different packages depending on the scope of the assessment required. In addition, for the loaded beam test, a layer of insulation is placed between the top flange of the beam and an ultra-lightweight concrete floor slab. This serves to reduce the heat sink effect of the slab and to minimise the effects of composite action although there is an option to use a heavier slab. UK beam tests use a segmented dense concrete slab in intimate contact with the top flange of the beam. Experience with the European test method has shown that problems associated with Lateral Torsional Buckling of the loaded beam have meant that both EN 13381 parts 4 and 8 had to be revised with regard to the loading method.

The European procedures do not always require a loaded column to be tested. However, when assessing intumescent coatings, an unloaded column 2000mm high must be tested to assess stickability.

Another major difference between European and UK testing is in the type of furnace thermocouple used. The European test uses a plate thermometer. This a special type of thermocouple used for measuring the temperature within the furnace. It consists of a small plate, insulated on one side, with a thermocouple welded to its centre. The plate thermometer is intended to reduce the differences between fire tests carried out in different furnaces and thus to promote European harmonisation. Experience has shown that use of the plate thermometer provides a significantly higher ‘thermal dose’ to some types of element (including structural steel) than the thermocouple used in the BS 476 test method.

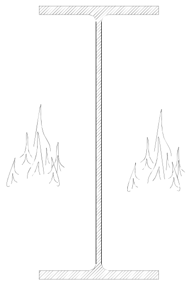
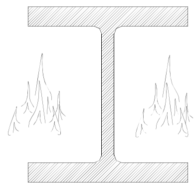
A.2 Section factor

A.2.1 General

The section factor of a hot rolled open section, a hot finished/formed hollow section or fabricated girder 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}. This definition can be found in Eurocode 3: Design of steel structures, Part 1-2: General rules, Structural fire design.

It is perhaps simpler to consider it as the heated perimeter of the exposed cross section (H_p) divided by the total cross sectional area (A), which is how it was defined in the 1990 version of BS 5950 Structural use of steelwork in building, Part 8: Code of practice for fire resistant design. These two definitions give the same answer for uniform cross-sections but the former is the manner in which it is referenced in the fire Eurocodes, in the 2003 version of BS 5950 Part 8, and which dominates most current literature. Section factors vary from $25m^{-1}$ for very large sections to over $300m^{-1}$ for small, slender sections. By convention, section factor is usually written A/V.

Figure 26 – Concept of section factor

Section Factor = A/V Where A = Surface area of steel exposed to fire per unit of length V = Volume of the section per unit length			
	High A Low V Fast Heating		Low A High V Slow Heating

A steel section with a large surface area (A) will receive more heat than one with a smaller surface area. Also, the greater the volume (V) of the section, the greater is the heat sink. It therefore follows, that a small thick section will have a slower rate of temperature increase in a fire when compared to a large thin one. The Section Factor (A/V) is thus a measure of the rate at which a section will heat up in a fire. The higher the value of the section factor, the greater will be the protection thickness required for a given fire resistance period. Values of section factor for the range of sections for fire exposure on both three and four sides are given in Annex 4, Table A.2 to A.13. Table A.1 also illustrates the appropriate 'perimeter dimension' to be used when calculating the section factor for a variety of steel sections in different situations.

In calculating the section factor values the full volume, V, is used whether the section is exposed on three or four sides as the whole of the steel section will be receiving heat. The value of A is the exposed surface area and that depends on the configuration of the fire protection. In the case of a 'box' protection, the surface area is taken as the sum of the inside dimensions of the smallest possible rectangular or square encasement (except for circular hollow sections - see Annex 4, Table A.1) whilst for a 'profile' protection, it is taken as the external surface area of the steel section itself. Where a section supports a floor or is against a wall which itself provide fire protection, the surface in contact is ignored in calculating A. For 'solid' protection the section factor value should be taken as that for box protection.

Where a spray or trowelled system has been tested as a profile protection, the use of the same material as a box protection is permissible, provided there is adequate evidence of physical performance (commonly referred to as 'stickability'). In the absence of a full programme of tests on the system as a boxed protection, the thickness should be derived on the basis of the section factor for the profiled application.

In some cases the appropriate section factor may not be based on simple geometric considerations. Guidance on some common cases is given below.

A.2.2 Cellular and castellated beams

Cellular beams are characterised by holes, usually but not always regularly spaced, in the web. They have the advantages that they can span longer distances than conventional hot rolled sections and services can be installed through the web openings, thus reducing the overall floor depth. They are usually created by one of two methods. The first involves cutting along the web of a hot rolled section (usually a universal beam or column) to a particular profile, separating the two parts and then welding these Tee sections to form a deeper beam section. Usually, a single section size is used for both halves of the cellular beam but asymmetric sections can be created by using different rolled sections for each part of the new section. The second method uses a combination of three plates welded together with the apertures cut into the web.

These sections are produced by specialist companies such as Westok and FABSEC (other manufacturers are available) and are purchased by the steelwork contractor to be fabricated into elements for a specific project. Rectangular and 'elongated' aperture shapes are available, although circular are the most common. Historically, the first cellular beams used hexagonal openings and were known as castellated beams. These are now very rare.

In modern cellular beam construction, a large range of aperture sizes and spacing/pitch is available and the area of steel between them is known as the web post. With regard to fire protection, the most important feature is that, unlike rolled sections which usually fail in bending in fire and for which the most important temperature is generally that of the lower flange, for cellular and castellated beams, the failure mode is generally web post buckling and it is the temperature of that part of the beam which is usually the most important. The dimensions of the residual 'web post' can therefore significantly affect the performance of the cellular beam in fire.

The issue of testing of fire protection for use with cellular beams is discussed in Section 4. Historically for the purposes of calculating the section factor of cellular beams, the following formula was used:

Section factor = 1400/t

Where t is the web thickness in mm. [Note: in situations where the web thickness varies, this is the bottom web thickness]

A.2.3 Section factor (A/V) for structural hollow sections

Fire test data exists on hot formed/finished structural hollow sections (SHS) as compression and flexural members, and the comparability between these sections and open (that is, hot rolled I or H) sections in terms of protection thickness related to section factor has been established.

The modifications listed below do not apply to intumescent coatings.

- For fire protection materials, whether boards or spray (on lath), *whose thicknesses have been assessed from test data on boxed 'I' sections* (see Figure 2 & 3), no change in thickness is required, i.e. the thickness for an SHS of a given section factor, is equal to that for the 'I' section of the same 'box' Section factor.
- For fire protection materials, whether board or spray *whose thickness has been assessed from test data on profiled I sections* (see Figure 2 & 3), some modification in thickness is required. The extent of the modification is related to the section factor of the section and is derived as follows:

    a) Establish the section factor of the SHS section.
    b) Establish the required thickness of profiled protection material based upon the tables relating to section factor and fire resistance period and protection thickness, derived for open sections. This is the thickness "d_p" (mm).
    c) Increase thickness d_p as follows (from BS 5950 Structural use of steelwork in building, Part 8: Code of practice for fire resistant design*)*:

For Section factor up to $250m^{-1}$	t = t {1 + (*A*/*V*)/1000}
For Section factor between 250 to $310m^{-1}$	t = 1.25t

Consideration should be given to the following:

- The maximum thickness that can be applied to SHS sections should not exceed that given by the manufacturer for open sections

- It should be noted that any changes resulting from the transposition from open sections to SHS sections may affect the retention of the material. Where modifications are considered significant, appropriate loaded fire resistance tests should be carried out.
- Where the fire protection thickness of open sections has been established by a test conducted on members which were “solid” protected, then a separate appraisal for the hollow section is necessary.

A.2.4 Section factor for partially exposed members

When a section is partially exposed to fire, for instance when a column is built into a wall or a beam is embedded in a floor slab, and robust construction materials such as brick, block or concrete have been used, the section factor may be traditionally calculated as shown in Annex 4, Table A.1. In such situations the same principle is used as for other configurations, where A is the surface area of the part of the section exposed to the fire and V is the volume of the section. The section factor will change depending upon the degree of exposure and the equations given in Annex 4, Table A.1 can be used.

It should be noted that the calculation method in Table 4.2 of Eurocode EN 1993-1-2:2005, for uses a more conservative value for the Section factor[A/V] as calculated by division of the **exposed steel perimeter** [A_{EXP}] by the **exposed steel cross section area** [V_{EXP}] rather than the entire volume of the steel section, despite the fact that heat is conducted into the entire volume of the steel section and also into the mass in contact with the embedded steel surface. That is, for partially exposed unprotected steel, the Eurocode section factor (A/V) = (A_{EXP} / V_{EXP}).

The method generally used in Annex 4, Table A.1 may not be generally applicable when steel is not embedded in fire resisting construction. In such cases it would be prudent to assume that the entire perimeter of the steel may become exposed to fire, and the section factor should then be calculated assuming full exposure.

Where the steel section penetrates through both sides of a fire resisting construction, consideration has to be given to requirements in addition to structural stability. For example, it is possible that a column with a fire resistant wall built within its flanges or level with the outer flanges may not comply with the appropriate integrity and/or insulation requirements for elements performing a fire separation function if the fire protection is sufficient to prevent structural collapse only.

This occurs because the insulation and integrity criterion must be satisfied for both steel member and wall. The thickness of protection to the exposed steel should be sufficient to ensure that the rise in mean surface temperature of the protection on the side remote from the fire does not exceed 140°C, and the rise in maximum surface temperature does not exceed 180°C above ambient.

In assessing fire protection requirements to maintain the structural performance of the column, the exposed steel on each side of the wall will have its own heated surface area, A, and therefore its own A/V, consequently different protection thicknesses may be required on each side depending upon the degree of exposure.

A.2.5 Section factor (A/V) for wind and stability bracing

The apparent cost of fire protecting bracing members is often expected to be high because the members are comparatively light and therefore have high section factors and correspondingly require high thicknesses of fire protection. The fire Eurocodes give no guidance on this, however, BS 5950 Structural use of steelwork in building, Part 8: Code of practice for fire resistant design recommends that the fire protection thickness should be based on the section factor of the steel member, or a value of $200m^{-1}$, whichever is the smaller value. This standard also states that in some cases, it might not be necessary to apply fire protection to bracing members and consideration should be given to:

a) Shielding bracing from fire by installing it in shafts or within walls.
b) The use of infill masonry walls, which can provide the sufficient shear capacity during a fire instead of relying on the steel bracing systems.

c) The possibility that only bracing systems within a fire compartment might be subjected to elevated temperatures and the other unaffected bracing systems might be sufficient to provide the required stability at the fire limit state.

d) The possibility that the steel beam to column connections might have sufficient stiffness to ensure stability at the fire limit state

The recommendations in previous editions for fire protection to bracing members are retained in Table 15.

Table 15 – Assessment of fire protection requirements for bracing

Building	Degree of fire protection to bracing system
Single storey Not more than 8m to eaves	None
Single storey More than 8m to eaves	Generally none
Two storey	Generally none. Walls and frame stiffness will contribute considerably to stability.
Other multi-storey	Protected to achieve required fire resistance. However the selection of thickness may be based on allowable reductions in applied loads in fire given in BS 5950-8: 2003 or BS EN 1990.

A.2.6 Tapered sections

Use the maximum section factor for the tapered steel section

A.2.7 Section factor (A/V) for lattice members

Ideally, wherever possible, a lattice beam should be judged by a full test as a loaded member. However, with existing fire testing equipment this is not always practicable and recourse to appraisal using section factors can be made.

When the elements of a lattice beam are to be individually protected, the thickness of protection required for each element should be based on the section factor of the individual element. Where a lattice beam is to be protected by encasing the entire beam by either boards, or sprays applied to an expanded metal lathing, no recommendation can be given and each case must be considered on its own merits, according to any test information available.

In the absence of a detailed analysis, a default critical/limiting temperature consistent with that used for columns exposed on four sides is recommended when assessing the fire protection requirements for the individual elements of a lattice girder. These are detailed in Section A.3.4 for design to both Eurocode 3: Design of steel structures, Part 1-2: General rules, Structural fire design and BS 5950 Structural use of steelwork in building, Part 8: Code of practice for fire resistant design. In all cases it is important that the final appraisal be based on a broad consideration of the lattice design.

A.2.8 Light gauge cold rolled sections

This type of section would normally necessitate separate appraisal because of the high values of A/V and the manner in which the sections are formed which can influence their failure criteria. Research is continuing to formulate recommendations for the applications of data given in this publication. Some information on the protection of cold formed members is given in the SCI publication 129 - *Building design using cold formed members: Fire Protection*.

Cold formed sections are generally formed from thin gauge steel. This loses strength in fire more quickly than hot rolled steel. In general, limiting temperatures for cold formed sections are 50°C to 100°C lower than for hot rolled sections. This, combined with the relatively high section factors for cold formed sections, means that fire protection thicknesses are relatively high.

A.3 Engineered approaches to structural fire protection

A.3.1 General

The fire Eurocodes, BS EN 1991: Actions on Structures, General actions, Part 1.2, Actions on structures exposed to fire; BS EN 1993: Design of steel structures, General rules, Part 1.2, Structural fire design; BS EN 1994: Design of composite steel and concrete structures, General rules, Part 1.2, Structural fire design and BS 5950: Structural use of steelwork in building, Part 8, Code of practice for fire resistant design are available for the design of structural steel in fire in the UK.

These codes concern themselves mainly with the design of individual elements of construction in fire. The behaviour of frames and assemblies in fire is usually dealt with using advanced fire engineering methods.

Although the Eurocodes and the British Standard are quite different in scope and complexity, they are based on a common understanding of the strength of structural steel in fire and also the factors which affect inherent fire resistance. The fire Eurocodes will eventually replace BS 5950-8: 2003, Structural use of steelwork in buildings – Part 8; Code of Practice for fire resistant design, but when this will take place is not yet clear and both codes will be available for a period of time. (See 1.4.2)

All Eurocodes have National Annexes. These are “official” national deviations from the published documents. A National Annex normally contains small changes to certain factors to bring the Eurocode in line with existing national standards. They also contain guidance on the use of Informative Annexes with particular emphasis on those which may and may not be used.

The basic concepts of how to use these codes to define limiting (failure) temperatures for structural steel are explained below.

A.3.2 Default limiting and critical temperatures

The variable load factors which are used for buildings in the fire Eurocodes vary according to the occupancy. These effectively divide buildings into 3 categories for the purposes of calculating critical temperatures. These are: offices & domestic; storage; and shopping & congregation. For steel designed to the Eurocodes, the following default critical temperatures should be used:

Table 16 – Default critical temperature from the Eurocodes (^{o}C)*

Building type	Non-composite beams carrying concrete floor slabs	Composite beams supporting concrete floor slabs	Hot rolled H sections columns in compression	Hot finished/formed structural hollow sections
Office/domestic	603	576	563	572
Storage	576	544	530	512
Shopping/congregational	583	553	539	521

*These temperatures are given in a report [1] kindly provided to the ASFP by Sherwin Williams in which the critical steel temperatures for structural steel designed to EN1993-1-2 and EN1994-1-2 with applied loads from EN1990 and EN1991-1-2 were assessed. Supporting evidence was also provided by International Paint Ltd. The purpose of the assessment was to allow fire protection manufacturers and laboratories to have available default critical steel temperatures to use when quoting for jobs. The report has been third party verified by the University of Manchester[2]”.

Where the building occupancy is not known, the following default critical temperatures should be used:

Table 17 – Default critical temperature from the Eurocodes when the building occupancy is not known

Non-composite beams carrying concrete floor slabs	Composite beams supporting concrete floor slabs	Hot rolled H section columns in compression	Hot finished/ formed structural hollow sections
575°C	550°C	530°C	515°C

BS 5950-8: 2003, Structural use of steelwork in buildings – Part 8; Code of Practice for fire resistant design divides all buildings into two groups: offices and others. For steel designed to BS 5950-8 the following limiting temperatures should be used if no other information is available. If the occupancy of the building is not known, the figures for 'Other' should be used.

Table 18 – Default limiting temperatures from BS 5950 Part 8 (^{o}C)

	Other	Offices
Hot rolled H sections in compression with $\lambda \leq 70$	540	580
Hot rolled H sections in compression with $\lambda > 70$	510	545
Non-composite beams carrying concrete floor slabs	620	650
Beams not carrying concrete floor slabs	555	585
Composite beams supporting steel deck floors	580*	610*
Hot finished/formed hollow sections in compression	520#	520#
*Assumes that the deck voids are filled. See A.3.5 # Typically this is 520°C although different manufacturers state different temperatures based on the testing and assessment for certain products		

λ is the slenderness, which is defined as the effective length divided by the radius of gyration. If it is not known it should be assumed to be > 70.

The default temperatures for composite beams, when used with composite steel deck floors, assume that the gap between the top flange of the beam and the deck is filled with a fire protective material. Where this does not happen, the adjustments described in Section 3.4 should be made.

It should be noted that the fire Eurocodes have introduced the issue of section classification into the calculation of critical temperatures. This was absent from BS 5950 Part 8. Hot rolled structural sections and hot finished/formed structural hollow sections are determined to be Class 1, 2, 3 or 4 depending on factors such as *the ratio of the outstand of a flange or the depth of a web to its thickness. This is explained in BS EN 1993 Design of steel structures. Part 1.1: General rules and rules for buildings, wh*ich states that "*The role of cross section classification is to identify the extent to which the resistance and rotation capacity of cross sections is limited by its local buckling resistance.*" Of particular importance is the identification of Class 4 sections which are defined as being those "...*in which local buckling will occur before the attainment of yield stress in one or more parts of the cross-section*."

Such sections are relatively rare but they will cause particular problems because critical temperatures can be as low as 350^{o}C. This problem is exacerbated by the fact that section classification is calculated differently in BS EN 1993 Part 1.2 than in BS EN 1993 Part 1.1. Thus, it is possible that a structural section that is Class 1, 2 or 3 in ambient design could be Class 4 in fire.

Fire protecting Class 4 sections is very difficult and their use should be avoided if at all possible. More details on this, including an explain of how section classification works, are available at http://www.steelconstruction.info/Eurocode_classification_of_sections_in_fire

A.3.3 Strength of steel at elevated temperature

As hot rolled/formed structural steel is heated it will retain its yield strength until it reaches a temperature of about 400°C and then, on further heating, it becomes steadily weaker. The variation of strength retention with temperature for the most commonly used grades of structural steel is given in Table 19. The values given are taken from BS EN 1993-1.2 and can be applied to the following structural steel grades: S235; S275; S355; S420 and S460 of EN 10025 and all grades of EN 10210 and EN 10219. They are repeated, with some minor variations, in BS 5950 Part 8, although, in that code, they are stated as applying to steel complying with grades S275 to S355 of BS EN 10025 and BS EN 10210-1 only.

Table 19 – Variation of the effective yield strength factor of normal structural steels with temperature from the Eurocodes

Temperature (°C)	20	100	200	300	400	500	600	700	800
Effective yield strength factor	1.00	1.00	1.00	1.00	1.0	0.78	0.47	0.23	0.11
Note: The factors are applied to the 'cold' strength of the steel to obtain the elevated temperature strength. For example, at 600°C the effective yield strength of S275 steel is 0.47 x 275 = 129.25 N/mm^2									

A.3.4 Loads in fire and variations in critical/limiting temperatures

The basic high temperature strength data shown in Table 19 was generated by testing a series of small samples of steel in the laboratory, where the whole of each test sample was at a uniform temperature and was axially loaded. When these conditions are repeated in a full scale member tests, for example, a loaded fire test on a full scale column heated uniformly and supporting a load that produces a force or moment equal to 47% of its room temperature resistance, it will fail at 600°C.

This is important because both the fire Eurocodes and BS 5950 Part 8 reflect the fact that fire is an accidental limit state and that extremes of fire and extremes of load are unlikely to occur simultaneously. Ambient temperature design to the structural Eurocodes is generally carried out using safety factors of 1.35 and 1.5 for dead and live loads (referred to in the Eurocodes as permanent and variable actions) respectively. However, in BS EN 1993-1-2, to reflect the low probability of high loads at the time of a fire, reduced dead and live load factors may be used.

The reduction factor (η_{fi}) for load combination in fire from BS EN 1990 is usually taken as:

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,1}}{\xi \gamma_G G_k + \gamma_{Q,1} Q_{k,1}}$$

where:

$Q_{k,1}$ is the principal variable action
G_k is the characteristic value of a permanent action
γ_G is the partial factor for permanent actions (1.35)
$\psi_{0,1}$ is the combination factor for the characteristic permanent action (0.7 for most other buildings)
$\gamma_{Q,1}$ is the partial factor for variable action (1.5)
ψ_{fi} is the combination factor for frequent values, given either by $\psi_{1,1}$ or $\psi_{2,1}$, see EN1990
ξ is a reduction factor for unfavourable permanent actions (0.925).

Typical values for an office are:

γ_{GA} = 1,0 γ_G = 1,35

γ_Q = 1,5 ξ = 0.925

$\psi_{0,1}$ = 0.7 ψ_{fi} = $\psi_{1,1}$ = 0.5

Assuming that the permanent load, G_k, is equal to the variable load Q_k

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,1}}{\xi \gamma_G G_k + \gamma_{Q,1} Q_{k,1}} = 0.545$$

Summarised, what this means is that a fully loaded structural section, in an office building, when designed to the Eurocodes, and with equal permanent and variable loads, can be assumed to be loaded to 54.5% of its full capacity when designing for fire. Interpolating between the data given in Table 19 in Section A.3.3, it can be seen that the critical (failure) temperature for a fully exposed structural section should be approximately 576°C. This is broadly in the range of the default for columns in offices given in Table 16 in Section A.3.2.

It should be noted that the values for $\psi_{0,1}$, ψ_{fi} and $\psi_{1,1}$ vary for different building occupancies and so default critical temperatures differ between occupancies in the Eurocodes. This is explored further in Section A.3.2.

The assessment of default limiting (failure) temperatures in BS 5950 Part 8 is simpler than it is in the fire Eurocodes. In that code, the relationship between the load in the fire condition and the load in ambient design is termed the load ratio. It is normally considered that a fully loaded section has a load ratio of 0.6 (i.e. in fire, it is loaded to 60% of its ambient load carrying capacity). This comes from an analysis of the dead and live load factors for cold (1.4 and 1.6 respectively) and fire design (1.0 and 0.8):

(1.0 + 0.8)/(1.4 + 1.6) = 0.6

By interpolating the data in Table 19, it can be seen that, for a section which is exposed on all four sides in a fire, and which is loaded to 60% of its room temperature capacity, it would fail at approximately 550°C. This explains why the default limiting (failure) temperature for columns in BS 5950 Part 8 is approximately this value (See Table 18, Section A.3.2).

For offices, the live load factor in fire is 0.5 and so the default load ratio is:

(1.0+0.5)/(1.4+1.6) = 0.5

A joint test programme carried out by Tata Steel (then British Steel) and the Building Research Establishment in the 1980s showed that where a section has a temperature profile (i.e. a variation in temperature) through the cross-section, this can have a marked effect on its performance in fire. If the section is not uniformly heated then, when the hotter part of the section reaches the temperature at which it will begin to yield plastically, it will transfer load to cooler regions of the section, which will still act elastically. As the temperature rises further, more load is transferred from the hot region by plastic yielding until eventually the load in the cool regions becomes so high that they too become plastic and the member fails.

One of the most common situations in which temperature gradients have a significant effect on the fire resistance of structural steel is where beams support concrete slabs. The effect of the slab is both to protect the upper surface of the top flange from the fire and to act as a heat sink. This induces significant temperature differences between the upper and lower flanges in standard fire tests. Test data shows that the critical/limiting temperature (in this case, the lower flange temperature) of fully loaded plain beams carrying concrete slabs is always higher than an equivalent section exposed to a fire on all four sides.

If a column or beam is not fully loaded then the critical/limiting temperatures will be higher than the defaults. As has been shown, a column carrying 47% of it ambient load capacity will fail at approximately 600°C. Similarly, it can be shown that a non-composite beam carrying a concrete floor slab and a load in fire calculated to be 25% of its ambient load capacity will fail at temperatures over 100°C higher than the temperatures at which it will fail when fully loaded. If these non-default critical/limiting temperatures are known, they can be used to reduce the thickness of fire protection, assuming that the manufacturer has carried out an appropriate multi-temperature assessment.

The appraisal of the critical/limiting temperature, other than defaults, of any structural section can be carried out using the fire Eurocodes and BS 5950 Part 8. However, these calculations should be only be carried out by a qualified engineer i.e. one with suitable experience and registered with the UK Engineering Council.

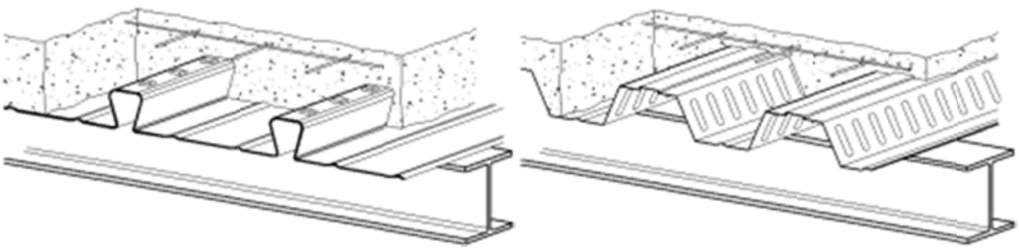
A.3.5 Deck voids above composite and non-composite beams

A.3.5.1 Background

The most common form of construction in multi-storey, non-residential buildings in the UK is composite beams supporting composite steel deck floors.

Composite steel deck floors comprise reinforced concrete cast on top of profiled steel decking, which acts as formwork during construction and external reinforcement at the final stage. The decking may be either re-entrant or trapezoidal, as shown in the Figure 27 below.

Figure 27 – Re-entrant and trapezoidal decking



Re-entrant decking Trapezoidal decking

The deck is usually through deck welded to the top flange of the beam by shot fired shear studs before an anti-crack mesh is installed and the concrete is poured. When the concrete is dry the steel and concrete work together to resist the loading. In certain rare instances, shear studs are not used and the construction is non-composite.

The use of beams oriented perpendicularly to profiled steel decks creates voids between the top flange of the beam and the metal deck. The consequence of this is that the temperature gradient discussed in A3.4 is compromised as the top flange gets hotter than would happen if the floor slab was a plain precast slab.

With a dovetail profile, the void is small and no action is generally necessary. With trapezoidal profiles, the void is comparatively large. This creates a situation where some actions are required to balance the impact of the added heating of the top flange. This can be either:

- Fill the void between the top flange of the beam and the deck with a suitable material.
- Leave the void unfilled but increase the thickness of the fire protection on the rest of the beam.

BS EN 1994-1-2, section 4.3.4.2.2 provides some assistance in assessing the impacts of unfilled voids. A method is provided for the calculation of temperature rises in beams with contour protection. When at least 85% of the upper flange of the steel profile is in contact with the concrete slab or, when any void formed between the upper flange and a profiled steel deck is filled with non-combustible material, the section factor of the top flange is calculated by reducing the length of the heated perimeter by a distance equal to the extent of the top flange. Otherwise, the full perimeter of the top flange is used to calculate the section factor. Thus, a beam with a filled trapezoidal or dovetail void will heat up more slowly than one which has an unfilled trapezoidal void and the impact of the unfilled void on the load carrying capacity of the beam can be calculated.

BS 5950 Part 8 does not explicitly address the filling of voids. Information provided on limiting temperatures for composite steel deck construction assumes that the voids are filled

The effect of not filling voids above composite beams was investigated by SCI and ASFP and others in a series of fire tests and reported in *SCI P109 Technical Report: The fire resistance of composite beams. Steel Construction Institute, 1991*. The guidance from that is repeated in Section A.3.5.4.

A.3.5.2 Guidance on filling the voids

Preformed blocks are available to fill the voids between the deck and the top flange of the beam but any non-combustible material with proven fire stopping ability may be used. If the beam is protected using a cementitious spray then that can be used. An intumescent coating may be used as long as the upper surface of the top flange has the same coating thickness as the other parts of the beam. All voids should be filled when the beam forms part of a compartment wall. See A.3.5.7.

A.3.5.3 Recommendations on void filling for non-composite beams with metal deck composite slabs

Where non-composite beams support trapezoidal steel deck floors, all voids must be filled. Although it is rare for a steel beam supporting a composite steel deck floor slab not to be designed to act compositely, a fire protection contractor will normally not be able to tell whether a beam is composite simply by visual inspection. In a finished building, the shear connectors will be covered by the floor slab and so the contractor will have to obtain confirmation from an appropriate engineer. Consequently, if the contractor is unable to determine if the beam is composite or not, and the deck is trapezoidal, all voids above the flange must be filled.

A.3.5.4 Recommendations on void filling for composite beams and slabs

This is an issue for trapezoidal, but not dovetail deck. Where the void is not filled, it is necessary to make adaptations to the structural fire protection thicknesses.

A.3.5.4.1 Beams using default critical/limiting temperatures

Guidance on the effect of filling or not filling voids above composite beams as reported in SCI P109 Technical Report: The fire resistance of composite beams. Steel Construction Institute, 1991 has traditionally been based on BS 5950-8: 2003, Structural use of steelwork in buildings – Part 8; Code of Practice for fire resistant design. Two sets of guidance were originally published, one based on an assumption that the thicknesses of fire protection applied to the beam was such that it that would limit temperature rises in the steel sections to 550°C for a given fire resistance time and the other based on the assumption that this temperature was 620°C. Applying fire protection thicknesses sufficient to limit temperature rises to 550°C is a very conservative approach for a composite beam and therefore the compensatory features required when counteracting the impacts of using unfilled trapezoidal voids were not as onerous as those required when the fire protection thickness was only sufficient to prevent the temperature reaching 620°C. Therefore, adopting the guidance appropriate for beams with protection thicknesses sufficient to restrict temperature rises to 620°C will be conservative.

The guidance appropriate to beams with sufficient protection to prevent temperature rises of 620°C is reproduced in Table 20. It is appropriate to both passive (non-reactive) and reactive types of fire protection. It can be applied to all situations where the critical/limiting temperature is less than 620°C. For cellular beams see A.3.5.5.

Table 20 – Recommendations for beams with unfilled voids

Trapezoidal deck				
Beam type	**Fire protection on beam**	**Fire resistance (minutes)**		
		Up to 60	**90**	**Over 90**
Composite	Passive (non-reactive) and reactive	Increase thickness by 20% or assess thickness using A/V increased by 30%*	Increase thickness by 30% or assess thickness using A/V increased by 50%*	Fill voids
		* The least onerous option may be used		
Non-composite	Fill voids			

Default critical temperatures in Eurocode design are always less than 620°C (see Section A.3.2). Therefore, applying the correction factors shown to beams designed according to the Eurocodes when default critical temperatures are being used is considered a reasonable approach.

It should be noted that the values given here may be conservative and a detailed analysis of any given design might yield a less conservative result. There may be value in checking with the product manufacturer as to whether they have alternative data.

A.3.5.4.2 Beams where limiting temperatures are based on an engineering approach

An engineered approach occurs where the default failure temperature for the beam is not accepted and an alternative critical/limiting temperature is calculated. In this instance, the effect of unfilled voids can be expressed in terms of a decrease in critical/limiting temperature at a given time compared to a protected beam with 'filled voids' carrying the same loading. The extent of the decrease is given in Table 21.

The guidance reproduced in Table 21. It is appropriate to both passive (non-reactive) and reactive types of fire protection and can be used to beams designed using both a BS 5950 and a Eurocode approach. For cellular beams see Section 3.5.5.

Table 21 – 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			

Thus, if the calculated critical/limiting temperature for a composite beam supporting a trapezoidal steel deck floor has been calculated to be 600°C, the required period of fire resistance is 90 minutes and the void between the deck and the top flange of the beam is left unfilled, the critical/limiting temperature changes to 600-90°C, which is 510°C.

It should be noted that the values given here may be conservative and a detailed analysis of any given design might yield a less conservative result. There may be value in checking with the product manufacturer as to whether they have alternative data. It is important to ensure that such data, if available, has been undergone an independent 3rd party certification.

A.3.5.5 Guidance on filling voids on beams with web openings (cellular beams)

Section 4 of this document discusses the special measures required for steel beams with web openings. (See also Section A.2.2). In such cases the, critical/limiting temperature of the beam can be reduced by the openings, depending on their size, shape, spacing and location. The critical/limiting temperature should be provided by the steel supplier and/or structural engineer. If no temperature is specified then no guidance can be offered at present about any aspect of fire protection.

Cellular beam manufacturers should be able to provide information on critical/limiting temperatures when the deck voids are unfilled. If not then the limiting temperature reductions in Sections A.3.5.4.1 and A. 3.5.4.2 must be used.

A.3.5.7 Guidance on voids at compartment walls

Voids must ordinarily be filled on beams that are part of a compartment wall otherwise the integrity and insulation criteria of the wall will be breached. Voids may only be left unfilled on beams that do not form part of a compartment wall. For decks with the profile running parallel to beams no special recommendations are made for profile fire protection materials but, for board protection, the boards should be taken past the edge of the flange to abut the underside of the deck.

Annex 4 – Protection configurations to calculate section factor (A/V) & tables of section factor for common section sizes/shapes

Table A.1 – Protection configurations with values of perimeter A in the calculation of section factor A/V

Note: the values are approximate in that radii at corners and roots of all sections may be ignored.

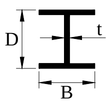
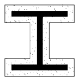
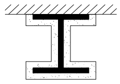
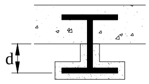
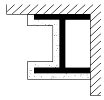
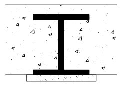
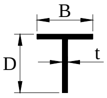
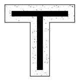
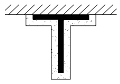
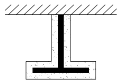
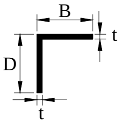
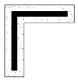
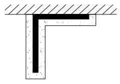
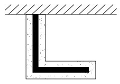
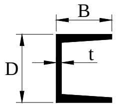
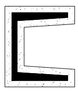
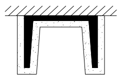
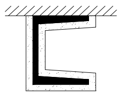
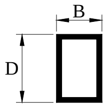
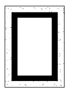
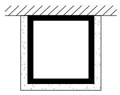
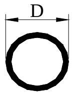
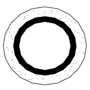
Steel section	Profile protection				
Universal beams, universal columns and joists (plain and castellated)  Hp	4 sides  2B + 2D + 2(B - t) = 4B + 2D - 2t	3 sides  B + 2D + 2(B - t) = 3B + 2D - 2t	3 sides  Partially exposed B + 2d + (B - t) = 2B + 2d - t	2 sides  B + D + 2(B - t)/2 = 2B + D - t	1 side  Partially exposed B
Structural and rolled tees  Hp	4 sides  2B + 2D	3 sides  Flange to soffit B + 2D	3 sides  Toe of web to soffit B + 2D + (B - t) = 2B + 2D - t		
Angles  Hp	4 sides  2B + 2D	3 sides  Flange to soffit B + 2D	3 sides  Toe of flange to soffit B + 2D + (B - t) = 2B + 2D - t		
Channels  Hp	4 sides  2B + 2D + 2(B - t) = 4B + 2D - 2t	3 sides  Web to soffit 2B + D + 2(B - t) = 4B + D - 2t	3 sides  Flange to soffit B + 2D + 2(B - t) = 3B + 2D - 2t		
Hollow sections, *square or rectangular*  Hp	4 sides  2B + 2D	3 sides  B + 2D			
Hollow sections, *circular*  Hp	 πD				
Example using 203 x 203 x 52 kg/m universal beam B = 204.3mm D = 206.2mm t = 7.9mm A = 66.282cm2	a) Profile protection - 4 sided exposure Hp = 4B+2D-2t=[4x204.3]+[2x206.2]-[2x7.9] = 817.2+412.2-15.8=1213.8mm=1.214m Hp/A = 1.214/0.006282 – 183.2m^{-1}		b) Profile protection - 3 sided exposure Hp = 3B+2D-2t=612.9+412.4-15.8 = 1009.5mm=1.01m Hp/A = 1.01/0.0066282 = 152.4m^{-1}		

Table A.1 continued…

Note: the values are approximate in that radii at corners and roots of all sections may be ignored.

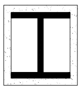
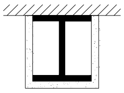
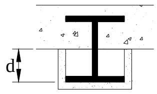
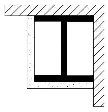
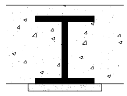
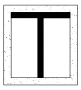
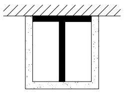
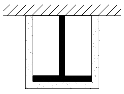
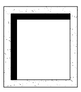
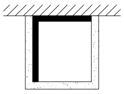
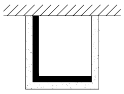
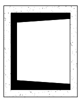
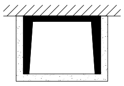
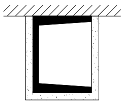
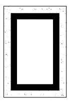
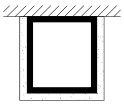
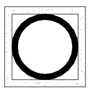
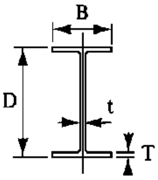
Steel section	Box and solid protection				
Universal beams, universal columns and joists (plain and castellated)	4 sides 	3 sides 	3 sides  Partially exposed	2 sides 	1 side  Partially exposed
Hp	2B + 2D	B + 2D	B + 2d	B + D	B
Structural and rolled tees	4 sides 	3 sides  Flange to soffit	3 sides  Toe of web to soffit		
Hp	2B + 2D	B + 2D	B + 2D		
Angles	4 sides 	3 sides  Flange to soffit	3 sides  Toe of flange to soffit		
Hp	2B + 2D	B + 2D	B + 2D		
Channels	4 sides 	3 sides  Web to soffit	3 sides  Flange to soffit		
Hp	2B + 2D	2B + D	B + 2D		
Hollow sections, *square or rectangular*	4 sides 	3 sides 			
Hp	2B + 2D	B + 2D			
Hollow sections, *circular*		*Note.* The air space created in boxing a section improves the insulation and a value of Hp/A, and therefore Hp, higher than for profile protection would be anomalous. Hence Hp is taken as the circumference of the tube and not 4D.			
Hp	πD				
Example continued	c) Box protection – 4 sided exposure Hp = 3B + 2D – 2t = 612.9 + 412.4 – 15.8 = 1009.5mm = 1.01m Hp/A = 0.821 / 0.0066282 = 123.9m^{-1}	d) Box protection – 3 sided exposure Hp = B +2D = 204.3 + 412.4 = 616.7mm = 0.617m Hp/A = 0.617/0.0066282 = 93.04m^{-1}			

Table A.2

UK Beams (UKB)

Dimensions to BS4 Part 1:2005



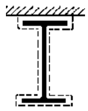
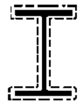
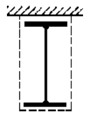
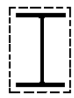
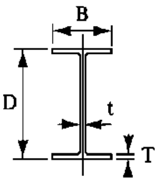
Designation		Depth of section D	Width of section B	Thickness		Area of section	Section factor A/V(Hp/A)			
							Profile		Box	
							3 sides	4 sides	3 sides	4sides
Serial size	Mass per metre			Web t	Flange T					
mm	kg	mm	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}
1016 x 305	487	1036.1	308.5	30.0	54.1	619.89	45	50	40	45
	438	1025.9	305.4	26.9	49.0	556.62	50	55	40	50
	393	1016.0	303.0	24.4	43.9	500.24	55	65	45	55
	349	1008.1	302.0	21.1	40.0	445.15	65	70	50	60
	314	1000.0	300.0	19.1	35.9	400.41	70	80	55	65
	272	990.1	300.0	16.5	31.0	346.86	80	90	65	75
	249	980.2	300.0	16.5	26.0	316.88	90	95	70	80
	222	970.3	300.0	16.0	21.1	282.82	95	110	80	90
914 x 419	388	921.0	420.5	21.4	36.6	494.22	60	70	45	55
	343	911.8	418.5	19.4	32.0	437.30	70	80	50	60
914 x 305	289	926.6	307.7	19.5	32.0	368.27	75	80	60	65
	253	918.4	305.5	17.3	27.9	322.83	85	95	65	75
	224	910.4	304.1	15.9	23.9	285.64	95	105	75	85
	201	903.0	303.3	15.1	20.2	255.92	105	115	80	95
838 x 292	226	850.9	293.8	16.1	26.8	288.56	85	100	70	80
	194	840.7	292.4	14.7	21.7	246.82	100	115	80	90
	176	834.9	291.7	14.0	18.8	224.02	110	125	90	100
762 x 267	197	769.8	268.0	15.6	25.4	250.64	90	100	70	85
	173	762.2	266.7	14.3	21.6	220.37	105	115	80	95
	147	754.0	265.2	12.8	17.5	187.19	120	135	95	110
	134	750.0	264.4	12.0	15.5	170.58	130	145	105	120
686 x 254	170	692.9	255.8	14.5	23.7	216.83	95	110	75	90
	152	687.5	254.5	13.2	21.0	194.08	105	120	85	95
	140	683.5	253.7	12.4	19.0	178.43	115	130	90	105
	125	677.9	253.0	11.7	16.2	159.48	130	145	100	115
610 x 305	238	635.8	311.4	18.4	31.4	303.33	70	80	50	60
	179	620.2	307.1	14.1	23.6	228.08	90	105	70	80
	149	612.4	304.8	11.8	19.7	190.04	110	125	80	95
610 x 229	140	617.2	230.2	13.1	22.1	178.19	105	120	80	95
	125	612.2	229.0	11.9	19.6	159.34	115	130	90	105
	113	607.6	228.2	11.1	17.3	143.94	130	145	100	115
	101	602.6	227.6	10.5	14.8	128.92	145	160	110	130
610 x 178	100	607.4	179.2	11.3	17.2	128.00	135	150	110	125
	92	603.0	178.8	10.9	15.0	117.00	145	160	120	135
	82	598.6	177.9	10.0	12.8	104.00	160	180	130	150
533 x 312	273	577.1	320.2	21.1	37.6	348.00	60	70	40	50
	219	560.3	317.4	18.3	29.2	279.00	70	85	50	65
	182	550.7	314.5	15.2	24.4	231.00	85	100	60	75
	151	542.5	312.0	12.7	20.3	192.00	105	120	75	90
533 x 210	138	549.1	213.9	14.7	23.6	176.00	95	110	75	85
	122	544.5	211.9	12.7	21.3	155.39	110	120	85	95
	109	539.5	210.8	11.6	18.8	138.86	120	135	95	110
	101	536.7	210.0	10.8	17.4	128.67	130	145	100	115

Table A.2

UK Beams (UKB)

Dimensions to BS4 Part 1:2005



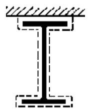
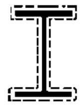
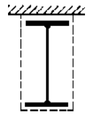
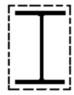
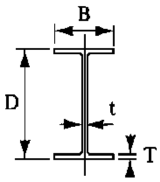
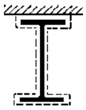
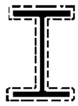
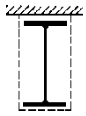
Designation		Depth of section D	Width of section B	Thickness		Area of section	Section factor A/V(Hp/A)			
							Profile		Box	
							3 sides	4 sides	3 sides	4sides
Serial size	Mass per metre			Web t	Flange T					
mm	kg	mm	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}
	92	533.1	209.3	10.1	15.6	117.38	140	160	110	125
	82	528.3	208.8	9.6	13.2	104.69	155	175	120	140
continued overleaf										
533 x 165	85	534.9	166.5	10.3	16.5	108.00	140	155	115	130
	75	529.1	165.9	9.7	13.6	95.20	160	175	130	145
	66	524.7	165.1	8.9	11.4	83.70	180	200	145	165
457 x 191	161	492.0	199.4	18.0	32.0	206.00	75	85	60	65
	133	480.6	196.7	15.3	26.3	170.00	90	100	70	80
	106	469.2	194.0	12.6	20.6	135.00	110	125	85	100
	98	467.2	192.8	11.4	19.6	125.26	120	135	90	105
	89	463.4	191.9	10.5	17.7	113.76	130	145	100	115
	82	460.0	191.3	9.9	16.0	104.48	140	160	105	125
	74	457.0	190.4	9.0	14.5	94.63	155	175	115	135
	67	453.4	189.9	8.5	12.7	85.51	170	190	130	150
457 x 152	82	465.8	155.3	10.5	18.9	104.53	130	145	105	120
	74	462.0	154.4	9.6	17.0	94.48	145	160	115	130
	67	458.0	153.8	9.0	15.0	85.55	155	175	125	145
	60	454.6	152.9	8.1	13.3	76.23	175	195	140	160
	52	449.8	152.4	7.6	10.9	66.64	200	220	160	180
406 x 178	85	417.2	181.9	10.9	18.2	109.00	125	140	95	110
	74	412.8	179.5	9.5	16.0	94.51	140	160	105	125
	67	409.4	178.8	8.8	14.3	85.54	155	175	115	140
	60	406.4	177.9	7.9	12.8	76.52	170	195	130	155
	54	402.6	177.7	7.7	10.9	68.95	190	215	145	170
406 x 140	53	406.6	143.3	7.9	12.9	67.90	180	200	140	160
	46	403.2	142.2	6.8	11.2	58.64	205	230	160	185
	39	398.0	141.8	6.4	8.6	49.65	240	270	190	215
356 x 171	67	363.4	178.1	9.1	15.7	85.49	140	160	105	125
	57	358.0	172.2	8.1	13.0	72.55	165	190	120	145
	51	355.0	171.5	7.4	11.5	64.91	185	210	135	160
	45	351.4	171.1	7.0	9.7	57.33	205	235	150	180
356 x 127	39	353.4	126.0	6.6	10.7	49.77	210	235	165	195
	33	349.0	125.4	6.0	8.5	42.13	250	280	195	225
305 x 165	54	310.4	166.9	7.9	13.7	68.77	160	185	115	140
	46	306.6	165.7	6.7	11.8	58.75	185	210	135	160
	40	303.4	165.0	6.0	10.2	51.32	210	240	150	185
305 x 127	48	311.0	125.3	9.0	14.0	61.23	160	180	120	145
	42	307.2	124.3	8.0	12.1	53.40	180	200	140	160
	37	304.4	123.4	7.1	10.7	47.18	200	225	155	180
305 x 102	33	312.7	102.4	6.6	10.8	41.83	215	240	175	200
	28	308.7	101.8	6.0	8.8	35.88	250	280	200	230
	25	305.1	101.6	5.8	7.0	31.60	280	315	225	255
254 x 146	43	259.6	147.3	7.2	12.7	54.77	170	195	120	150
	37	256.0	146.4	6.3	10.9	47.16	195	225	140	170

Table A.2

UK Beams (UKB)

Dimensions to BS4 Part 1:2005



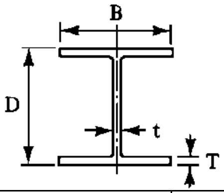
Designation		Depth of section D	Width of section B	Thickness		Area of section	Section factor A/V(Hp/A)			
							Profile		Box	
Serial size	Mass per metre			Web t	Flange T		3 sides	4 sides	3 sides	4side s
										
mm	kg	mm	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}
	31	251.4	146.1	6.0	8.6	39.68	230	270	165	200
254 x 102	28	260.4	102.2	6.3	10.0	36.08	220	250	175	200
	25	257.2	101.9	6.0	8.4	32.04	250	280	190	225
	22	254.0	101.6	5.7	6.8	28.02	280	320	220	255
continued overleaf										
203 x 133	30	206.8	133.9	6.4	9.6	38.21	205	240	145	180
	25	203.2	133.2	5.7	7.8	31.97	245	285	170	210
203 x 102	23	203.2	101.8	5.4	9.3	29.40	235	270	175	205
178 x 102	19	177.8	101.2	4.8	7.9	24.26	260	305	190	230
152 x 89	16	152.4	88.7	4.5	7.7	20.32	270	315	195	235
127 x 76	13	127.0	76.0	4.0	7.6	16.52	280	325	200	245

NB - Data on older and other steel sizes can be found on ASFP website/technical section

Table A.3

Columns (UKC)

Dimensions to BS4 Part 1:2005



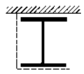
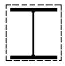
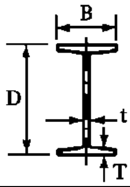
Designation				Thickness			Section factor A/V(Hp/A)			
							Profile		Box	
Serial size	Mass per metre	Depth of section D	Width of section B	Web t	Flange T	Area of section	3 sides 	4 sides 	3 sides 	4sides 
mm	kg	mm	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}
356 x 406	1086	569.5	454.4	78.0	125	1387	15	20	10	15
	990	549.7	448.3	71.9	115	1263	20	20	10	15
	900	531.4	442.3	65.9	106	1150	20	25	15	15
	818	514.1	436.9	60.5	97	1044	20	25	15	20
	744	497.8	432.1	55.6	88.9	948	25	25	15	20
	677	483.1	427.8	51.2	81.5	863	25	30	15	20
	634	474.6	424.0	47.6	77.0	807.548	25	30	15	20
	551	455.6	418.5	42.1	67.5	701.930	30	35	20	25
	467	436.6	412.2	35.8	58.0	594.909	35	40	20	30
	393	419.0	407.0	30.6	49.2	500.574	40	50	25	35
	340	406.4	403.0	26.6	42.9	433.036	45	55	30	35
	287	393.6	399.0	22.6	36.5	365.708	50	65	30	45
	235	381.0	394.8	18.4	30.2	299.432	65	75	40	50
356 x 368	202	374.6	374.7	16.5	27.0	257.219	70	85	45	60
	177	368.2	372.6	14.4	23.8	225.506	80	95	50	65
	153	362.0	370.5	12.3	20.7	194.803	90	110	55	75
	129	355.6	368.6	10.4	17.5	164.335	110	130	65	90
305 x 305	283	365.3	322.2	26.8	44.1	360.426	45	55	30	40
	240	352.5	318.4	23.0	37.7	305.789	50	60	35	45
	198	339.9	314.5	19.1	31.4	252.414	60	75	40	50
	158	327.1	311.2	15.8	25.0	201.364	75	90	50	65
	137	320.5	309.2	13.8	21.7	174.415	85	105	55	70
	118	314.5	307.4	12.0	18.7	150.202	100	120	60	85
	97	307.9	305.3	9.9	15.4	123.448	120	145	75	100
254 x 254	167	289.1	265.2	19.2	31.7	212.855	60	75	40	50
	132	276.3	261.3	15.3	25.3	168.134	75	90	50	65
	107	266.7	258.8	12.8	20.5	136.381	95	110	60	75
	89	260.3	256.3	10.3	17.3	113.311	110	135	70	90
	73	254.1	254.6	8.6	14.2	93.100	130	160	80	110
203 x 203	127	241.4	213.9	18.1	30.1	162.00	65	80	45	55
	113	235.0	212.1	16.3	26.9	145.00	75	90	45	60
	100	228.6	210.3	14.5	23.7	127.00	80	100	55	70
	86	222.2	209.1	12.7	20.5	109.636	95	115	60	80
	71	215.8	206.4	10.0	17.3	90.427	110	135	70	95
	60	209.6	205.8	9.4	14.2	76.373	130	160	80	110
	52	206.2	204.3	7.9	12.5	66.282	150	180	95	125
	46	203.2	203.6	7.2	11.0	58.731	170	200	105	140
152 x 152	51	170.2	157.4	11.0	15.7	65.20	120	145	75	100
	44	166.0	155.9	9.5	13.6	56.10	135	165	85	115
	37	161.8	154.4	8.0	11.5	47.112	160	195	100	135
	30	157.6	152.9	6.5	9.4	38.263	195	235	120	160
	23	152.4	152.2	5.8	6.8	29.245	250	305	155	210

Table A.4

JOISTS

Dimensions to BS 4 Part 1:1993



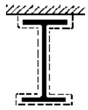
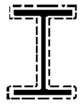
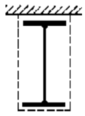
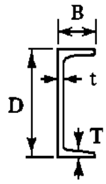
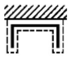
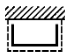
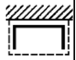
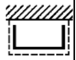
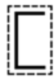
Designation		Depth of section D	Width of section B	Thickness		Area of section	Section factor A/V (Hp/A)			
							Profile		Box	
Serial size	Mass per metre			Web t	Flange T		3 sides	4 sides	3 sides	4sides
										
mm	kg	mm	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}
203 X 152	52.3	203.2	152.4	8.9	16.5	66.6	115	140	85	105
152 X 127	37.3	152.4	127.0	10.4	13.2	47.5	130	155	90	120

Table A.5

Parallel Flange Channels

Dimensions to BS 4 Part 1: 2005



Designation		Depth of section D	Width of section B	Thickness		Area of section	Section factor A/V (Hp/A)							
							Profile				Box			
Serial size	Mass per metre			Web t	Flange T		3 sides			4 sides	3 sides			4 sides
														
mm	Kg	mm	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}
430 x100	64.40	430	100	11.0	19.0	82.09	135	95	75	150	115	75	75	130
380 x 100	54.00	380	100	9.5	17.5	68.74	150	110	85	165	125	85	85	140
300 x 100	45.50	300	100	9.0	16.5	58.00	150	115	85	165	120	85	85	140
300 x 90	41.40	300	90	9.0	15.5	52.78	160	120	90	175	130	90	90	150
260 x 90	34.80	260	90	8.0	14.0	44.38	170	135	100	190	135	100	100	160
260 x 75	27.60	260	75	7.0	12.0	35.14	205	150	115	225	170	115	115	190
230 x 90	32.20	230	90	7.5	14.0	40.97	170	140	100	195	135	100	100	155
230 x 75	25.70	230	75	6.5	12.5	32.69	200	155	115	225	165	115	115	185
200 x 90	29.70	200	90	7.0	14.0	37.86	170	140	100	195	130	100	100	155
200 x 75	23.40	200	75	6.0	12.5	29.87	200	160	115	225	160	115	115	185
180 x 90	26.10	180	90	6.5	12.5	33.19	185	155	110	210	135	110	110	165
180 x 75	20.30	180	75	6.0	10.5	25.91	215	175	125	245	170	125	125	195
150 x 90	23.90	150	90	6.5	12.0	30.41	180	160	110	210	130	110	110	160
150 x 75	17.90	150	75	5.5	10.0	22.77	220	190	130	255	165	130	130	200
125 x 65	14.80	125	65	5.5	9.5	18.80	225	195	135	260	170	135	135	200
100 x 50	10.20	100	50	5.0	8.5	13.00	255	215	155	295	190	155	155	230

NB – Data on older and other steel sizes can be found on ASFP website / technical section

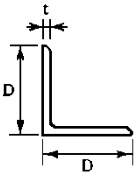
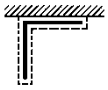
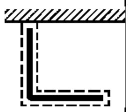
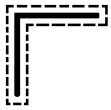
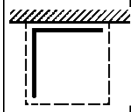
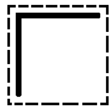
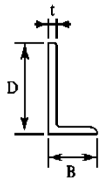
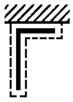
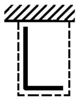
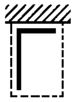
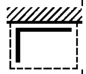
Table A.6 **Equal Angles (UKA)** **Dimensions to** **BS EN 10056-1:1999**				**Section factor A/V (Hp/A)**				
				Profile			**Box**	
				3 sides		**4 sides**	**3 sides**	**4 sides**
								
Size **D x D**	**Thickness** **t**	**Mass per metre**	**Area of Section**					
mm	**mm**	**Kg/m**	**cm^2**	**m^{-1}**	**m^{-1}**	**m^{-1}**	**m^{-1}**	**m^{-1}**
200 x 200	24	71.1	90.6	65	85	85	65	90
	20	59.9	76.3	75	100	105	80	105
	18	54.2	69.1	85	110	115	85	115
	16	48.5	61.8	95	125	125	95	130
150 x 150	18	40.1	51.0	85	110	115	90	120
	15	33.8	43.0	100	135	135	105	140
	12	27.3	34.8	125	165	170	130	170
	10	23.0	29.3	150	195	200	155	205
120 x 120	15	26.6	33.9	105	135	140	105	140
	12	21.6	27.5	125	165	170	130	175
	10	18.2	23.2	150	200	200	155	205
	8	14.7	18.7	185	245	250	190	255
100 x 100	15	21.9	27.9	105	135	140	110	145
	12	17.8	22.7	130	165	170	130	175
	10	15.0	19.2	150	200	205	155	210
	8	12.2	15.5	185	245	250	195	260
90 x 90	12	15.9	20.3	130	165	175	135	175
	10	13.4	17.1	150	200	205	160	210
	8	10.9	13.9	190	245	250	195	260
	7	9.6	12.2	215	280	285	220	295

Table A.7 Unequal Angles (UKA) Dimensions to BS EN 10056-1:1999				Section factor A/V (Hp/A)									
				Profile					Box				
				3 sides				4 sides	3 sides				4 sides
Designation		Mass per metre	Area of section										
Size D x B	Thick ness t												
mm	mm	kg	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}
200 x 150	18	47.1	60.0	115	115	90	80	115	90	85	90	85	115
	15	39.6	50.5	135	135	105	95	135	110	100	110	100	140
	12	32.0	40.8	165	165	130	120	170	135	125	135	125	170
200 x 100	15	33.7	43.0	135	135	115	90	135	115	95	115	95	140
	12	27.3	34.8	165	165	140	110	170	145	115	145	115	170
	10	23.0	29.2	200	200	165	130	200	170	135	170	135	205
150 x 90	15	26.6	33.9	135	135	110	95	140	115	95	115	95	140
	12	21.6	27.5	170	170	140	115	170	140	120	140	120	175
	10	18.2	23.2	200	200	165	140	205	170	145	170	145	205
150 x 75	15	24.8	31.7	135	135	115	90	140	120	95	120	95	140
	12	20.2	25.7	170	170	140	115	170	145	115	145	115	175
	10	17.0	21.7	200	200	170	135	205	175	140	175	140	210
125 x 75	12	17.8	22.7	170	170	140	115	170	145	120	145	120	175
	10	15.0	19.1	200	200	165	140	205	170	145	170	145	210
	8	12.2	15.5	250	250	205	170	250	210	180	210	180	260
100 x 75	12	15.4	19.7	170	170	135	125	175	140	125	140	125	180
	10	13.0	16.6	205	205	160	145	205	165	150	165	150	210
	8	10.6	13.5	250	250	200	180	255	205	185	205	185	260
100 x 65	10	12.3	15.6	205	205	165	140	205	170	145	170	145	210
	8	9.9	12.7	250	250	200	175	255	210	180	210	180	260
	7	8.8	11.2	285	285	230	200	290	235	205	235	205	295

NB – Data on older and other steel sections can be found on ASFP website/technical section

Table A.8

Tees (UKT)
Split from UK Beams

Dimensions to BS4 Part 1:2005

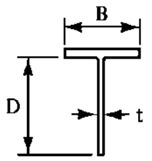
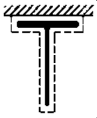
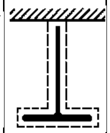
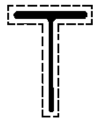
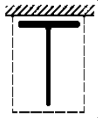
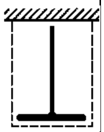
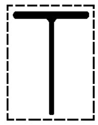
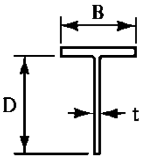
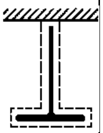
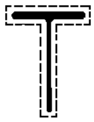
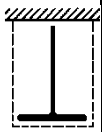
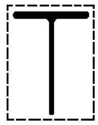
						Section factor A/V (Hp/A)					
						**Profile**			**Box**		
						3 sides		**4 sides**	**3 sides**		**4 sides**
											
Serial size	**Mass per metre**	**Width of section B**	**Depth of section D**	**Web thickness t**	**Area of section**						
mm	**kg**	**mm**	**mm**	**mm**	**cm^2**	**m^{-1}**	**m^{-1}**	**m^{-1}**	**m^{-1}**	**m^{-1}**	**m^{-1}**
254 x 343	62.6	253.0	338.9	11.7	79.73	115	145	145	115	115	150
305 x 305	119.0	311.4	317.9	18.4	152	60	80	80	60	60	85
	89.5	307.1	310.0	14.1	114.03	80	105	105	80	80	110
	74.6	304.8	306.1	11.8	95.01	95	125	125	95	95	130
229 x 305	69.9	230.2	308.5	13.1	89.08	95	120	120	95	95	120
	62.5	229.0	306.0	11.9	79.66	105	130	135	105	105	135
	56.5	228.2	303.7	11.1	71.96	115	145	145	115	115	150
	50.6	227.6	301.2	10.5	64.45	125	160	160	130	130	165
178 x 305	50.1	179.2	303.7	11.3	63.9	120	150	150	125	125	150
	46.1	178.8	301.5	10.9	58.7	130	160	160	135	135	165
	40.9	177.9	299.3	10.0	52.1	145	180	180	150	150	185
312 x 267	136.7	320.2	288.8	21.1	174	50	70	70	50	50	70
	109.4	317.4	280.4	18.3	139	60	85	85	65	65	85
	90.7	314.5	275.6	15.2	116	75	100	100	75	75	100
	75.3	312.0	271.5	12.7	95.9	90	120	120	90	120	120
210 x 267	69.1	213.9	274.5	14.7	23.6	85	110	110	85	85	110
	61.0	211.9	272.2	12.7	77.69	95	120	125	95	95	125
	54.5	210.8	269.7	11.6	69.43	105	135	135	110	110	140
	50.5	210.0	268.3	10.8	64.33	115	145	145	115	115	150
	46.0	209.3	266.5	10.1	58.68	125	160	160	125	125	160
	41.1	208.8	264.1	9.6	52.34	140	175	180	140	140	180
165 x 267	42.3	166.5	267.1	10.3	54.0	130	155	160	130	130	160
	37.4	165.9	264.5	9.7	47.6	145	175	180	145	145	180
	32.8	165.1	262.4	8.9	41.9	160	200	200	165	165	205
191 x 229	80.7	199.4	246.0	18.0	103	65	85	85	65	65	85
	66.6	196.7	240.3	15.3	84.9	80	100	100	80	80	105
	52.9	194.0	234.6	12.6	67.4	95	125	125	100	100	125
	49.1	192.8	233.5	11.4	62.62	105	135	135	105	105	135
	44.6	191.9	231.6	10.5	58.87	115	145	145	115	115	150
	41.0	191.3	229.9	9.9	52.23	125	160	160	125	125	160
	37.1	190.4	228.4	9.0	47.31	135	175	175	135	135	175
	33.5	189.9	226.6	8.5	42.75	150	190	195	150	150	195
152 x 229	41.0	155.3	232.8	10.5	52.26	115	145	145	120	120	150
	37.1	154.4	230.9	9.6	47.23	130	160	160	130	130	165
	33.6	153.8	228.9	9.0	42.77	140	175	175	145	145	180

Table A.8 Tees (UKT) Split from UK Beams Dimensions to BS4 Part 1:2005						Section factor A/V (Hp/A)					
						Profile			Box		
						3 sides		4 sides	3 sides		4 sides
											
Serial size	Mass per metre	Width of section B	Depth of section D	Web thickness t	Area of section						
mm	kg	mm	mm	mm	cm^2	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}	m^{-1}
152 x 229	29.9	152.9	227.2	8.1	38.11	155	195	195	160	160	200
	26.1	152.4	224.8	7.6	33.31	180	220	225	180	180	225
178 x 203	42.6	181.9	208.6	10.9	54.3	110	140	140	110	110	145
	37.1	179.5	206.3	9.5	47.24	125	160	160	125	125	165
	33.5	178.8	204.6	8.8	42.76	135	175	175	140	140	180
	30.0	177.9	203.1	7.9	38.25	150	195	195	155	155	200
	27.0	177.7	201.2	7.7	34.47	165	215	215	170	170	220
140 x 203	26.6	143.3	203.3	7.9	34.0	160	200	200	160	160	205
	23.0	142.2	201.5	6.8	29.31	185	230	230	185	185	235
	19.5	141.8	198.9	6.4	24.82	215	270	270	215	215	275
171 x 178	33.5	173.2	181.6	9.1	42.74	125	160	165	125	125	165
	28.5	172.2	178.9	8.1	36.27	145	190	190	145	145	195
	25.5	171.5	177.4	7.4	32.44	160	210	210	160	160	215
	22.5	171.1	175.6	7.0	28.66	180	235	240	180	180	240
127 x 178	19.5	126.0	176.6	6.6	24.88	190	235	240	195	195	245
	16.5	125.4	174.4	6.0	21.06	220	280	280	225	225	285
165 x 152	27.0	166.9	155.1	7.9	34.38	135	185	185	140	140	185
	23.0	165.7	153.2	6.7	29.37	160	210	215	160	160	215
	20.1	165.0	151.6	6.0	25.65	180	240	245	185	185	245
127 x 152	24.0	125.3	155.4	9.0	30.61	140	180	180	140	140	185
	20.9	124.3	153.5	8.0	26.69	160	200	205	160	160	210
	18.5	123.4	152.1	7.1	23.58	180	225	230	180	180	235
102 x 152	16.4	102.4	156.3	6.6	20.91	195	240	245	200	200	245
	14.1	101.8	154.3	6.0	17.93	225	280	280	230	230	285
	12.4	101.6	152.5	5.8	15.80	255	315	320	255	255	320
146 x 127	21.5	147.3	129.7	7.2	27.38	145	195	200	150	150	200
	18.5	146.4	127.9	6.3	23.58	170	225	230	170	170	235
	15.5	146.1	125.6	6.0	19.83	195	270	270	200	200	275
102 x 127	14.1	102.2	130.1	6.3	18.03	195	250	255	200	200	260
	12.6	101.9	128.5	6.0	16.01	220	280	285	225	225	290
	11.0	101.6	126.9	5.7	14.00	250	320	320	255	255	325
133 x 102	15.0	133.9	103.3	6.4	19.10	175	240	245	180	180	250
	12.5	133.2	101.5	5.7	15.98	205	285	290	210	210	295

NB – Data on older and other steel sections can be found on ASFP website/technical section

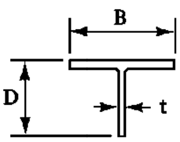
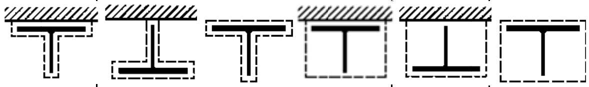
TABLE A.9 Structural Tees Split from UK Columns Dimensions to BS4 Part 1:2006						Section factor A/V (Hp/A)					
						Profile			Box		
						3 sides		4 sides	3 sides		4 sides
											
Serial size	Mass per metre	Width of section B	Depth of section D	Web thick ness t	Area of section						
mm	kg	mm	mm	mm	cm^2	m-1	m-1	m-1	m-1	m-1	m-1
305 x 152	79.0	311.2	163.5	15.8	100.67	60	90	95	65	65	95
	68.4	309.2	160.2	13.8	87.20	70	105	105	70	70	110
	58.9	307.4	157.2	12.0	75.10	80	120	120	85	85	125
	48.4	305.3	153.9	9.9	61.72	95	145	145	100	100	150
254 x 127	83.5	265.2	1144.5	19.2	106	50	75	75	50	50	75
	66.0	261.3	138.1	15.3	84.06	65	90	95	65	65	95
	53.5	258.8	133.3	12.8	68.18	75	110	115	75	75	115
	44.4	256.3	130.1	10.3	56.65	90	135	135	90	90	135
	36.5	254.6	127.0	8.6	46.55	105	160	160	110	110	165
203 x 102	63.7	213.9	120.7	18.1	81.2	55	80	80	55	55	80
	56.7	212.1	117.5	16.3	72.3	60	90	90	60	60	90
	49.8	210.3	114.3	14.5	63.4	70	100	100	70	70	100
	43.0	209.1	111.0	12.7	54.81	75	115	115	80	80	115
	35.5	206.4	107.8	10.0	45.20	90	135	135	95	95	140
	30.0	205.8	104.7	9.4	38.18	105	160	160	110	110	165
	26.0	204.3	103.0	7.9	33.13	120	180	185	125	125	185
	23.0	203.6	101.5	7.2	29.36	135	200	205	140	140	210
152 x 76	25.6	157.4	85.1	11.0	32.6	100	145	145	100	100	150
	22.0	155.9	83.0	9.5	28.0	110	165	170	115	115	170
	18.5	154.4	80.8	8.0	23.55	130	195	195	135	135	200
	15.0	152.9	78.7	6.5	19.12	160	235	240	160	180	240
	11.5	152.2	76.1	5.8	14.62	205	305	310	210	210	310

Table A.10

Circular Hollow Sections

Dimensions to EN 10210 S355J2H

Outside diameter	Wall thickness t	Mass per metre	Area of section a	Section factor A/V (Hp/A) Profile	Section factor A/V (Hp/A) Box
mm	mm	Kg/m	cm^2	m^{-1}	m^{-1}
21.3	2.6	1.20	1.53	440	440
	2.9	1.32	1.68	400	400
	3.2	1.43	1.82	370	370
26.9	2.6	1.56	1.98	425	425
	2.9	1.72	2.19	385	385
	3.2	1.87	2.38	355	355
33.7	2.6	1.99	2.54	415	415
	2.9	2.20	2.81	375	375
	3.2	2.41	3.07	345	345
	3.6	2.67	3.40	310	310
	4.0	2.93	3.73	285	285
42.4	2.6	2.55	3.25	410	410
	2.9	2.82	3.60	370	370
	3.2	3.09	3.94	340	340
	3.6	3.44	4.39	305	305
	4.0	3.79	4.83	275	275
	5.0	4.61	5.87	230	230
48.3	2.9	3.25	4.14	365	365
	3.2	3.56	4.53	335	335
	3.6	3.97	5.06	300	300
	4.0	4.37	5.57	270	270
	5.0	5.34	6.80	225	225
60.3	2.9	4.11	5.23	360	360
	3.2	4.51	5.74	330	330
	3.6	5.03	6.41	295	295
	4.0	5.55	7.07	270	270
	5.0	6.82	8.69	220	220
76.1	2.9	5.24	6.67	358	358
	3.2	5.75	7.33	325	325
	3.6	6.44	8.20	290	290
	4.0	7.11	9.06	265	265
	5.0	8.77	11.2	215	215
	6.3	10.80	13.8	175	175
88.9	2.9	6.15	7.84	355	355
	3.2	6.76	8.62	325	325
	3.6	7.57	9.65	290	290
	4.0	8.38	10.7	260	260
	5.0	10.3	13.2	210	210
	6.3	12.8	16.3	170	170
table continued overleaf					
114.3	3.2	8.77	11.2	320	320
	3.6	9.83	12.5	285	285

Table A.11

Square Hollow Sections

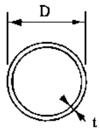
Dimensions to EN 10210 S355J2H

Designation Size D x D	Wall thickness t	Mass per metre	Area of section a	Section factor A/V (Hp/A) 3 sides	Section factor A/V (Hp/A) 4 sides
mm	mm	Kg/m	cm^2	m^{-1}	m^{-1}
40 x 40	3.0	3.41	4.34	275	370
	3.2	3.61	4.60	260	350
	3.6	4.01	5.10	235	315
	4.0	4.39	5.59	215	290
	5.0	5.28	6.73	180	240
50 x 50	3.0	4.35	5.54	270	365
	3.2	4.62	5.88	255	340
	3.6	5.14	6.54	230	305
	4.0	5.64	7.19	210	280
	5.0	6.85	8.73	175	230
	6.3	8.31	10.6	140	190
60 x 60	3.0	5.29	6.74	270	360
	3.2	5.62	7.16	250	335
	3.6	6.27	7.98	225	300
	4.0	6.90	8.79	205	275
	5.0	8.42	10.7	170	225
	6.3	10.3	13.1	140	185
	8.0	12.5	16.0	115	150
70 x 70	3.0	6.24	7.94	265	355
	3.2	6.63	8.44	250	335
	3.6	7.40	9.42	225	300
	4.0	8.15	10.4	205	270
	5.0	9.99	12.7	165	220
	6.3	12.3	15.6	135	180
	8.0	15.0	19.2	110	145
80 x 80	3.0	7.18	9.14	265	350
	3.2	7.63	9.72	250	330
	3.6	8.53	10.9	220	295
	4.0	9.41	12.0	200	270
	5.0	11.6	14.7	165	220
	6.3	14.2	18.1	135	180
	8.0	17.5	22.4	110	145
90 x 90	3.6	9.66	12.3	220	295
	4.0	10.7	13.6	200	265
	5.0	13.1	16.7	160	215
	6.3	16.2	20.7	130	175
	8.0	20.1	25.6	105	140
100 x 100	3.6	10.8	13.7	220	295
	4.0	11.9	15.2	200	265
table continued overleaf					
100 x 100	5.0	14.7	18.7	160	215
	6.3	18.2	23.2	130	175

Table A.10

Circular Hollow Sections

Dimensions to EN 10210 S355J2H

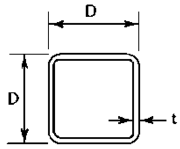


Outside diameter	Wall thickness t	Mass per metre	Area of section a	Section factor A/V (Hp/A) Profile 	Section factor A/V (Hp/A) Box 
mm	mm	Kg/m	cm^2	m^{-1}	m^{-1}
114.3	4.0	10.9	13.9	260	260
	5.0	13.5	17.2	210	210
	6.3	16.8	21.4	170	170
139.7	3.2	10.8	13.7	320	320
	3.6	12.1	15.4	285	285
	4.0	13.4	17.1	255	255
	5.0	16.6	21.2	205	205
	6.3	20.7	26.4	165	165
	8.0	26.0	33.1	135	135
	10.0	32.0	40.7	110	110
168.3	5.0	20.1	25.7	205	205
	6.3	25.2	32.1	165	165
	8.0	31.6	40.3	130	130
	10.0	39.0	49.7	105	105
	12.5	48.0	61.2	85	85
193.7	5.0	23.3	29.6	205	205
	6.3	29.1	37.1	165	165
	8.0	36.6	46.7	130	130
	10.0	45.3	57.7	105	105
	12.5	55.9	71.2	85	85
219.1	5.0	26.4	33.6	205	205
	6.3	33.1	42.1	165	165
	8.0	41.6	53.1	130	130
	10.0	51.6	65.7	105	105
	12.5	63.7	81.1	85	85
	14.2	71.8	91.4	75	75
	16.0	80.1	102	65	65
244.5	5.0	29.5	37.6	205	205
	6.3	37.0	47.1	165	165
	8.0	46.7	59.4	130	130
	10.0	57.8	73.7	105	105
	12.5	71.5	91.1	85	85
	14.2	80.6	103	75	75
	16.0	90.2	115	65	65
273	5.0	33.0	42.1	205	205
	6.3	41.4	52.8	160	160
	8.0	52.3	66.6	130	130
	10.0	64.9	82.6	105	105
table continued overleaf					
273	12.5	80.3	102	85	85
	14.2	90.6	115	75	75
	16.0	101	129	65	65

Table A.11

Square Hollow Sections

Dimensions to EN 10210 S355J2H



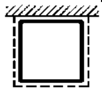
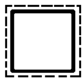
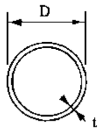
Designation Size D x D	Wall thickness t	Mass per metre	Area of section a	Section factor A/V (Hp/A) 3 sides 	Section factor A/V (Hp/A) 4 sides 
mm	mm	Kg/m	cm^2	m^{-1}	m^{-1}
100 x 100	8.0	22.6	28.8	104	140
	10.0	27.4	34.9	90	115
120 x 120	4.0	14.4	18.4	195	260
	5.0	17.8	22.7	160	215
	6.3	22.2	28.2	130	170
	8.0	27.6	35.2	105	140
	10.0	33.7	42.9	85	115
	12.5	40.9	52.1	70	95
140x 140	5.0	21.0	26.7	160	210
	6.3	26.1	33.3	130	170
	8.0	32.6	41.6	100	135
	10.0	40.0	50.9	85	110
	12.5	48.7	62.1	70	90
150 x 150	5.0	22.6	28.7	160	210
	6.3	28.1	35.8	125	170
	8.0	35.1	44.8	100	135
	10.0	43.1	54.9	85	110
	12.5	52.7	67.1	70	90
	16.00	65.2	83.0	55	75
160 x 160	5.0	24.1	30.7	160	210
	6.3	30.1	38.3	125	170
	8.0	37.6	48.0	100	135
	10.0	46.3	58.9	85	110
	12.5	56.6	72.1	70	90
	14.2	63.3	80.7	60	80
	16.0	70.2	89.4	55	75
180 x 180	5.0	27.3	34.7	155	210
	6.3	34.0	43.3	125	170
	8.0	42.7	54.4	100	135
	10.0	52.5	66.9	80	110
	12.5	64.4	82.1	65	90
	14.2	72.2	92.0	60	80
	16.0	80.2	102	55	70
200 x 200	5.0	30.4	38.7	155	210
	6.3	38.0	48.4	125	165
	8.0	47.7	60.8	100	135
	10.0	58.8	74.9	85	110
	12.5	72.3	92.1	65	90
table continued overleaf					
200 x 200	14.2	81.1	103	60	80
	16.0	90.3	115	55	70
250 x	5.0	38.3	48.7	155	205

Table A.10

Circular Hollow Sections

Dimensions to EN 10210 S355J2H

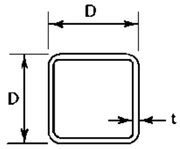


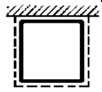
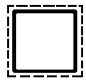
Outside diameter	Wall thickness t	Mass per metre	Area of section a	Section factor A/V (Hp/A) Profile 	Section factor A/V (Hp/A) Box 
mm	mm	Kg/m	cm^2	m^{-1}	m^{-1}
323.9	5.0	39.3	50.1	205	205
323.9	6.3	49.3	62.9	160	160
	8.0	62.3	79.4	130	130
	10.0	77.4	98.6	105	105
	12.5	96.0	122	85	85
	14.2	108	138	75	75
	16.0	121	155	65	65
355.6	6.3	54.3	69.1	160	160
	8.0	68.6	87.4	130	130
	10.0	85.2	109	100	100
	12.5	106	135	85	85
	14.2	120	152	75	75
	16.0	134	171	65	65
406.4	6.3	62.2	79.2	160	160
	8.0	78.6	100	130	130
	10.0	97.8	125	100	100
	12.5	121	155	80	80
	14.2	137	175	75	75
	16.0	154	196	65	65
457	6.3	70.0	89.2	160	160
	8.0	88.6	113	130	130
	10.0	110	140	105	105
	12.5	137	175	80	80
	14.2	155	198	75	75
	16.0	174	222	65	65
508.0	6.3	77.9	99.3	160	160
	8.0	98.6	126	125	125
	10.0	123	156	100	100
	12.5	153	195	80	80
	14.2	173	220	75	75
	16.0	194	247	65	65

Table A.11

Square Hollow Sections

Dimensions to EN 10210 S355J2H



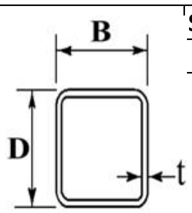
Designation Size D x D	Designation Wall thickness t	Mass per metre	Area of section a	Section factor A/V (Hp/A) 3 sides 	Section factor A/V (Hp/A) 4 sides 
mm	mm	Kg/m	cm^2	m^{-1}	m^{-1}
250	6.3	47.9	61.0	125	165
250 x 250	8.0	60.3	76.8	100	130
	10.0	74.5	94.9	80	105
	12.5	91.9	117	65	85
	14.2	103	132	60	75
	16.0	115	147	55	70
260 x 260	6.3	49.9	63.5	125	165
	8.0	62.8	80.0	100	130
	10.0	77.7	98.9	80	105
	12.5	95.8	122	65	85
	14.2	108	137	60	75
	16.0	120	153	55	70
300 x 300	6.3	57.8	73.6	125	165
	8.0	72.8	92.8	100	130
	10.0	90.2	115	80	105
	12.5	112	142	65	85
	14.2	126	160	60	75
	16.0	141	179	50	70
350 x 350	8.0	85.4	109	100	130
	10.0	106	135	80	105
	12.5	131	167	65	85
	14.2	148	189	55	75
	16.0	166	211	50	70
400 x 400	8.0	97.9	125	100	130
	10.0	122	155	80	105
	12.5	151	192	65	85
	14.2	170	217	55	75
	16.0	191	243	50	70
	20.0	235	300	40	55

NB – Data on older and other steel sections can be found on ASFP website/technical section

Table A.12

Rectangular Hollow Sections

Dimensions to EN 10210 S355J2H



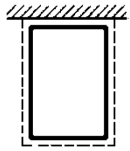
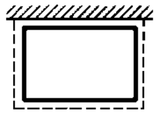
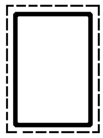
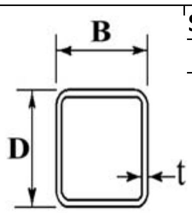
Designation		Mass per metre	Area of the section	Section factor A/V (Hp/A)		
				3 sides		4 sides
						
Size D x B	Thickness t					
mm	mm	Kg	cm^2	m^{-1}	m^{-1}	m^{-1}
50 x 30	3.0	3.41	4.34	300	255	370
	3.2	3.61	4.60	285	240	350
	3.6	4.01	5.10	255	215	315
	4.0	4.39	5.59	235	200	290
	5.0	5.28	6.73	195	165	240
60 x 40	3.0	4.35	5.54	290	255	365
	3.2	4.62	5.88	275	240	340
	3.6	5.14	6.54	245	215	305
	4.0	5.64	7.19	225	195	280
	5.0	6.85	8.73	185	160	230
	6.3	8.31	10.6	150	135	190
80 x 40	3.0	5.29	6.74	300	240	360
	3.2	5.62	7.16	280	225	335
	3.6	6.27	7.98	250	200	300
	4.0	6.90	8.79	230	185	275
	5.0	8.42	10.7	190	150	225
	6.3	10.3	13.1	155	125	185
	8.0	12.5	16.0	125	100	150
90 x 50	3.0	6.24	7.94	290	240	355
	3.2	6.63	8.44	275	225	335
	3.6	7.40	9.42	245	205	300
	4.0	8.15	10.4	225	185	270
	5.0	9.99	12.7	185	150	220
	6.3	12.3	15.6	150	125	180
	8.0	15.0	19.2	120	100	150
100 x 50	3.0	6.71	8.54	295	235	355
	3.2	7.13	9.08	275	220	330
	3.6	7.96	10.1	250	200	300
	4.0	8.78	11.2	225	180	270
	5.0	10.8	13.7	185	150	220
	6.3	13.3	16.9	150	120	180
	8.0	16.3	20.8	120	100	145
	10.0	19.6	24.9	100	80	120
100 x 60	3.0	7.18	9.14	285	240	350
	3.2	7.63	9.72	270	230	330
	3.6	8.53	10.9	240	205	295
	4.0	9.41	12.0	220	185	270
	5.0	11.6	14.7	180	150	220
	6.3	14.2	18.1	145	125	180
	8.0	17.5	22.4	120	100	145
120 x 60	3.6	9.66	12.3	245	195	300
	4.0	10.7	13.6	220	180	265
	5.0	13.1	16.7	180	145	215
	6.3	16.2	20.7	145	120	175
	8.0	20.1	25.6	120	95	140

Table A.12

Rectangular Hollow Sections

Dimensions to EN 10210 S355J2H



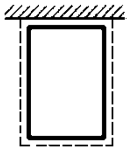
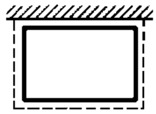
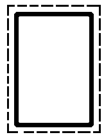
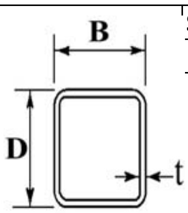
Designation		Mass per metre	Area of the section	Section factor A/V (Hp/A) 3 sides		4 sides
						
Size D x B	Thickness t					
mm	mm	Kg	cm^2	m^{-1}	m^{-1}	m^{-1}
	10.0	24.3	30.9	100	80	120
120 x 80	3.6	10.8	13.7	235	205	295
	4.0	11.9	15.2	210	185	265
	5.0	14.7	18.7	175	150	215
	6.3	18.2	23.2	140	120	175
	8.0	22.6	28.8	115	100	140
	10.0	27.4	34.9	95	80	115
150 x 100	4.0	15.1	19.2	210	185	260
	5.0	18.6	23.7	170	150	215
	6.3	23.1	29.5	135	120	170
	8.0	28.9	36.8	110	95	135
	10.0	35.3	44.9	90	80	115
	12.5	42.8	54.6	75	65	95
150 x 125	4.0	16.6	21.2	200	190	260
	5.0	20.6	26.2	165	155	210
	6.3	25.6	32.6	130	125	170
	8.0	32.0	40.8	105	100	135
	10.0	39.2	49.9	85	80	110
	12.5	47.7	60.8	70	70	90
160 x 80	4.0	14.4	18.4	220	175	260
	5.0	17.8	22.7	180	145	215
	6.3	22.2	28.2	145	115	170
	8.0	27.6	35.2	115	95	140
	10.0	33.7	42.9	95	75	115
	12.5	40.9	52.1	80	65	95
200 x 100	5.0	22.6	28.7	175	140	210
	6.3	28.1	35.8	140	115	170
	8.0	35.1	44.8	110	90	135
	10.0	43.1	54.9	95	75	110
	12.5	52.7	67.1	75	60	90
	16.0	65.2	83.0	60	50	75
200 x 120	5.0	24.1	30.7	170	145	210
	6.3	30.1	38.3	140	115	170
	8.0	37.6	48.0	110	95	135
	10.0	46.3	58.9	90	75	110
	12.5	56.6	72.1	75	65	90
	14.2	63.3	80.7	65	55	80
	16.0	70.2	89.4	60	50	75
200 x 150	5.0	26.5	33.7	165	150	210
	6.3	33.0	42.1	135	120	170
	8.0	41.4	52.8	105	95	135
	10.0	51.0	64.9	80	80	110
	12.5	62.5	79.6	70	65	90
	14.2	70.0	89.2	65	60	80
	16.0	77.7	99.0	55	55	70

Table A.12

Rectangular Hollow Sections

Dimensions to EN 10210 S355J2H



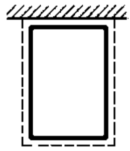
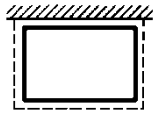
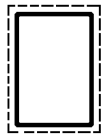
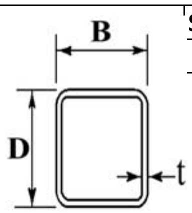
Designation		**Mass per metre**	**Area of the section**	**Section factor A/V (Hp/A)**		
				3 sides		**4 sides**
						
Size D x B	**Thickness t**					
mm	**mm**	**Kg**	**cm^2**	**m^{-1}**	**m^{-1}**	**m^{-1}**
250 x 100	5.0	26.5	33.7	180	135	210
	6.3	33.0	42.1	145	110	170
	8.0	41.4	52.8	115	85	135
	10.0	51.0	64.9	95	70	110
	12.5	62.5	79.6	75	60	90
	14.2	70.0	89.2	70	50	80
	16.0	77.7	99.0	65	45	70
250 x 150	5.0	30.4	38.7	170	145	210
	6.3	38.0	48.4	135	115	165
	8.0	47.7	60.8	110	90	135
	10.0	58.8	74.9	90	75	110
250 x 150	12.5	72.3	92.1	75	60	90
	14.2	81.1	103	65	55	80
	16.0	90.3	115	60	50	70
250 x 200	10.0	66.7	84.9	85	80	110
	12.5	82.1	105	70	65	90
	14.2	92.3	118	60	55	80
260 x 140	5.0	30.4	38.7	170	140	210
	6.3	38.0	48.4	140	115	165
	8.0	47.7	60.8	110	90	135
	10.0	58.8	74.9	90	75	110
	12.5	72.3	92.1	75	60	90
	14.2	81.1	103	65	55	80
	16.0	90.3	115	60	50	70
300 x 100	5.0	30.4	38.7	180	130	210
	6.3	38.0	48.4	145	105	165
	8.0	47.7	60.8	115	85	135
	10.0	58.8	74.9	95	70	110
	12.5	72.3	92.1	80	55	90
	14.2	81.1	103	70	50	80
	16.0	90.3	115	65	45	70
300 x 150	8.0	54.0	68.8	110	90	130
	10.0	66.7	84.9	90	70	110
	12.5	82.1	105	75	60	90
	14.2	92.3	118	65	55	80
	16.0	103	131	60	50	70
300 x 200	5.0	38.3	48.7	165	145	205
	6.3	47.9	61.0	135	115	165
	8.0	60.3	76.8	105	95	130
	10.0	74.5	94.9	85	75	105
	12.5	91.9	117	70	60	85
	14.2	103	132	60	55	75
	16.0	115	147	55	50	70
300 x 250	6.3	52.8	67.3	130	120	165
	8.0	66.5	84.8	100	95	130

Table A.12

Rectangular Hollow Sections

Dimensions to EN 10210 S355J2H



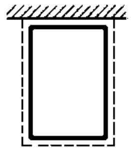
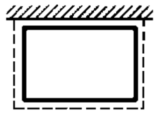
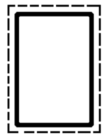
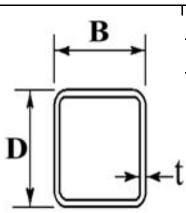
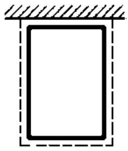
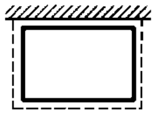
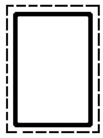
Designation		Mass per metre	Area of the section	Section factor A/V (Hp/A) 3 sides		Section factor A/V (Hp/A) 4 sides
Size D x B	Thickness t					
mm	mm	Kg	cm^2	m^{-1}	m^{-1}	m^{-1}
	10.0	82.4	105	85	80	105
	12.5	102	130	65	65	85
	14.2	115	146	60	55	75
	16.0	128	163	55	50	70
350 x 150	6.3	47.9	61.0	140	110	165
	8.0	60.3	76.8	110	85	130
	10.0	74.5	94.9	90	70	105
	12.5	91.9	117	75	55	85
	14.2	103	132	65	50	75
	16.0	115	147	60	45	70
350 x 250	6.3	57.8	73.6	130	115	165
	8.0	72.8	92.8	105	95	130
	10.0	90.2	115	85	75	105
350 x 250	12.5	112	142	70	60	85
	14.2	126	160	60	55	75
	16.0	141	179	55	50	70
400 x 120	6.3	49.9	63.5	145	100	165
400 x 120	8.0	62.8	80.0	115	80	130
	10.0	77.7	98.9	95	65	105
	12.5	95.8	122	75	55	85
	14.2	108	137	70	50	80
	16.0	120	153	65	45	70
400 x 150	6.3	52.8	67.3	145	105	165
	8.0	66.5	84.8	115	85	130
	10.0	82.4	105	90	70	105
	12.5	102	130	75	55	85
	14.2	115	146	65	50	75
	16.0	128	163	60	45	70
400 x 200	6.3	57.8	73.6	140	110	165
	8.0	72.8	92.8	110	90	130
	10.0	90.2	115	90	70	105
	12.5	112	142	70	60	85
	14.2	126	160	65	50	75
	16.0	141	179	60	45	70
400 x 300	8.0	85.4	109	105	95	130
	10.0	106	135	85	75	105
	12.5	131	167	70	60	85
	14.2	148	189	60	55	75
	16.0	166	211	55	50	70
450 x 250	8.0	85.4	109	105	90	130
	10.0	106	135	85	70	105
	12.5	131	167	70	60	85
	14.2	148	189	65	50	75
	16.0	166	211	55	45	70
500 x 200	8.0	85.4	109	110	85	130

Table A.12 **Rectangular Hollow Sections** **Dimensions to EN 10210 S355J2H**				**Section factor A/V (Hp/A)**		
				3 sides		**4 sides**
						
Designation		**Mass per metre**	**Area of the section**			
Size D x B	**Thickness t**					
mm	**mm**	**Kg**	**cm^2**	**m^{-1}**	**m^{-1}**	**m^{-1}**
	10.0	106	135	90	70	105
	12.5	131	167	75	55	85
	14.2	148	189	65	50	75
	16.0	166	211	60	45	70
500 x 300	8.0	97.9	125	105	90	130
	10.0	122	155	85	75	105
	12.5	151	192	70	60	85
	14.2	170	217	60	50	75
	16.0	191	243	55	45	70
	20.0	235	300	45	40	55

NB – Data on older and other steel sections can be found on ASFP website/technical section

Table A.13
CASTELLATED SECTIONS

Castellated Universal Beams			Castellated Universal Beams (continued)			Castellated Universal Columns		
Serial size		Mass per metre	Serial size		Mass per metre	Serial size		Mass per metre
Original	Castellated		Original	Castellated		Original	Castellated	
mm	mm	kg	mm	mm	kg	mm	mm	kg
914 x 419	1371 x 419	388	457 x 152	686 x 152	82	356 x 406	546 x 406	634
		343			74			551
914 x 305	1371 x 305	289			67			467
		253			60			393
		224			52			340
		201	406 x 178	609 x 178	74			287
838 x 292	1257 x 292	226			67			235
		194			60	356 x 368	534 x 368	202
		176			54			177
762 x 267	1143 x 267	197	406 x 140	609 x 140	46			153
		173			39			129
		147	356 x 171	534 x 171	67	305 x 305	458 x 305	283
686 x 254	1029 x 254	170			57			240
		152			51			198
		140			45			158
		125	356 x 127	534 x 127	39			137
610 x 305	915 x 305	238			33			118
		179	305 x 165	458 x 165	54			97
		149			46	254 x 254	381 x 254	167
610 x 229	915 x 229	140			40			132
		125	305 x 127	458 x 127	48			107
		113			42			89
		101			37			73
533 x 210	800 x 210	122	305 x 102	458 x 102	33	203 x 203	305 x 203	86
		109			28			71
		101			25			60
		92	254 x 146	381 x 146	43			52
		82			37			46
457 x 191	686 x 191	98			31	152 x 152	228 x 152	37
		89	254 x 102	381 x 102	28			30
		82			25			23
		74			22			
		67	203 x 133	305 x 133	30			
					25			

Annex 5 – Bibliography and References

ASSOCIATION FOR SPECIALIST FIRE PROTECTION www.asfp.org.uk

TGD 8	Code of practice for junctions between different fire protection systems (structural steel elements)
TGD 11	Code of practice for the specification and on-site installation of intumescent coatings for the fire protection of structural steelwork
TGD 13	Code of practice for over cladding reactive coatings
TGD 14	Code of practice for the installation and inspection of board systems for the fire protection of structural steelwork
TGD 15	Code of practice for the installation and inspection of sprayed non-reactive coatings for the fire protection of structural steelwork
TGD 16	Code of Practice for off-site applied intumescent coatings

BRITISH STANDARDS INSTITUTION www.bsi-global.com

BS 449-2: 1996	Structural steel in buildings: 1996 Metric units
BS 476:	Fire tests on building materials and structures
BS 476-20: 1987	Method for determination of the fire resistnce of load bearing elements of construction (general principles)
BS 476-21: 1987	Method for determination of the fire resistance of load bearing elements of construction
BS 476-23: 1987	Methods for determination of the fire resistance of the contribution of components to the fire resistance of a structure
BS 5950	The stuctural use of steelwork in buildings
BS 5950-8: 2003	Structural use of steelwork in buildings – Part 8; Code of Practice for fire resistant design

BSI/ EUROPEAN STANDARDS www.bsi-global.com

BS EN 1363-1:2012	Fire resistance tests - Part 1: General requirements
BS EN 1991:	Actions on Structures. General actions - Part 1.2 Actions on structures exposed to fire
BS EN 1993:	Design of steel structures. General rules - Part 1.2 Structural fire design
BS EN 1994:	Design of composite steel and concrete structures. General rules - Part 1.2 Structural fire design.
BS EN 13501-2: 2003	Fire classification of construction products and building elements: Classification using data from fire resistance tests, excluding ventilation services
EN 13381-4: 2013	Test methods for determining the contribution to the fire resistance of structural members: Part 4: Applied passive protection to steel members
EN 13381-8: 2013	Test methods for determining the contribution to the fire resistance of structural members: Part 8: Applied reactive protection to steel members
prEN 13381-9: 2013	Test methods for determining the contribution to the fire resistance of structural members: Part 9: Applied fire protection systems to steel beams with web openings
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ETAG 018-1	Fire protective products: Part 1: General
ETAG 018-2	Fire protective products: Part 2: Reactive coatings for fire protection of steel elements
ETAG 018-3:	Fire protective products: Part 3: Renderings and rendering kits intended for fire resisting applications
ETAG 018-4:	Fire protective products: Part 4: Fire protective board, slab and mat products and kits

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Commission Decision (Fire Resistance)	2000/367/EC of 3rd May 2000

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Construction [Design and Management] Regulations 2007 : Managing health and safety in construction

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The Building Regulations [Northern Ireland] 2012
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STEEL CONSTRUCTION INSTITUTE [SCI] www.steel-sci.org

SCI P109: 1991	The fire resistance of composite beams –Lawson R.M and Newman G.M
SCI P109: 2nd Edition	The fire resistance of composite floors with steel decking [2nd Edition] – Newman GM
SCI RT 1356v08: 2013	Fire design of composite beams with rectangular and circular web openings

SCOTLAND www.infoscotland.com/firelaw
The Building (Scotland) Regulations 2006
Technical Handbook 2013 for domestic and non-domestic buildings http://www.scotland.gov.uk/Topics/Built-Environment/Building/Building-standards

THE FIRE TEST STUDY GROUP [UK] [FTSG] www.ftsg.co.uk

UKAS www.ukas.com
The United Kingdom Accreditation Service

Reports referenced for limiting temperatures in Annex 3.2

1. Report on the effect of Eurocodes on steel temperatures for fire protection assessments – Document GR1029 version 11 – July 2013
2. Limiting temperatures according to Eurocodes – Professor Yong Wang, University of Manchester – August 2013