BS ISO 834-11:2014

BSI Standards Publication

Fire resistance tests — Elements of building construction

Part 11: Specific requirements for the assessment of fire protection to structural steel elements

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National foreword

This British Standard is the UK implementation of ISO 834-11:2014.

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A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

ISO 834 consists of the following parts, under the general title *Fire resistance tests — Elements of building construction*:

— *Part 1: General requirements*

— *Part 2: Guidance on measuring uniformity of furnace exposure on test samples* [Technical Report]

— *Part 3: Commentary on test method and guide to the application of the outputs from the fire-resistance test* [Technical Report]

— *Part 4: Specific requirements for loadbearing vertical separating elements*

— *Part 5: Specific requirements for loadbearing horizontal separating elements*

— *Part 6: Specific requirements for beams*

— *Part 7: Specific requirements for columns*

— *Part 8: Specific requirements for non-loadbearing vertical separating elements*

— *Part 9: Specific requirements for non-loadbearing ceiling elements*

— *Part 10: Specific requirements to determine the contribution of applied fire protection materials to structural steel elements*

— *Part 11: Specific requirements for the assessment of fire protection to structural steel elements*

— *Part 12: Specific requirements for separating elements evaluated on less than full scale furnaces*

Introduction

Technological advances in the fire protection of structural steelwork have resulted in a range of materials being developed that are now in widespread use throughout the building construction industry. These are broadly categorized as intumescent coatings, sprays, renders, and boards and are often referred to as lightweight systems in comparison to the some of the more traditional materials such as brick, block, and concrete.

Fire protection materials reduce the rate of temperature rise of steel members when exposed to fire by a variety of methods. Apart from influencing heat transfer mechanism, such as conduction, convection, and radiation, they often involve thermo-physical transformations, exothermic chemical reactions, as well as shape changes that increase the thickness of the material and delay the rate at which the underlying steel substrate heats up. Relatively simple changes such as the release of free moisture at around 100 °C, or water of crystallization and sublimation, which all occur within specific temperature ranges, often result in a plateau of rising temperature versus time of varying magnitude depending upon the type of material and even the way in which it is applied to the steel substrate.

Understanding the behaviour of fire protection materials is complicated, not least when the physical/chemical reactions and changes in thermal properties occur at different temperatures and at different rates, depending on their chemical constitution and reaction temperature. This makes the development of suitable standards for testing and quantifying their behaviour as insulation materials difficult.

In addition, with recent advances in structural fire engineering in which steel members are no longer considered to fail at a unique temperature, information on fire protection thicknesses is a requirement that can be specified over a range of limiting temperatures depending upon the type of loading system (bending, shear, tension, and compression), the magnitude of the applied loads, and the degree of exposure of the surface with respect to the fire/furnace.

Therefore, to rationalize the behaviour of fire protection products for protecting structural steelwork into simple design tables that manufacturers can use to specify their products involves the permutation of a large number of parameters.

In Europe, the development of testing and assessment protocols for fire protecting structural steel commenced during the 1990s under a European mandate within CEN TC127 (Fire resistance tests) and was the beginning of drafting European standards such as DD ENV YYY5. Since then, fire protection manufacturers in collaboration with the test laboratories throughout Europe have developed a series of test packages and assessment methods over the past 15 years which have been through a rigorous appraisal process by the fire protection industry. This work has culminated in the drafting of EN 13381 Parts 4 and 8 which broadly cover passive and reactive products.

Some of the key issues in developing these standards have been identifying the number of specimens required in a test package to characterize the performance of a fire protection product over the range of fire resistance times, applicable section factors, type of structural element, and design temperature. In addition, because of the vagaries in fire resistance testing, it has been necessary to establish a rationale for applying correction factors to the test results for use in the assessment process partly to maximize the validity of the data and keep the costs of testing to a minimum.

In Europe, four assessment methods have been developed, referred to as Graphical method, Differential equation analysis (variable l), Differential equation analysis (constant l), and Numerical regression analysis. Each method has been through a process of validation and are now included in the standards EN 13381 Parts 4 and 8.

In this part of ISO 834, the four methods have been directly incorporated into the standard and technically are identical to the European counterparts. However, it is recognized that other assessment methods may be suitable and therefore this part of ISO 834 provides a set of criteria for their acceptability. One such method which has undergone an evaluation process and meets the criteria for acceptability is the 3D method developed in the UK and currently used for reactive materials.

The 3D assessment was formerly presented as a published research paper at the SC2/WG2 meeting in Kyoto, Japan in November 2006 (N414). Since 2006, it has been published and presented in various forms in the technical journals and seminars and is now included in the Dutch Standard NEN 7878 (2011) and the Dutch Fire Safety Handbook (2011).

This part of ISO 834 recognizes that some assessment method/s are more suited to particular types of fire protection materials, and for this reason, they are presented as Informative Annexes, which enables freedom of choice in their application. However, only a single method can be used for the assessment process for a particular data set and cannot be mixed.

This part of ISO 834 specifies methods for assessing fire protection systems applied to structural steel members, employed in buildings as beams, columns, or tension members. This part of ISO 834 is intended for use in conjunction with the testing described in ISO 834-10.

Fire resistance tests — Elements of building construction —

Part 11: Specific requirements for the assessment of fire protection to structural steel elements

1 Scope

The assessment detailed in this part of ISO 834 is designed to cover a range of thicknesses of the fire protection material, a range of steel sections characterized by their section factors, a range of design temperatures, and a range of valid fire resistance classification periods.

This part of ISO 834 covers fire protection systems that include both passive (boards, mats, slabs, and spray materials) and reactive materials as defined in this document.

The assessment procedure is used to establish

a) on the basis of the temperature data derived from testing loaded and unloaded specimens, a correction factor and practical constraints on the use of the fire protection system (the physical performance) and

b) on the basis of the temperature data derived from testing unloaded short steel specimens, the thermal properties of the fire protection material (the thermal performance).

The limits of applicability of the results of the assessment are defined together with permitted direct application of the results to different steel section sizes and strength grades (but not stainless steels) and to the fire protection system tested. The results of the tests obtained according to ISO 834-10 and the assessment in this part of ISO 834 are directly applicable to steel sections of “I” and “H” cross-sectional shape and hollow sections. Results from analysis of I or H sections are directly applicable to angles, channels, and T-sections for the same section factor, whether used as individual elements or as part of a fabricated steel truss.

The results of the assessment are applicable to fabricated sections.

This part of ISO 834 does not apply to concrete-filled hollow sections, beams, or columns containing holes or openings of any type or solid bar.

Any assessment method is acceptable provided it meets the acceptability criteria given in 5.5. Examples of assessment methods in common use are given in Annexes C to G.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 834-1, *Fire-resistance tests — Elements of building construction — Part 1: General requirements*

ISO 834-10, *Fire resistance tests — Elements of building construction — Part 10: Specific requirements to determine the contribution of applied fire protection materials to structural elements*

ISO 8421-2, *Fire protection — Vocabulary — Part 2: Structural fire protection*

ISO 13943, *Fire safety — Vocabulary*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 834-1, ISO 13943, ISO 8421-2, and the following apply.

3.1
characteristic steel temperature
temperature of the structural steel member which is used for the determination of the correction factor for stickability which is calculated according to 5.2.2

3.2
design temperature
temperature of the steel member for structural design purposes

3.3
fire protection
protection afforded to the steel member by the fire protection system such that the temperature of the steel member is limited throughout the period of fire exposure

3.4
fire protection system
fire protection material together with any supporting system including mesh reinforcement as tested

Note 1 to entry: The reactive fire protection materials system includes the primer and top coat if applicable.

3.5
fire protection thickness
dry thickness of a single-layer fire protection system or the combined thickness of all layers of a fire protection system

Note 1 to entry: The thickness of elements of the supporting system or joint cover strips is not included in the fire protection thickness.

Note 2 to entry: For reactive fire protection systems, the thickness is the mean dry film thickness of the coating excluding primer and top coat if applicable.

3.6
H section
steel member with wide flanges compared with the section depth whose main function is to carry axial loads parallel to its longitudinal axis which can be combined with bending and shear

3.7
I section
steel joist or girder with short flanges shaped like a letter “I” whose main function is to carry loads transverse to its longitudinal axis

Note 1 to entry: These loads usually cause bending of the beam member. The flanges may be parallel or tapered.

3.8
passive fire protection material
material, which do not change their physical form on heating, providing protection by virtue of their physical or thermal properties

Note 1 to entry: Passive fire protection materials may include materials containing water or undergo endothermic reactions which, on heating produce cooling effects. These may take the form of sprayed coatings, renderings, mat products, boards, or slabs.

3.9
reactive fire protection material
material 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 insulative and cooling effects

3.10
reference section
steel section which is taken from the same length of steel as its equivalent loaded section

3.11
section factor (unprotected steel)
ratio of the fire exposed perimeter area of the structural steel member, per unit length, A_m to its cross-sectional volume per unit length, V

3.12
section factor (profiled fire protection system):
ratio of the fire exposed outer perimeter area of the steel structural member excluding the protection material, per unit length, A_m to its cross sectional volume per unit length, V

3.13
section factor (boxed fire protection system)
ratio of the internal surface area of the smallest possible rectangle or square box encasement which can be measured around the steel structural member, A_m, to its volume per unit length, V

3.14
steel member
element of building construction, which is load bearing and fabricated from steel

Note 1 to entry: For the purpose of this part of ISO 834, the steel used in the testing must be of the same grade.

3.15
steel temperature
overall mean temperature to be used as input data for the analysis is calculated according to 5.2.1

3.16
stickability
ability of a fire protection system to remain sufficiently coherent and in position for a well-defined range of deformations, furnace, and steel temperatures, such that the efficacy of the fire protection is not significantly impaired

3.17
test package
set of steel sections which may include short or long specimens that is tested to evaluate the stickability of the fire protection system and to provide thermal data over a range of protection thickness, steel section factor, and steel temperatures

3.18
test specimen
steel section plus the fire protection system under test

Note 1 to entry: The steel test section, representative of a steel member for the purposes of this test, comprises long and short steel columns or beams.

4 Symbols and abbreviated terms

Symbol	Unit	Description
A	m^2	area
A_m	m^2	exposed perimeter area of the structural steel member, per unit length

Symbol	Unit	Description
A_p	m^2	for profile protection: exposed outer perimeter area of the structural steel member excluding the protection material, per unit length for encased protection: the internal surface area of the smallest possible rectangle or square box encasement which can be measured around the structural steel member
c_a	J/(kgK)	temperature-dependent specific heat capacity
c_p	J/(kgK)	temperature-independent specific heat capacity of the fire protection material
$c_{n,n+1...}$	-	regression constants in constant λ method of assessment
d	mm	thickness
d_i	mm	protection thickness of the short section
$d_{n,n+1...}$	-	regression coefficients
d_{max}	mm	maximum protection thickness of the loaded section
d_{min}	mm	minimum protection thickness of the loaded section
d_p	mm	thickness of fire protection material
$d_{p(max)}$	mm	maximum thickness of fire protection material
$d_{p(min)}$	mm	minimum thickness of fire protection material
d_{SC}	mm	thickness of fire protection material on an unloaded short column section
d_{UB}	mm	thickness of fire protection material of an unloaded beam section
D	mm	protection thickness for the loaded section or tall section
D_1	mm	protection thickness for the reference section
D_p	min	length of the moisture plateau
k	-	correction factor
k_i	-	stickability correction factor for the short section at thickness d_i
k_{imax}	-	stickability correction factor at maximum protection thickness
k_{imin}	-	stickability correction factor at minimum protection thickness
K	-	constant applied to $\lambda_{\delta\ (p)}$
K_d	-	range factor for thickness
K_s	-	range factor for section factor
n	-	number of specimens
P	m	perimeter of the steel section exposed to fire
S	m^{-1}	section factor of the loaded or tall section
S_1	m^{-1}	section factor of the reference section
s_p	m^{-1}	section factor at factor K_s
s_{max}	m^{-1}	maximum section factor at K_s factor of 1
s_{min}	m^{-1}	minimum section factor at K_s factor of 0
t_w	mm	thickness of the wall of the hollow steel section
t	min	time from the commencement of the test
t_1	min	time for the reference section to reach the design temperature
t_c	min	corrected time for thickness and section factor

Symbol	Unit	Description
t_d	min	time required for a short section to reach the design temperature
t_e	min	time for an unloaded section to reach an equivalent temperature to the loaded beam at time t
t_i	min	time for the loaded section to reach the design temperature
t_recal	min	time at recalculated steel temperature
V	m^3/m	volume of the steel section per unit length
Δt	min	time interval
$\Delta\theta_\mathrm{at}$	°C	increase in steel temperature during the time interval Δt
θ	°C	design temperature
θ_at	°C	average steel temperature at time t
$\theta_\mathrm{c(SC)}$	°C	corrected mean temperature of an unloaded column section
$\theta_\mathrm{c(uC)}$	°C	corrected mean temperature of an unloaded beam section
θ_LB	°C	characteristic steel temperature of a loaded beam
θ_LC	°C	characteristic steel temperature of a loaded column
$\theta_\mathrm{m(SC)}$	°C	modified steel temperature of an unloaded section
θ_t	°C	average temperature of the furnace at time t
θ_p	°C	protective material temperature at time t
θ_LC	°C	characteristic steel temperature of a loaded column
θ_UB	°C	characteristic temperature of a short unloaded reference beam
$\lambda_{ave(p)}$	W/(mK)	mean value of λ_p calculated from all the short sections at a temperature θ
$\lambda_\mathrm{char(p)}$	W/(mK)	characteristic value of the thermal conductivity of the fire protection material
λ_p	W/(mK)	effective thermal conductivity of the fire protection material
$\lambda_\mathrm{p,t}$	W/(mK)	thermal conductivity of the fire protection material at time t and for a thickness d_p of protection material
$\lambda_{\delta\mathrm{(p)}}$	W/(mK)	standard deviation of λ_p calculated from all the short sections at a temperature θ
ρ	Kg/m^3	density
ρ_a	Kg/m^3	density of steel (normally 7 850 kg/m^3)
ρ_{LB}	Kg/m^3	density of the fire protection on a loaded beam
$\rho_{protection}$	Kg/m^3	density of the fire protection material
ρ_{UB}	Kg/m^3	density of the fire protection material on the unloaded beam
ρ_{UC}	Kg/m^3	density of the fire protection material on the unloaded column section
LB	-	loaded beam
LC	-	loaded column
TC	-	tall column
LHB	-	loaded hollow beam
LHC	-	loaded hollow column
SIB	-	short I-section beam
SIC	-	short I-section column

Symbol	Unit	Description
TCHS	-	tall circular hollow beam
TRHS	-	tall rectangular hollow beam
SHB	-	short hollow beam
SHC	-	short hollow column
RB	-	reference beam

5 Assessment

5.1 General

The assessment shall begin with the collection of the data from the fire testing obtained according to ISO 834-10.

The temperature data obtained from the loaded and unloaded steel sections are used as a basis for relating the time to reach a specified steel temperature, the thickness of fire protection material, and section factor. Where the performance at minimum and maximum protection thickness of the loaded section or tall column is less than that of the equivalent short reference section, the time to reach the design temperature shall be corrected in accordance with Annex A.

The section factor and applied material thickness of the reference sections shall be within ±10 % of their equivalent loaded or tall sections. The analysis of the data shall be made on the basis of an assessment of the test data where the predicted performance satisfies the acceptance criteria given in 5.5 and is fully described in the assessment report.

The results of the assessment may not be used to extrapolate fire protection thicknesses beyond the maximum thicknesses evaluated.

Examples of the methods of analysis are given in Annexes C to G. It is incumbent upon the test laboratory or other approved organization/company, in consultation with the manufacturer, to utilize the most appropriate method to provide the best fit of the test data.

Only one method shall be utilized to provide the full scope of the assessment of the data from the testing of the product, i.e. different methods cannot be used to evaliate different portions of the test data.

This part of ISO 834 defines test packages to suit the scope of the assessment for the methodologies described in this International Standard determined in accordance with the principles given in ISO 834-10.

I or H sections and hollow sections are treated separately for the purposes of the assessment.

5.2 Temperature data

5.2.1 Steel temperature for calculations

The steel temperature for calculation purposes shall be the overall mean temperature of each section calculated as follows:

— For I and H section beams, this refers to the mean temperature of the upper flange plus the mean temperature of the web plus the mean temperature of the lower flange, divided by three.

— For I, H, and hollow section columns, this refers to the sum of the mean temperature of each measuring station divided by the number of measuring stations.

— For hollow section beams, this refers to the mean temperature of the sides of the section plus the mean temperature of the bottom face, divided by two.

5.2.2 Characteristic steel temperature

The characteristic temperature is calculated as (mean temperature + maximum temperature)/2.

5.3 Correction for discrepancy in stickability and insulation performance over the thickness range tested

Correction factors shall be determined for the thickness range tested in accordance with Annex B. Linear interpolation shall be applied to correct the time to reach the design temperature for the short sections.

The characteristic steel temperature derived in accordance with 5.2.2 will be used to determine the correction factor assessment procedures for thermal performance

5.4 Assessment procedures for thermal performance

Assessment of thermal performance shall be carried out on the basis of the corrected times to reach the design temperatures of each short section and they must satisfy the criteria for acceptability and limitations given in 5.5 and Clause 7 respectively.

A minimum number of short steel sections shall be tested according to ISO 834-10. If further data points are required, additional specimens shall be tested.

5.5 Criteria for acceptability of the assessment method used and the resulting analysis

The acceptability of the analysis within the range of steel section temperatures (as defined by ISO 834-10 or the sponsor) 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 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 comply with the following rules provided all other parameters remain constant:

   1) The thickness of fire protection material increases with fire resistance time.

   2) As the section factor increases, the fire resistance time decreases.

   3) As the fire resistance time increases, the temperature increases.

   4) As the thickness increases, the temperature decreases.

   5) As the section factor increases, the temperature increases.

   6) As the section factor increases, the thickness increases.

The criteria for acceptability shall be individually applied to all design temperatures included in the scope of the assessment. This should be carried out in 50 °C steps, starting at 50 °C below the minimum temperature within the scope or 350 °C, whichever is the higher, up to the maximum temperature within the scope. There must be at least three temperature steps of 50 °C within the scope of the assessment.

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

6 Report of the assessment

The report of the assessment shall include the following:

a) The name/address of the body providing the assessment and the date it was carried out. Reference to the name/address of the test laboratory, the unique test reference number, and report number(s).

b) The name(s) and address(es) of the sponsor(s). The name of the manufacturer of the product or products and the manufacturer or manufacturers of the construction.

c) Generic description of the product or products, particularly the fire protection system and any component parts (where known). If unknown, this shall be stated.

d) General description of the test specimens forming the basis of the assessment including the measured dimensions of the test specimens.

e) The reason for the omission of any test data.

f) The assessment method used.

g) The mean steel temperatures used in the analysis in accordance with 5.2.1.

h) The corrected times used in the analysis determined as described in Annex A.

i) The values of all thermal data required to be calculated by the chosen assessment method.

j) For all methods of analysis the ability of the method to satisfy the criteria for acceptability as specified in 5.5.

k) The thermal analysis shall produce a series of tables and graphical presentations relating to fire resistance classification periods appropriate to the performance of the protection material. Each table or graphical presentation shall show the minimum thicknesses of fire protection material required to maintain the design temperature. (An example of the presentation of such tabulated information is given in Table 1). Any alternative presentation of the data specified by the sponsor appropriate to local/National needs and different design temperature limits and intervals of section factor may be used. Whatever the presentation of the data are adopted, interpolation is only allowed over a maximum range of 50 °C and 10 m^{-1}.

l) The report shall also include a statement regarding the limits of direct application of the assessment procedure, especially with regard to the range of section factors, design temperatures, material thicknesses, fire resistance periods, three- or four-sided protection, etc.

m) The report will include tables of actual and predicted times.

Table 1 — Example of tabulated data

Fire resistance period – 30 minutes								
Design temperature °C	**350**	**400**	**450**	**500**	**550**	**600**	**650**	**700**
Section factor m^{-1}	**Thickness of fire protection material to maintain steel temperature below design temperature**							
40								
50								
60								
70								
80								
90								
100								
110								
120								
130								
140								
150								
160								
170								
180								
190								
200								
210								
220								
230								
240								
250								
260								
270								
280								
290								
300								

Temperature range for illustration only. Actual range to be determined by the scope of the assessment.

7 Limits of the applicability of the results of the assessment

7.1 General

The results from the assessment procedure are applicable to the fire protection system over the range of fire protection material thicknesses tested, the values of section factor A_m/V tested, and the maximum temperatures established during the test.

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. In order for this to apply, it is necessary for beams to have been tested in accordance with 7.2.1 of ISO 834-10.

For an assessment to be valid for any fire resistance period, the loaded sections protected with the maximum protection thickness shall achieve a loadbearing capacity performance as defined in 11.3.1 and 11.3.2 of ISO 834-10 within 85 % of this period.

The fire resistance period resulting from the test and assessment is limited to the maximum period of testing or some shorter period for which the sponsor requires approval.

The results of the assessment are applicable to all other grades of steel to that tested as specified in ISO 834-10. These shall be hot finished, mild or micro-alloyed steel that have not been heat treated to improve their mechanical properties.

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

The assessment is only applicable to the method of application used in the test specimen preparation.

The results of the assessment are also applicable to fabricated sections.

Nominal extensions only beyond those variables evaluated during the test are permitted. All permitted extensions must be applied concurrently and are given as follows:

7.2 Permitted protection thickness for beams

a) Maximum permitted thickness: Up to 5 % above the maximum thickness tested on a loaded beam.

b) Minimum permitted thickness: Up to 5 % below the minimum tested on a loaded beam.

7.3 Permitted protection thickness for columns

a) Maximum permitted thickness: Up to 5 % above the maximum thickness tested on a loaded column. If only loaded beams are tested, the maximum permitted thickness will be that of the loaded beam.

b) Minimum permitted thickness: Up to 5 % 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 that tested on a short unloaded column.

7.4 Permitted section factor for beams

a) Maximum permitted section factor: Up to 10 % above the maximum section factor of any beam section tested.

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

c) Where only columns have been tested, then the minimum permitted extension factors are based on the minimum section factor of any section tested

7.5 Permitted section factor for columns

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

b) 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 protection 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.

7.6 Specific issues for passive protection

The method of fixing boards (or slabs) is confined to the method used for the test specimens since it may not be suitable for other situations. The suitability of the tested fixing system for different applications shall be demonstrated by appropriate testing.

For renderings applied to large sections outside the scope of testing, it may be necessary to include reinforcing mesh.

The testing of passive protection shall take into account various factors including the following:

a) Orientation – fixing methods may vary between columns and beams

b) Shape - fixing methods may vary between different shaped sections, e.g. rectangular and circular sections, channels, and T's, etc.

c) Loading – flexural and compression loads may affect the performance of the fixing method in different ways

d) Numbers of layers – the combination of layers may perform differently compared with a single layer of the same overall thickness

e) The web depth – for deep web depths, a different support system may be needed

f) The spacing used between the boards and the test specimens in the fire tests shall be as follows: tested distance −5 mm to +50 mm with no change in fixing

The testing may be limited to any or all of the above but the scope of the assessment will be restricted accordingly.

Annex A
(normative)

The applicability of the results of the assessments for passive protection to sections other than I or H sections

A.1 Structural hollow sections

Test data exists on structural hollow sections (SHS) as compression and flexural members which, together with recent research, have indicated comparability between SHS sections and "I" or "H" sections in terms of the fire protection thickness related to the section factor. The test information has been analysed for rectangular, square, and circular sections to establish comparability with respect to fire protection thickness, section factor, and fire resistance performance and the approaches in A.1.1, A.1.2, and A.1.3 are recommended for both three- and four-sided protection to both beams and columns.

However, the sponsor may wish to carry out testing on structural hollow sections in accordance with ISO 834-10 to obtain more suitable data.

A.1.1 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_p/V value is equal to that for the "I" or "H" section of the same "box" A_p/V value.

A.1.2 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_m/V value of the section as follows:

a) Establish the A_m/V value of the structural hollow section.

b) Determine the thickness d_p, in millimetres, of the fire protection material based on the "I" or "H" section data in accordance with Formulae (A.1) or (A.2).

c) For A_p/V values up to 250 m^{-1}, increase the thickness as follows:

$$\textit{Modified thickness} = d_p\left(1+\frac{A_p/V}{1\,000}\right) \tag{A.1}$$

d) For A_p/V values higher than 250 m^{-1}, increase the thickness *as* follows:

$$\textit{Modified thickness = 1.25} \tag{A.2}$$

A.1.3 Alternative fixing methods for boards/slabs

Where the method of fixing boards to hollow sections is not the same as that used for the testing of the "I" or "H" sections, the suitability of the fixing system shall be demonstrated by appropriate testing. The testing should take into account the following:

a) orientation – fixing methods may vary between rectangular columns and beams

b) shape - fixing methods may vary between rectangular and circular sections

c) loading – flexural and compression loads may affect the fixing method in different ways

d) numbers of layers – the combination of layers may perform differently compared with a single layer of the same overall thickness

e) multi-layered boards of different thickness – the size of the fixings may vary depending upon whether the thinner layer is on the outside or the inside

The testing may be limited to any or all of the above but the scope of the assessment will be restricted accordingly. The appropriate tests for hollow sections should be as defined in ISO 834-10.

A.1.4 Limitations

The maximum thickness that can be applied to structural hollow sections shall not exceed the maximum thickness assessed for "I" or "H" sections.

The rules outlined in this annex may be used provided that the different section shape does not require new fixing techniques and does not affect the physical performance of the fire protection system.

Annex B
(normative)

Correction of data/nominal thickness

B.1 Correction of data

B.1.1 Procedure

To take into account the stickability performance of the product, the data for the short sections should be corrected against the loaded beams, loaded columns, and tall columns (reactive only), depending upon the selected test programme given in Tables H.1 and I.1 for reactive and passive materials. The correction procedures required for the test packages given in Tables H.1 and I.1 are listed in Tables B.1 and B.2 for reactive and passive materials respectively.

The protection thickness for all reference sections must be within the tolerances stated in Annexes B and C of ISO 834-10 for passive and reactive systems respectively.

Table B.1 — Correction procedures for various test packages for reactive materials

Ref	Correction procedures required for the test packages listed in Tables H.1 and H.2
a)	Correct I and H beam data using minimum and maximum thickness loaded beams and reference beams.
b)	Correct I and H column data using minimum and maximum thickness loaded columns and reference columns.
c)	Correct I and H column data using the worst case of the maximum thickness loaded beam and reference or the maximum thickness tall column and reference column. For the column assessment, correct I and H column data using the minimum thickness loaded beam and the reference beam and the worst case of maximum thickness loaded beam and reference beam and maximum thickness tall column and reference column.
d)	Correct I and H column data for a beam assessment using minimum and maximum thickness loaded beams and reference beams. For the column assessment, correct I and H column data using the minimum thickness loaded beam and the reference beam and the worst case of maximum thickness loaded beam and reference beam and maximum thickness tall column and reference column.
e)	Correct hollow column data using the worst case of the maximum thickness loaded column and its equivalent tall maximum thickness column and reference column.
f)	Correct hollow beam data using the maximum thickness loaded beam and reference beam.
g)	Correct hollow beam data using minimum and maximum thickness loaded beams and reference beams.
h)	Correct hollow column data using minimum and maximum thickness loaded columns and reference columns.

For reactive materials where the reference column is not included in the furnace with the loaded column, then the worst case of the loaded column and reference column or the tall column and reference column shall be used.

Table B.2 — Correction procedures for various test packages for passive materials

Ref	Correction procedures required for the test packages listed in Tables I.1 and I.2
a)	Correct I and H beam data using minimum and maximum thickness loaded beams and reference beams.
b)	Correct I and H column data using minimum and maximum thickness loaded columns and reference columns.
c)	Correct I and H beam and column data using the minimum and maximum thickness loaded beams and reference beams.
d)	Correct I and H column data using minimum and maximum thickness loaded beams and reference beams.
e)	Correct hollow beam data using minimum and maximum thickness loaded beams and reference beams.
f)	Correct hollow column data using minimum and maximum thickness loaded columns and reference columns.

For all protection systems, the short section data are corrected for “stickability” against the loaded or tall sections (reactive materials only). This is carried out by comparing the time for the loaded or tall section (reactive materials only) to reach the design temperature with that of the equivalent short reference section. In all cases, the temperature is calculated as the characteristic temperature according to 5.2.2

The correction factor is calculated for each design temperature required within the scope of the assessment. The corrected time to each design temperature for each section shall be used in the analysis

B.1.2 Method

The loaded or tall section (reactive materials only) and its equivalent short reference section may not have identical section factors and protection thickness, in which case, the time 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 Formula (B.1):

$$t_c = t_1 \times \left({S_1}/{S} \right) \times \left({D}/{D_1} \right) \tag{B.1}$$

The correction factor for k is calculated using Formula (B.2):

Correction factor $$k = {t_1}/{t_c} \tag{B.2}$$

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. Examples are given in Tables B.3 and B.4 for reactive and passive protection materials respectively.

Table B.3 — Calculation of the correction factor for reactive materials

Section type	**Thickness** mm	**Section factor** A_m/V m^{-1}	**Time to reach design temp** min	**Corrected time for thickness and section factor** t_c min	**Correction factor** $(k = t/t_c)$
Loaded beam (LB)	2,50 (D)	158 (S)	67 (t_1)	75,6	0,88
Reference beam (RB)	2,56 (D_1)	161 (S_1)	76 (t_1)		

Table B.4 — Calculation of the correction factor for passive materials

Section type	**Thickness** mm	**Section factor** A_m/V m^{-1}	**Time to reach design temp** min	**Corrected time for thickness and section factor** t_c min	**Correction factor** $(k = t/t_c)$
Loaded beam (LB)	45,0 (D)	158 (S)	128 (t_1)	144,2	0,89
Reference beam (RB)	46,1 (D_1)	161 (S_1)	145 (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 maximum and minimum protection thickness.

The correction factor is determined at minimum and maximum thickness using the above methodology.

The correction factor for short sections with thicknesses within the range is obtained by linear interpolation using the Formula (B.3):

$$k_i = \left(\frac{k_{max} - k_{min}}{d_{max} - d_{min}} \right) (d_i - d_{min}) + k_{min} \qquad \text{(B.3)}$$

Corrected time for the short section = k_i × time to the design temperature.

Examples of the calculation relating to the correction of loaded and reference beams is given in Tables B.5 and B.6 for reactive and passive protection materials respectively.

Table B.5 — Example calculation for beams, for reactive materials

Section type	Thick-ness mm	Section factor A_m/V m^{-1}	Time to reach design temp min	Corrected time for thickness and section factor t_c min	Correction factor k
LB d_{max}	2,50	158	67	75,6[a]	0,88 (k_{max})
RB d_{max}	2,56	161	76		
LB d_{min}	0,38	155	40	40,7[a]	0,98 (k_{min})
RB d_{max}	0,39	154	42		

[a] 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 B.5 b.

Table B.5 b — Continuation, example calculation for beams, for reactive materials

Short section	Thickness d_i mm	Time to design temperature min	Factor k_i	Modified time min
short beam	1,25	75	0,939	70,4

Factor k_i is obtained by linear interpolation between k_{max} and k_{min} using Formula (B.2).

Table B.6 — Example calculation for beams, for passive materials

Section type	Thick-ness mm	Section factor A_m/V m^{-1}	Time to reach design temp min	Corrected time for thickness and section factor t_c min	Correc-tion factor k
LB d_{max}	45,0	158	128	144,2[a]	0,89 (k_{max})
RB d_{max}	46,1	161	145		
LB d_{min}	8,5	155	69	72,8[a]	0,95 (k_{min})
RB d_{min}	8,1	154	67		

[a] Time that the short beam would have achieved if its protection thickness and section factor was the same as that of the equivalent loaded beam. An example is given in Table B.6 b.

Table B.6 b — Continuation, example calculation for beams, for passive materials

Short section	Thickness d_i mm	Time to design temperature min	Factor K_i	Modified time min
short beam	25,5	85	0,931	79,1

Factor k_i is obtained by linear interpolation between k_{max} and k_{min} using Formula (B.2).

Short unloaded sections shall be corrected in accordance with Tables B.1 or B.2 for reactive and passive materials respectively.

The correction factors for all design temperatures above the temperature at which the loaded section fails loadbearing capacity as defined in ISO 834-1 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.

B.2 Nominal thickness-Graphical method

It is unlikely that a set of data will have exactly the same thickness for each of the sections; therefore, the performance at an actual thickness should be adjusted to reflect a nominal thickness in order to draw more meaningful plots. The nominal thickness is calculated as the mean of the individual thicknesses in the nominal range.

For each data point adjust the corrected time to reach the specified design temperature derived in accordance with B.1 on a pro-rata basis of nominal and actual thickness. Examples for reactive and passive materials are given below:

Reactive materials:

Assuming linear behaviour to adjust the time to reach a specified temperature for a nominal thickness of 0,500 mm, use a data point of 0,523 mm actual thickness with a time to reach a specified design temperature of 64 min, calculate 0,500/0,523 × 64 to obtain 61 min for this data point. Corrections using this approach should be limited to ±10 % of the nominal thickness considered.

Passive materials:

Assuming linear behaviour to adjust the time to reach a specified temperature for a nominal thickness of 50,0 mm, use a data point of 52,3 mm actual thickness with a time of 64 min, calculate 50,0/52,3 × 64, to obtain 61 min.

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

Annex C
(informative)

Assessment methodology: Graphical approach

C.1 Methodology

The following stepwise methodology shall be performed:

a) Step 1: Determination of nominal thickness

b) Step 2: Preparation of graphs

c) Step 3: Methods for plotting lines or curves

d) Step 4: Application of criteria for acceptability

e) Step 5: Derivation of intercepts

f) Step 6: Linear interpolation

g) Step 7: Reporting of results

Input Data:

— the design temperatures as defined in 5.5 which must have at least three steps of 50 °C

— the corrected times to reach the design temperatures

— the calculated section factor for the steel members

— the mean thickness of the protection only (for reactive coatings this is the thickness of the reactive part of the coating system)

Step 1 – Nominal Thickness:

For each section with a nominally similar thickness of coating, adjust the time for the section to reach the specified design temperature as given in B.2 with respect to a nominal thickness.

Step 2 – Graph:

For each section tested within each nominal thickness range and for each design temperature, plot the inverse section factor (V/A_m) against the adjusted time (see B.2) to reach the steel design temperature as shown in Figure C.1. An additional conservative "virtual" data point represented by the coordinates V/A_m of 0,0m and the time taken to reach each design temperature taken as specified from the heating curve in ISO 834-1 can be used for all design temperatures and nominal protection thicknesses. This virtual data point can be used in constructing each nominal thickness line.

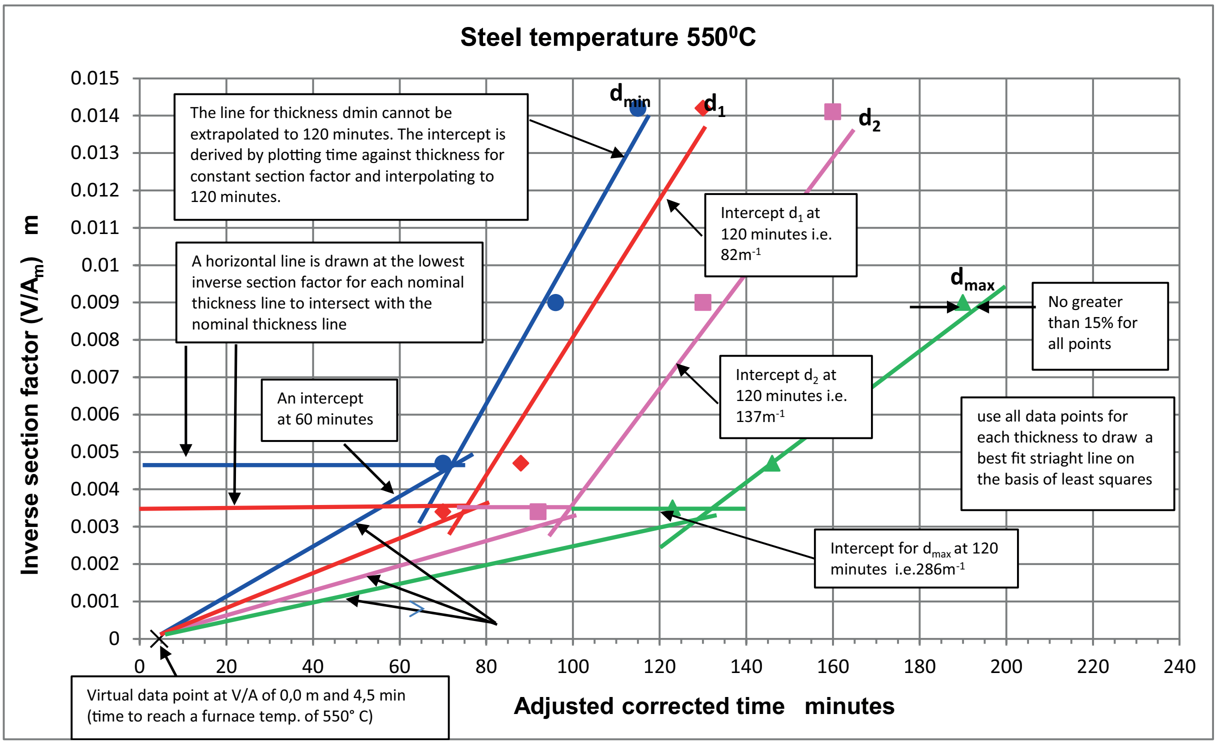


Figure C.1 — Inverse section factor vs. adjusted time for a steel temperature of 550 °C

Step 3 - Line Plotting:

The plots may be drawn as best fit straight lines or curves or a simple point to point line construction

Straight Line

For each thickness, draw a horizontal line from the “Y” axis at the lowest inverse section factor from Tables H.1 and H.2. For each set of data points of the same nominal thickness, draw a best fit straight line based on the principle of least squares ensuring the slope of the line is positive. A straight line may be drawn from the virtual data point through the lowest predicted data point horizontal to that real data point as shown in Figure C.1.

Curved Line

For any nominal thickness requiring a curve fit plot, a minimum of six data points will be required. The additional data points must be accommodated within the minimum data set from Tables H.2 and H.3 and Tables I.6 and I.7 for reactive and passive materials respectively. The curve must be a parabolic least squares fit and shall pass through the virtual point.

Point to Point

For any nominal thickness requiring a point-to-point plot, a minimum of six data points will be required. The additional data points shall be accommodated within the minimum data set from Tables H.2 and H.3 and Tables I.6 and I.7 for reactive and passive materials respectively in between each pair of consecutive section factors that have been tested. Where there are two points of the same A/V, the most conservative point shall be used.

As section factor increases, the time to reach a given design temperature shall be decreasing; otherwise, points which do not meet this requirement shall be omitted.

Step 4 - Compliance with 5.5:

Apply the three criteria given in 5.5 a), b), and c) for each design temperature as shown in the example given in Figure C.2. Figure C.2 shows a plot of inverse section factor against the predicted time and adjusted corrected time for an average thickness of nominal thickness range at a particular design temperature.

The data given for this example is given in Figure C.1. If for any line criteria a) is not met, then the line in question must be moved towards the "Y" axis maintaining the slope 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 which is redetermined and the process is repeated until the criteria are met.

Criteria d) shall be satisfied in all respects for the scope of the assessment.

Where a thickness line crosses over another thickness line, then the results of the final analysis in the thickness tables shall default to the conservative thickness line above the point of crossover.

From the data in Table C.1 and Figure C.2, consider data point 3 in which, the predicted value is given by the intercept with the plot line, a corresponding predicated time may be obtained from the x-axis (or by using the formula for the line if the data point is above the horizontal line), in this case 39,5 min.

Table C.1 — Adjustment of fire resistance times

Data point	Section factor m^{-1}	Inverse Section factor m	Time to design temperature min
1	70	0,014 286	84
2	110	0,009 091	58
3	185	0,005 405	43
4	285	0,003 509	28

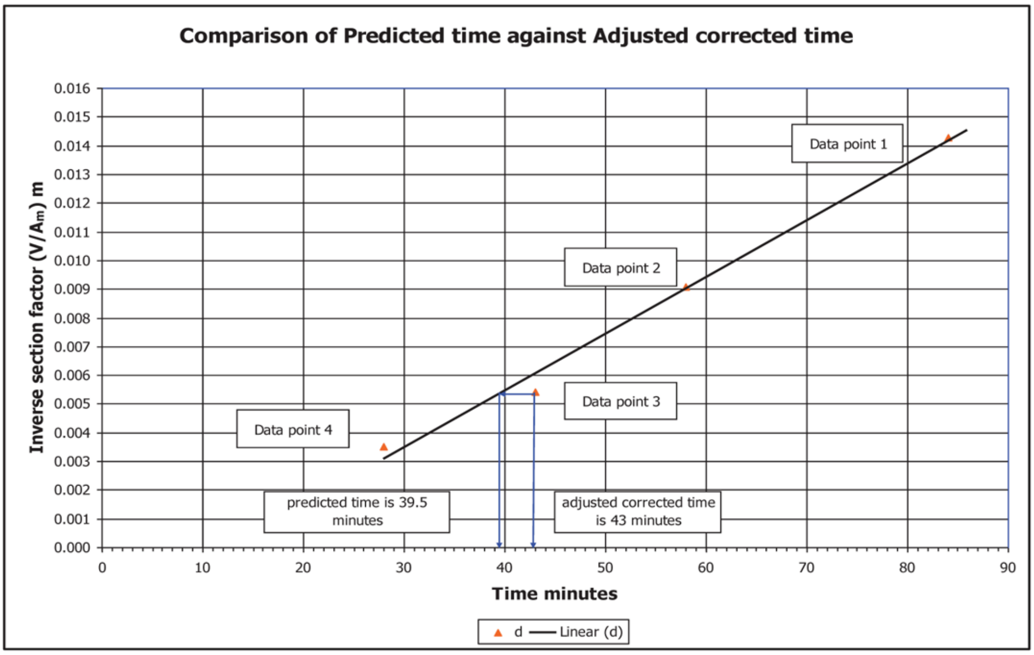


Figure C.2 — Adjustment of fire resistance times

The same approach can be applied to each data point for all nominal thickness lines and steel design temperatures. In this case, Table C.2 may be obtained and the criteria for acceptability applied to the values.

Table C.2 — Corrected and predicted times to design temperature

Data point	Corrected time to design temperature min	Predicted time to design temperature min
1	84	83,9
2	58	58,0
3	43	39,5
4	28	30,0

Step 5 – Deriving Intercepts:

For each design temperature and each nominal material thickness plot, establish the limiting 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 as shown in Figure C.3.

Where a nominal thickness line does not intersect a fire resistance period, as shown on Figure C.1 for the minimum thickness and 60 min, an intercept may be derived by interpolation by plotting an additional graph of nominal thickness against time for a constant section factor.

Reactive protection materials

For reactive fire protection materials, an example plot is shown in Figure C.3 which is based on a hypothetical minimum thickness of 0,200 mm and intermediate thicknesses of 0,450 mm and 0,850 mm.

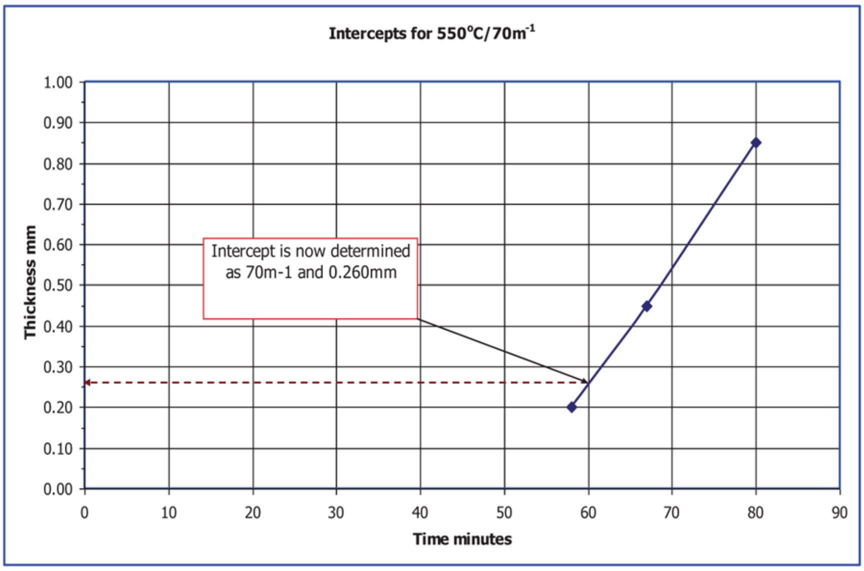


Figure C.3 — Method for deriving intercepts – reactive materials

Passive protection materials

For passive protection, an example plot is shown in Figure C.4 which is based on a hypothetical minimum thickness of 8 mm and intermediate thicknesses of 15 mm and 25 mm.

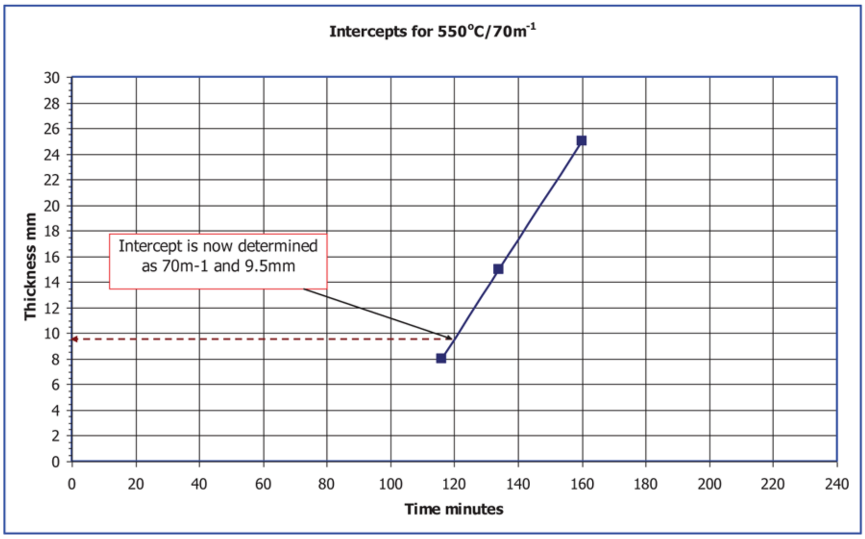


Figure C.4 — Method for deriving intercepts – passive materials

Step 6 – Linear Interpolation:

For each design temperature and fire resistance period, determine the limiting section factors against the nominal dry film thicknesses.

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.

For reactive materials, the number of thickness steps required between the maximum and minimum thicknesses are given in Table C.3.

Table C.3 — Requirements of the number of steps between thicknesses – reactive materials

Maximum/minimum thickness mm	**Number of thickness steps**
Up to 3,0	4
>3,0 up to 5,0	5
>5,0	6

For passive materials, the number of thickness steps required between the maximum and minimum thicknesses are given in Table C.4.

Table C.4 — Requirements of the number of steps between thicknesses – passive materials

Maximum/minimum thickness mm	**Number of thickness steps**
Up to 40	4
>40 up to 75	5
>75	6

Step 7 – Reporting of Results:

Report the results of the assessment according to Clause 6.

The virtual data point represents a conservative data point for protected steel. It is a data point provided by the standard furnace temperature/time relationship defined in ISO 834 for the design temperature. It is appropriate for unprotected steel for all design temperatures and section factors within the scope of the assessment since the steel section cannot be at a higher temperature than the furnace temperature. This facilitates the drawing of a conservative curve from this point to the intersection of the horizontal line by the straight line.

Annex D
(informative)

Assessment methodology: Differential equation analysis (variable λ approach)

D.1 Methodology

The following stepwise methodology shall be performed:

a) Step 1: Basic formula

b) Step 2: Input data

c) Step 3: Preparation of input data

d) Step 3a: Determination of moisture plateau (passive materials only)

e) Step 4: Determination of elementary variable conductivities from each short column

f) Step 5: Determination of the temperature of protective material

g) Step 6: Transformation of conductivities

h) Step 7: Determination of average variable conductivities for the protective material

i) Step 8: Check on criteria of acceptability

j) Step 9: Adjustment of characteristic variable conductivities

k) Step 10: Presentation of the results

l) Step 11: Reporting of the results

Step 1 – Basic formula:

The basic differential formula for reactive materials is given in Formula (D.1):

$$\Delta\theta_{\text{a,t}} = \frac{\lambda_{\text{p,t}}}{d_{\text{p}}} \times \frac{A_{\text{p}}}{V} \times \frac{1}{c_{\text{a}} \times \rho_{\text{a}}} \times \left(\theta_{\text{t}} - \theta_{\text{a,t}}\right) \times \Delta t \tag{D.1}$$

The basic differential formula for passive materials is given in Formula (D.2):

$$\Delta\theta_{\text{a,t}} = \left[\frac{\lambda_{\text{p,t}}}{d_{\text{p}}} \times \frac{A_{\text{p}}}{V} \times \left(\frac{1}{1+\varphi/3}\right) \times \left(\theta_{\text{t}} - \theta_{\text{a,t}}\right)\Delta t\right] - \left[\left(e^{\varphi/10} - 1\right)\Delta\theta_{\text{t}}\right] \tag{D.2}$$

where

$$\varphi = \frac{c_{\text{p}}\rho_{\text{p}}}{c_{\text{a}}\rho_{\text{a}}} \times d_{\text{p}} \times \frac{A_{\text{m}}}{V}$$

In both Formulae (D.1) and (D.2)

with $\Delta\theta_{a,t} \geq 0$ and $\Delta t \leq 0{,}5$ min

if the calculated Δt is higher than 0,5 min, then 0,5 min should be chosen.

To satisfy the numerical stability criteria, the time increment Δt shall be chosen to be not more than 80 % of the critical time increment and be given by

$$\Delta t = 0{,}8 \times \frac{c_a \times \rho_a}{\lambda_{p,t}/d_p} \times \frac{V}{A_p} \tag{D.3}$$

A_p/V is a known geometrical property of the test specimen and it must be derived from actual dimensions of steel elements and calculated according to Figure D.1.

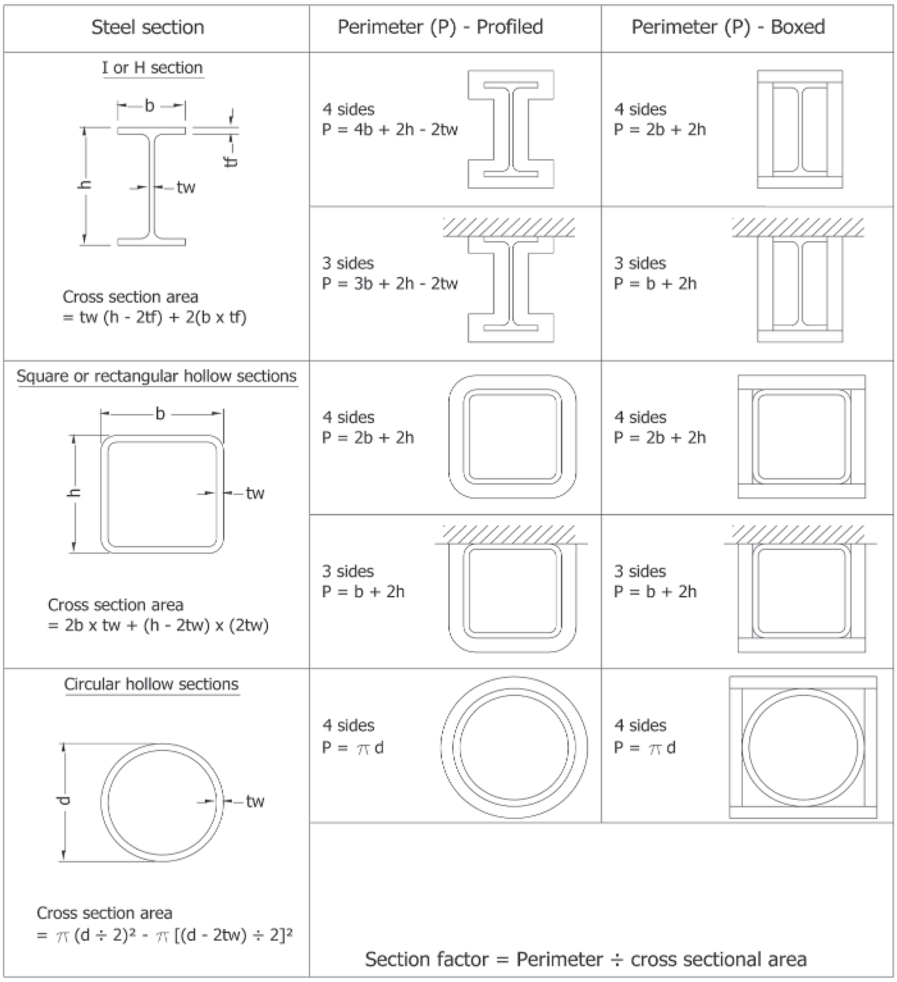


Figure D.1 — Calculation of section factors

Where the sponsors has not supplied data, then the following values are used for the protective material:

— c_p = 1 000 J/(kgK)

— ρ_p = 100 kg/m^3

Step 2 – Input data:

To carry out the assessment properly, the following input data for all non-loaded short elements are required:

— design temperature which shall have at least three steps of 50 °C;

— corrected times to reach the design temperature;

— uncorrected average steel temperatures;

— calculated section factors;

— mean thickness of the fire protection material (for reactive systems, this is the mean thicknesses of reactive product only).

Step 3 – Preparation of input data:

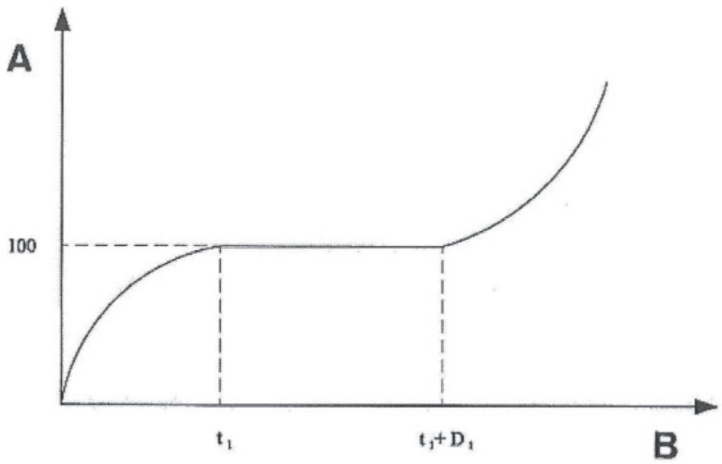
For each specimen, the input temperatures mentioned in Step 2 must be validated according to the following rules:

a) There should be no decrease in the average temperature between two time increments.

b) If this happens, the lower temperature is discarded and the temperature used is determined from a linear interpolation between previous increment in time and the next incremental value.

Step 3a - Determination of moisture plateau length (passive materials only)

Determine a smooth curve of moisture plateau length (D_p) versus fire protection thickness (d_p) shown in Figure D.2 and as follows:



Key

A temperature °C

B time (min)

Figure D.2 — Determination of moisture plateau

$$D_p = C \times d_p^3 \tag{D.4}$$

In which

$$C = \frac{\sum_{i=1}^{n} d_p^3 \times D_p}{\sum_{i=1}^{n} d_p^6} \tag{D.5}$$

Step 4 – Determination of elementary variable conductivities from each short column:

For each short section, basic Formula (D.6) provides the thermal conductivity of the protective material versus time for reactive materials.

$$\lambda_{p,t} = d_p \times \frac{V}{A_p} \times c_a \times \rho_a \times \frac{1}{\left(\theta_t - \theta_{a,t}\right) \times \Delta t} \times \Delta\theta_{a,t} \qquad \text{(D.6)}$$

For passive materials, this is given by Formula (D.7):

$$\lambda_{p,t} = d_p \times \frac{V\left(1+\varphi/3\right)}{A_p} \times c_a \times \rho_a \times \frac{1}{\left(\theta_t - \theta_{a,t}\right) \times \Delta t} \times \left[\Delta\theta_{a,t} + \left(e^{\varphi/10} - 1\right)\Delta\theta_t\right] \qquad \text{(D.7)}$$

NOTE In this step, the uncorrected average steel temperatures are used.

Step 5 – Determination of the temperature of protective material:

For each short column and for each time interval, determine the protective material temperature $\theta_{p,t}$ from Formula (D.8):

$$\theta_{p,t} = \left[\left(\theta_{t-1} + \theta_t\right) / 2 + \left(\theta_{a,t-1} + \theta_{a,t}\right) / 2 \right] / 2 \qquad \text{(D.8)}$$

Step 6 – Transformation of conductivities:

Transform the $\left(\lambda_p \text{ vs } t\right)\lambda_{p,t}$ values to $\left(\lambda_p \text{ vs } \theta_{p,t}\right)\lambda_{p,\theta_p}$ values.

Step 7 – Determination of average variable conductivities for the protective material:

Since the thermal conductivity may be dependent upon the thickness of the protective material, two thermal conductivities should be determined respectively for the minimum and maximum thicknesses of protective material.

For passive materials, values of thermal conductivity calculated between the start and finish of the moisture plateau are not used in this process.

For the minimum thickness, the λ_{mean} (θ_p) relevant to short non-loaded sections protected with minimum thickness must be considered.

For the maximum thickness, the λ_{mean} (θ_p) relevant to short non-loaded sections protected with maximum thickness must be considered.

For each of the above, the following procedure is adopted:

a) from the elementary variable conductivities λ_{p,θ_p}, a mean variable conductivity λ_{mean} (θ_p) of the protective material must be determined according to Step 7a;

b) then an average variable conductivity λ_{ave} (θ_p) must be determined according to Step 7b.

<u>Step 7a:</u>

For the sections protected with minimum thickness and sections protected with maximum thickness from each elementary variable conductivity λ_{p,θ_p}, calculate the arithmetical mean values of λ_{mean} (θ_p) for successive range [θ_p, θ_p + 50] for θ_p from 0 to 1 000 °C at 50 °C intervals, i.e. for 21 ranges. The corresponding temperature θ_p for each arithmetical mean value λ_{mean} lies in the middle of each interval considered, e.g. 375 °C, 425 °C, 475 °C, etc.

<u>Step 7b:</u>

Two average variable conductivities must be calculated for the minimum and maximum thickness of protective material.

For the sections protected with minimum thickness, the average variable thermal conductivity and corresponding standard deviation must be calculated for each 50 °C temperature range.

For the sections protected with minimum thickness, the average variable thermal conductivity and corresponding standard deviation must be calculated for each 50 °C temperature range.

For both sets and for each range [θ_p, θ_p + 50] for θ_p from 0 to 1 000 °C at 50 °C intervals and from each arithmetical mean values of λ_{mean} (θ_p), calculate the arithmetical average values of λ_{ave} (θ_p) and the standard deviation σ (θ_p) associated for θ_p from 0 to 1 000 °C at 50 °C intervals, i.e. for 21 values.

Step 8 – Verification of the fitness of average variable conductivities:

Step 8a:

Using the thermal conductivities calculated in Step 7b, the temperature time curves for each section are computed and the computed times to reach the design temperature are compared with the measured times.

For each short element, recalculate the steel temperature by using Formula (D.9) (reactive materials) and Formula (D.10) (passive materials) and with $\lambda_{ave}\left(\vartheta_p\right)$ for θ_p from 0 to 1 000 °C at 50 °C intervals.

$$\Delta\theta_{a,t} = \frac{1}{c_a \times \rho_a} \times \frac{\lambda_{ave}\left(\theta_p\right)}{d_p} \times \frac{A_p}{V} \times \left(\theta_t - \theta_{a,t}\right) \times \Delta t \quad \text{(D.9)}$$

$$\Delta\theta_{a,t} = \left[\frac{1}{C_a \times \rho_a} \times \frac{\lambda_{ave}\left(\theta_p\right)}{d_p} \times \frac{A_p}{V} \times \frac{1}{1+\varphi/3} \times \left(\theta_t - \theta_{a,t}\right) \times \Delta_t\right] - \left[\left(e^{\varphi/10} - 1\right) \times \Delta\theta_t\right] \quad \text{(D.10)}$$

For temperatures θ_p higher than 1 000 °C, use value of λ_{ave} (θ_p) determined for 20th range [950, 1 000] °C.

For passive materials when the steel temperature reaches 100 °C, the time to reach 100 °C is increased by the length of the moisture plateau, D_p, and the process continued.

The value of λ_{ave} (θ_p) related to d_p must be calculated by considering linear interpolation between the λ_{ave} (θ_p) calculated for minimum and maximum thicknesses of protective material, as described in Step 7b.

Step 8b:

From each recalculated steel temperature of non-loaded short element, determine times t_{recal} to reach the steel design temperatures.

Step 8c:

Compare all the t_{recal} versus t_{exp}, according to the acceptability criteria as defined in 5.5.

If the three criteria are simultaneously satisfied, the average variable conductivities λ_{ave} (θ_p) for θ_p from 0 to 1 000 °C at 50 °C intervals and for minimum and maximum thicknesses respectively can be estimated as representative of the performance of the reactive product.

If the three criteria are satisfied then, proceed to Step 10.

If the three criteria are not satisfied, the average variable conductivities λ_{ave} (θ_p) must be modified in order that the three acceptability criteria are satisfied simultaneously. Proceed to Step 9.

Step 9 – Adjustment of characteristic variable conductivities:

If the three acceptability criteria are not matched simultaneously, the average conductivities λ_{ave} (θ_p) must be modified using Formula (D.11):

$$\lambda_{adj}\left(\theta_p\right)=\lambda_{ave}\left(\theta_p\right)+K\times\sigma\left(\theta_p\right) \tag{D.11}$$

The value of K must be the lowest possible value.

The calculation is started with K equal to 0,001 and repeating Step 8 using λ_{adj} (θ_p) instead of λ_{ave} (θ_p). This process is repeated with further increments in K until the three acceptability criteria are met simultaneously.

Step 10 - Presentation of the results:

Use the relevant λ_{ave} (θ_p) or λ_{adj} (θ_p) conductivities issued from either Step 8c or from Step 9, with Formula (D.5) or (D.6) to determine the predicted temperature of steel elements belonging to the shape factor range and to the thickness of protective product range as defined in 5.5.

Use these steel temperatures presented in the assessment report as required in Clause 6.

Step 11 – Reporting of the results:

Report the results and their assessment according to Clause 6.

Annex E
(informative)

Assessment methodology: Differential equation analysis (constant λ approach)

E.1 Methodology

The following stepwise methodology shall be performed:

a) Step 1: Input data from test results

b) Step 2: Determining the λ for a defined design steel temperature

c) Step 3: Linear regression

d) Step 4: Verification of criteria of acceptability

e) Step 5: Modification of c_0

f) Step 6: Presentation of results

g) Step 7: Reporting of the results

Step 1 – Input data from test results:

Input Data

— the design temperatures as defined in 5.5

— the corrected times to reach the design temperatures

— the calculated section factor for the steel members

— the mean thickness of the protection material only

— for passive materials only, the moisture plateau is determined as follows:

For each short section, evaluate the moisture plateau length D_p as shown in Figure E.1 according to the following procedure:

The moisture plateau is the distance in minutes between the intercept of the straight line (d_1) and that of the similar straight line (d_2) with the line t = 100 °C

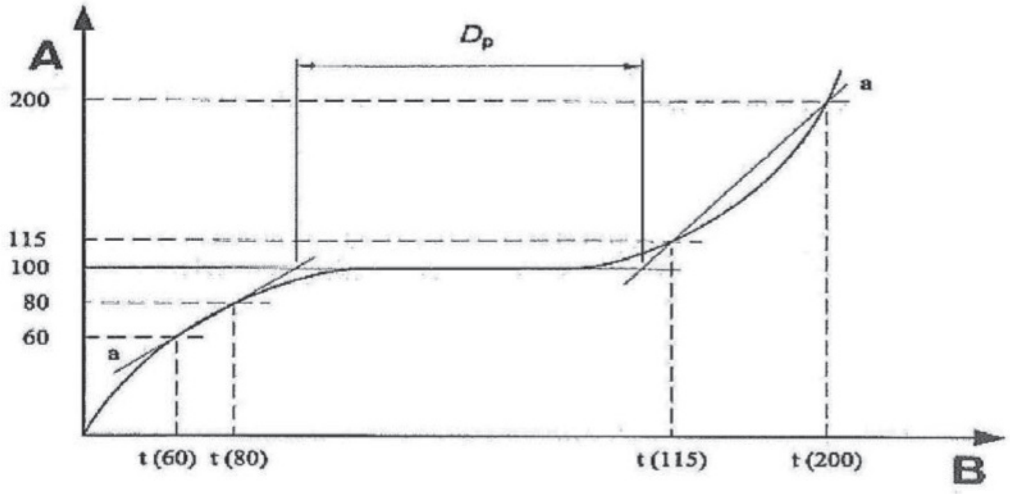
where

d_1 is the straight line drawn through the following temperature points (60 °C/$t_{60\,°C}$) and (80 °C/$t_{80\,°C}$);

d_2 is the straight line drawn through the following temperature /time points (115 °C/$t_{60\,°C}$) and (200 °C/$t_{80\,°C}$).

For the determination of the moisture plateau, the steel temperature of each short section is calculated as defined in 3.15;

— the corrected times taking account the moisture plateau to reach the design temperature, i.e. corrected time as defined in B.1 minus the moisture plateau D_p



Key

A temperature °C

B time (min)

Figure E.1 — Determination of the length of the moisture plateau

Step 2 – Determining the λ for a defined design steel temperature:

Formula (E.1) provides a relationship of the steel temperature against time. All variables except λ are known. For each short section, determine λ using Formula (E.1) by iteration in order to match the corrected time and calculated time to reach the design steel temperature.

Basic formula

The temperature increase during a time step Δt of a steel section protected by a protection material can be determined using the basic differential Formula (E.1) for reactive materials and Formula (E.2) for passive materials:

$$\Delta\theta_{\mathrm{a,t}} = \left[\frac{\lambda_{\mathrm{p,t}}/d_{\mathrm{p}}}{c_{\mathrm{a}}\rho_{\mathrm{a}}} \times \frac{A_{\mathrm{m}}}{V} \times \left(\theta_{\mathrm{t}} - \theta_{\mathrm{a,t}}\right)\Delta t \right] \quad \text{(E.1)}$$

$$\Delta\theta_{\mathrm{a,t}} = \left[\frac{\lambda_{\mathrm{p,t}}/d_{\mathrm{p}}}{c_{\mathrm{a}}\rho_{\mathrm{a}}} \times \frac{A_{\mathrm{m}}}{V} \times \left(\frac{1}{1+\varphi/3} \right) \times \left(\theta_{\mathrm{t}} - \theta_{\mathrm{a,t}}\right)\Delta t \right] - \left[\left(e^{\varphi/10} - 1 \right) \Delta\theta_{\mathrm{t}} \right] \quad \text{(E.2)}$$

where

$$\varphi = \frac{c_{\mathrm{p}}\rho_{\mathrm{p}}}{c_{\mathrm{a}}\rho_{\mathrm{a}}} \times d_{\mathrm{p}} \times \frac{A_{\mathrm{m}}}{V}$$

Step 3 – Linear regression:

For a defined steel temperature, a general function for λ can be obtained by linear regression (least squares method) and using the formula

$$\lambda_{\mathrm{p}} = c_0 + c_1 \times A_{\mathrm{m}}/V + c_2 \times d_{\mathrm{p}} \quad \text{(E.3)}$$

Determine the constants c_0, c_1, and c_2 by solving the regression formula using all the data points of the short sections for a defined design steel temperature.

Step 4a – Verification of criteria for acceptability (reactive materials):

For each design steel temperature, calculate λ using the constants c_0, c_1, and c_2 and Formula (E.3). Use the basic Formula (E.1) to calculate the theoretical time to reach the given steel temperature for each short section.

Determine whether the results meet the acceptability criteria of 5.5 a), b), and c).

Step 4b – Verification of criteria for acceptability (passive materials):

Determine a smooth curve of moisture plateau length (D_p) versus fire protection material thickness (d_p) shown in Figure E.1 as follows:

$$D_p = C \times d_p^3 \qquad \text{(E.4)}$$

where

$$C = \frac{\sum_{i=1}^{n} d_p^3 \times D_p}{\sum_{i=1}^{n} d_p^6}$$

where

n is the number of specimens;

D_p is the moisture plateau length for each short section calculated according to Step 1 (minutes);

d_p is the thickness of fire protection material on each short section (mm).

For each design steel temperature, calculate λ using the constants c_0, c_1 and c_2 and Formula (E.3). Use the basic Formula (E.2) to calculate the theoretical time to reach the given steel temperature for each short column.

The moisture plateau length may be introduced as follows and as shown in Figure E.1.

— Calculate θ_a using Formula (E.2) until θ_a = 100 °C obtained to give time t_1.

— Calculate D_p as a function of the thickness of fire protection material d_p.

— Add this time to t_1.

For time after ($t_1 + D_p$), calculate θ_a using Formula (E.2).

Determine whether the results meet the acceptability criteria of 5.5 a), b), and c).

Step 5 – Modification of c_0:

If the acceptability criteria are not met initially, repeat Step 4 with modified c_0 until the acceptability criteria of 5.5 a), b), and c) are met. The outcome of the analysis is the combination of regression coefficients c_0 (modified if appropriate), c_1, and c_2.

Step 6 – Presentation of the results:

Use the regression coefficients c_0, c_1, and c_2, as well as Formula (E.1) (reactive) and Formula (E.2) (passive) with Formula (E.3), taking into account the moisture plateau, if relevant, to determine the information to be presented in the report of the assessment as required in Clause 6.

Step 7 – Reporting of the results:

Report the results and their assessment according to Clause 6.

Annex F
(informative)

Assessment methodology: Numerical regression analysis

F.1 Methodology

The following stepwise methodology shall be performed:

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

b) Step 6: Reporting of the results

Input Data:

— design temperatures as defined in 5.5

— corrected times to reach the design temperatures

— calculated section factor for the steel members

— thickness of the protection material only

Basic Formula

The multiple linear numerical regression analysis is conducted using Formula (F.1).

$$t = a_0 + a_1 d_p + a_2 \frac{d_p}{A_m/V} + a_3 \theta_a + a_4 d_p \theta_a + a_5 d_p \frac{\theta_a}{A_m/V} + a_6 \frac{\theta_a}{A_m/V} + a_7 \frac{1}{A_m V} \quad \text{(F.1)}$$

where

a_0 to a_7 are regression coefficients.

Steps 1 to 5: Use of output data from the test results:

Step 1:

Determine the constants a_0, a_1, a_2, a_3, a_4, a_5, a_6, and a_7 by solving the regression formula using all the test data for design temperatures from the minimum to the maximum temperature appropriate for which the analysis is requested, in 50 °C intervals.

Step 2:

Using the constants, 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 measured times and determine whether the results meet the criteria of 5.5 a), b), and c).

Step 4:

If necessary, determine for each of the three acceptance criteria a simple linear modification factor “x” where “x” ≤ 1.0 which, when applied to all the regression constants, causes the predicted times to just meet the acceptance criteria.

Step 5:

Use the modified regression coefficients to determine the information to be presented in the report of the assessment as required in Clause 6. This will require the transposition of Formula (F.1) to determine the protection thickness required for a given section factor for each required period of fire resistance period and for each steel temperature. Formula (F.2) should be used to determine the thickness.

$$d_p = \frac{t - a_0 - a_3\theta_a - \left(\frac{a_6\theta_a}{A_m/V}\right) - \left(\frac{a_7}{A_m/V}\right)}{a_1 + a_4\theta_a + \left(\frac{a_2}{A_m/V}\right) + \left(\frac{a_5\theta_a}{A_m/V}\right)} \tag{F.2}$$

Step 6: Reporting of the results:

Report the results and their assessment according to Clause 6.

Annex G
(informative)

Assessment methodology: 3D Interpolation method (reactive systems)

G.1 Methodology

The following stepwise methodology shall be performed:

a) Step 1: Use corrected data from test results

b) Steps 2 - 5: Determination of triangles (domains)

c) Steps 6 - 8: Determination of line formulae and plane formulae

d) Step 9: Calculate performance time as a function of dry film thickness

e) Step 10: Calculate performance time as a function of section factor

f) Steps 11 - 13: Calculate required dry film thickness as a function of section factor for specific performance times for each design temperature

g) Step 14: Presentation of results

h) Step 15: Reporting of results

Input data:

The data shall be modified in accordance with the principles given in Annex A.

Basic formulae:

The basic formulae are as follows:

Line formula:

$$y = ax + b \quad \text{(G.1)}$$

Plane formula:

$$ax + by + cz + d = 0 \quad \text{(G.2)}$$

Step 1: Use output data from test results:

Calculate the modified times for each short section to reach the required design temperatures (the temperatures of interest), e.g. 350 °C to 750 °C in 50 °C intervals using the methodology detailed in Annex A.

Steps 2 to 5: Determination of triangles (domains):

Step 2:

Prepare an orthogonal xy-axis system, where *x* represents the section factor (A_p/V) and *y* represents the dry film thickness.

Step 3:

Determine and plot the coordinates (x_i, y_i) for each test specimen, where x_i is the section factor (A_p/V) and y_i is the dry film thickness for test specimen i.

Step 4:

Identify and create triangular domains in the xy-plane using the points (x_i, y_i) as the corner points, in accordance with the following algorithm:

a) Draw the perimeter of the data set by linking subsequent outermost points in the xy-plane with straight lines.

b) Start drawing triangles which share one edge with the perimeter.

c) Divide a trapezium shape (formed by four points at the corners) into two triangles in such a way that the division line is the shortest possible.

d) Work from low A_p/V value to high A_p/V value and work from low to high dry film thickness.

Step 5:

Identify every triangle with a reference.

Steps 6 to 8: Determination of line formulae and plane formulae:

Step 6:

Determine the formulae for the lines which form the triangles.

The formula for the line through the points has a general form:

$$y = ax + b \quad (G.3)$$

Step 7:

Add a z-axis to the orthogonal xy-axis system, where z represents performance time.

Determine and plot the coordinates (x_i, y_i, z_i) for each test specimen

where

x_i is the section factor (A_p/V) for short section i;

y_i is the dry film thickness for short section i;

z_i is the time to reach the design temperature for short section i.

Step 8:

For each triangle, determine the formula of the plane that contains the corner points. The corner points are (x_i, y_i, z_i), where i = 1, 2, 3………n. The formula of the planes has a general form:

$$ax + by + cz + d = 0 \quad (G.4)$$

Each triangular domain has its own unique plane formula .

Step 9: Calculate performance time as a function of dry film thickness:

Calculate the performance time t as a function of dry film thickness. This is established by considering a vertical cross section through the collection of planes for a chosen A_p/V.

Do this for all A_p/V values of interest.

Determine the performance time t for constant A_p/V by inputting a range of dry film thickness values in the plane formula , i.e. calculate the z-value for a range of y-values with constant x. Use the applicable plane formula within the domain of each plane.

Step 10: Calculate performance time as a function of section factor:

Calculate the performance time t as a function of A_p/V. This is established by considering a vertical cross section through the collection of planes for a chosen dry film thickness.

Do this for all dry film thickness values of interest.

Determine the performance time t for constant dry film thickness by inputting a range of A_p/V values in the plane formula , i.e. calculate the z-value for a range of x-values with constant y. Use the applicable plane formula within the domain of each plane.

Steps 11 to 13 - Calculate required dry film thickness as a function of section factor for specific performance times for each design temperature:

Step 11:

Calculate the required dry film thickness as a function of A_p/V in order to achieve a certain performance time t. This is established by considering a horizontal cross section through the collection of planes for a chosen performance time.

Repeat this process for all performance times of interest, i.e. 30, 60, 90, and 120 min.

Determine the required dry film thickness as a function of section factor A_p/V for constant performance time t by inputting a range of A_p/V values in the plane formula , i.e. calculate the y-value for a range of x-values with constant z. Use the applicable plane formula within the domain of each plane.

Step 12:

Repeat step 8 to 12 for every required design temperature (temperature of interest).

Design temperatures may be any temperature, e.g. 350 °C, 400 °C, 450 °C, 500 °C, 550 °C, 600 °C, 620 °C, 650 °C, 700 °C, and 750 °C.

Step 13:

It is possible to determine the steel temperature development as a function of the heating time for any combination of dry film thickness and A_p/V within the domain of the data set (perimeter of all points in the xy-plane). This procedure allows for the steel temperature of any test specimen to be predicted as a function of the heating time, i.e. for test specimens that have not been tested.

This can be achieved by repeating step 8 to 12 for every temperature T from 20 °C up to 750 °C, with temperature steps of 1 °C, i.e. for 20 °C, 21 °C, 22 °C, 23 °C … 750 °C.

Calculate the performance time for every temperature by inputting the dry film thickness and A_p/V in the plane formula for every temperature T.

The temperature development as a function of the heating time is obtained by linking the temperature of the plane formula with the performance time returned from that particular plane formula , e.g.

— 20 °C = 0 min, 23 s

— 21 °C = 2 min, 44 s

— 22 °C = 6 min, 16 s

— 23 °C = 7 min, 34 s

— ... etc.

— 750 °C = 113 min 12 s

Step 14: Presentation of the results:

Present the temperature data and performance times obtained in a scatter plot.

Prepare the graphical outputs and the tables as required in Clause 6.

Step 15: Reporting the results:

Report the assessment results according to Clause 6.

Modification to meet criteria for acceptability:

An analysis carried out using the 3D Interpolation method will automatically meet the criteria for acceptability outlined at 5.5 a), b), and c). In cases where 5.5 d) is not met, then a modification must be carried out. This is done by maintaining a constant value of thickness (Figure G.1) or performance time (Figure G.2) as appropriate in the region of the graphical output where the output is not monotonically rising or is not monotonically declining (see Figure G.2). This should be done conservatively over as short a range as possible such that the unacceptable slope of line is avoided. Figures G.1 and G.2 show examples of correcting for negative and positive slopes:

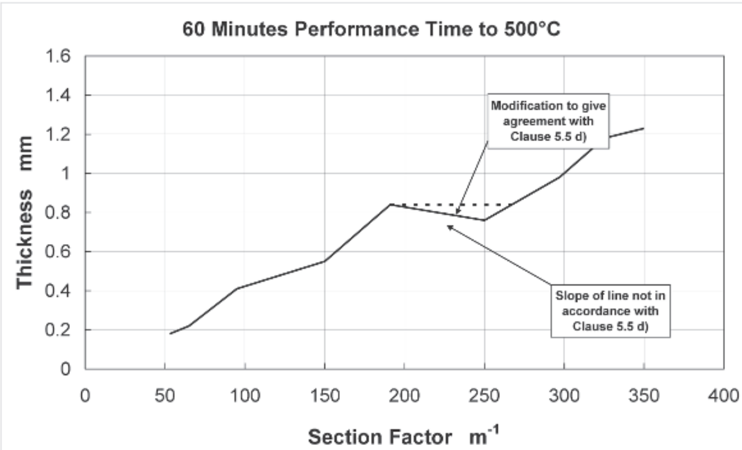


Figure G.1 — Correction for negative slope

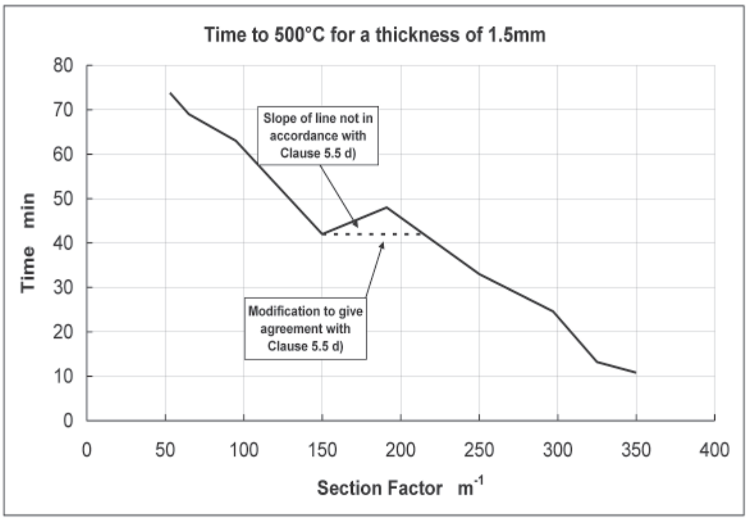


Figure G.2 — Correction for positive slope

Annex H
(normative)

Selection of test specimens — Reactive materials

H.1 Principle of selection

The scope of the assessment will determine the selection of the test specimens. Table H.1 allows for various assessments to be carried out depending upon whether the manufacturer wants to carry out limited or extensive testing. Each test package indicates the minimum number of test specimens required for the given scope.

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table H.1 — Selection of test packages

Scope	Test package	LBmin + LBmax	LCmin + LCmax	TCmax	LHB max	LHB min	LHC max	LHC min	RB	SIB	SIC	TCHS	TRHS	SHB	SHC	Total short sections	Correction procedures from Table B.1
I beams	1	✓								13						13	a)
I columns	2		✓								13					13	b)
I beams + I columns	3	✓		✓						13	13					26	a), c)
I beams + I columns	3A	✓		✓					2		13					15	d)
I beams + I columns + hollow columns	4	✓		✓			✓			13	13	✓	✓		6	32	a), c), e)
I beams + I columns + hollow columns	4A	✓		✓			✓		2		13	✓	✓		6	21	d), e)
I beams + I columns + hollow beams	5	✓		✓	✓					13	13			6		32	a), c), f)
I beams + I columns + hollow beams	5A	✓		✓	✓				2		13			6		21	d), f)
I beams + I columns + hollow beams + hollow columns	6	✓		✓	✓		✓			13	13	✓	✓	6	6	38	a), c), e), f)
I beams + I columns + hollow beams + hollow columns	6A	✓		✓	✓		✓		2		13	✓	✓	6	6	27	d), e), f)
I beams + hollow beams + hollow columns	7	✓			✓		✓			13		✓	✓	6	6	25	a), e), f)
I columns + hollow columns + hollow beams	8		✓		✓		✓				13	✓	✓	6	6	25	b), e), f)
hollow beams + hollow columns	9				✓	✓	✓	✓				✓	✓	6	6	12	g), h)
I beams + hollow beams	10	✓			✓	✓				13				6		19	a), g)
I columns + hollow columns	11		✓				✓	✓			13	✓	✓		6	19	b), h)

Table H.1 *(continued)*

Scope	Test package	LBmin + LBmax	LCmin + LCmax	TCmax	LHB max	LHB min	LHC max	LHC min	RB	SIB	SIC	TCHS	TRHS	SHB	SHC	Total short sections	Correction procedures from Table B.1
I beams + hollow columns	12	✓					✓	✓		13		✓	✓		6	19	a), h)
I columns + hollow beams	13		✓		✓	✓					13			6		19	b), g)
hollow beams	14				✓	✓								6		6	g)
hollow columns	15						✓	✓				✓	✓		6	6	h)

Key:

I refers to both I and H shapes.

LB = Loaded Beam.

LC = Loaded Column.

TC = Tall Column.

LHB = Loaded Hollow Beam.

LHC = Loaded Hollow Beam.

SIB = Short I-section beam.

SIC = Short I-section column.

TCHS = Tall Circular Hollow Beam.

TRHS = Tall Rectangular Hollow Beam.

SHB = Short Hollow Beam.

SHC = Short Hollow Column.

RB = Reference beam.

The test programmes for unloaded sections are required to explore the relationship between fire resistance, dry film thickness, and section factor.

Where the column referring to reference beams is only relevant to test packages where a beam assessment is carried out using short column data, then reference beams at minimum and maximum are required in addition to the short column test sections. In all other cases, the reference beams and columns shall be included in the selected short sections.

Testing of circular and rectangular hollow columns protected with reactive coatings does not conclusively demonstrate that one particular shape is more onerous than another. To allow test data to be used for both types, testing should be undertaken to adequately demonstrate which particular shape is more onerous prior to assessing both hollow shapes on the basis of testing one shape only.

To determine whether the coating performs differently on circular or rectangular hollow columns, a tall column of each type with a nominal section factor of 160 m^{-1} protected with the same coating thickness that relates to the nominal maximum should be tested or the minimum section factor to suit the scope of the assessment.

The nominal section size for tall circular and rectangular hollow columns should be 168,3 mm diameter by 6,3 mm wall thickness and 160 mm × 160 mm × 8,0 mm wall thickness respectively, or the minimum wall thickness to suit the scope of the assessment. In this case, it may be necessary to select the loaded hollow specimen with the same wall thickness as the tall column so that data correction can be carried out using the same reference section.

A comparison of the steel temperature profiles with respect to time to reach each of the design temperatures to be included in the assessment shall be made and the most onerous performance determined.

Once the determination of the most onerous hollow type has been made, the loaded hollow column and short sections may be selected accordingly.

Alternatively tests on both circular rectangular hollow sections may be conducted and assessed separately. In each case, a loaded section will be required with the maximum thickness.

H.2 Sections required for correction for stickability

To take into account the stickability performance of the fire protection product, the temperature data for the short sections is to be corrected against the loaded beams and loaded columns depending upon the selected test programme. The methodology for determining the stickability correction is dependent on the scope of the test package selected from Table H.1 and is described in 5.3.

H.3 Sections required for thermal analysis

H.3.1 Short and H sections

The sections will be selected to cover the range of protection thickness, section factor, and fire resistance period and will include the short reference section equivalent to the loaded section or tall section. Tables H.2 and H.3 give the minimum number of sections required. Additional sections can be tested to allow curve fitting as described in Annex C (graphical method) and Annex G (3D method).

Additional short and tall sections will be required for the analysis of hollow sections similarly chosen to cover the range of protection thickness, section factor, and fire resistance period.

The selection of the specimens will be determined by the scope of the assessment required for the product. This will be on the basis of section factor range (maximum and minimum) and thickness range (maximum and minimum) for each fire resistance period. The range factors will be 1,0 for maximum and 0,0 for minimum and will be determined by the manufacturer.

For short I or H sections, Table H.2 applies.

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table H.2 — Selection of section factor range and thickness range for I and H sections

Section range factor (K_s)	Thickness range factor (K_d)			
	0,0 (d_{min})	0,2 – 0,5	0,5 – 0,8	1,0 (d_{max})
0,0 (s_{min})	✓	✓	✓	
	✓ptp			
0,2 – 0,5	✓		✓	✓
	✓ptp			
	✓ptp	✓ptp	✓ptp	✓ptp
0,5 – 0,8	✓	✓	✓	✓
		✓ptp	✓ptp	✓ptp
		✓ptp	✓ptp	✓ptp
1,0 (s_{max})		✓	✓	✓

If the graphical method of analysis according to Annex C is to be used, then reference shall be made to Table C.3 to ensure that the correct number of thickness steps are included in the selection of the test specimens.

Table H.2 applies to beams and columns separately.

Table H.2 is an example and in any choice there shall be at least three sections in each row and three sections in each column except in the case of the additional ptp sections.

The loaded beam at maximum thickness shall be in the section factor range of 0,2 to 1,0 and the loaded beam at minimum thickness shall be in the section factor range of 0,2 to 0,8.

Actual thicknesses and section factor are calculated in accordance with Formulae (H.1) and (H.2) respectively.

At least one short beam section shall have a minimum web depth of 600 mm.

The minimum number of short sections is 13 for beams and 13 for columns.

The section factors indicated in Table H.2 with a ptp reference are required as additional sections which are intermediate to the section factor ranges on either side when using a point-to-point graphical assessment for a particular nominal thickness line.

If only short columns are used to assess beams, then reference beams shall also be included for both minimum and maximum loaded beam tests.

If only short columns are used to assess beams, then the maximum web depth will be limited to the web depth of the loaded beam plus 50 %.

H.3.2 Hollow sections

For short hollow sections, Table H.3 applies.

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table H.3 — Selection of section factor range and thickness range for hollow sections

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})		✓	✓

Table H.3 applies to hollow beams and columns separately.

Table H.3 is an example and in any choice there shall be at least two sections in each row and two sections in each column.

The loaded hollow beam at maximum thickness shall be in the section factor range of 0,5 to 1,0 and the loaded hollow beam at minimum thickness shall be in the section factor range of 0,5 to 1,0.

Actual thickness and section factor are calculated in accordance with Formulae (H.1) and (H.2) respectively.

The minimum number of short sections is six for beams and six for columns.

This lower number of sections than in Table H.2 only allows for a limited assessment, i.e. a fixed protection thickness for each section factor with no interpolation between the tested thickness ranges. For a full assessment, then the same approach and number of sections given in Table H.2 shall be used.

The actual values of the range factor may be derived from Formulae (H.1) and (H.2).

For thickness:

$$d_p = K_d \left(d_{max} - d_{min} \right) + d_{min} \tag{H.1}$$

e.g. Thickness range 0,2 to 1,2 mm

Then thickness for a K_s factor of 0,5 is [(1,2 – 0,2) × 0,5] + 0,2 = 0,7 mm.

For section factor:

$$s_p = K_s \left(d_{max} - d_{min} \right) + d_{min} \tag{H.2}$$

where

s_p is the section factor at factor K_s;

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

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

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

Then section factor for a K_s factor of 0,5 is [(300 - 60) × 0,5] + 60 = 180 m^{-1}.

The section factor may be determined by the manufacturer subject to the selection of the actual test profile by the test laboratory. The test specimens used shall be selected from the tables in Annex J.

Annex I
(normative)

Selection of test specimens — Passive materials

I.1 Principle of selection

The scope of the assessment will determine the selection of the test specimens. Tables I.1 and I.2 allows for various assessments to be carried out depending upon whether the manufacturer wants to carry out limited or extensive testing. Each test package indicates the minimum number of test specimens required for the given scope.

Loaded beam testing of a particular fire protection supporting system is applicable also to columns using the same supporting system. The same protection system is defined as a system that identically reflects the bottom half of the beam protection system. It must also use the same fixing method in the upper half of the beam. For example, if the beam system only uses support noggins, then the column protection system can be regarded as being the same if the noggins are also used in the column protection system and they are located at the same spacing. If the beam system uses angles in the upper part of the beam casing but not in the lower part, then the same angles must be used in the column casing system. Otherwise, the two systems are regarded as different and a loaded column must be tested.

Fire protection systems that include a different number of layers of board, slab, or mat must be regarded as more than one system. Therefore, a single-layer system requires a separate package of tests and assessment from the multi-layered system. For example, if a board system requires up to three layers of board, then two test and assessment packages are required, i.e. one for the single-layer system and one for the two- and three-layer systems combined.

If fire protection render systems are tested without any reinforcing mesh, then mesh can be added in practice. If mesh is used in the tested system, then it must be used in practice.

Table I.1 applies to boards and sprayed coatings. In the case of boards, slabs, or mats, the column and beam fixing methods must be the same for the combined columns and beams option (test packages 3 and 4)

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table I.1 — Selection of test packages

Scope	Test package	Loaded beams selected from I.2	Loaded columns selected from I.2	RB[b]	RC[c]	SIB	SIC	Total short sections	Correction procedures from Table B.2
I beams[a]	1	✓		2		11		13	a)
I columns	2		✓		2		11	13	b)
I beams[a] + I columns	3	✓		2			13	15	d)
I beams[a] + I columns	4	✓		2			13	26	c)

Key:

a I means both I and H shapes.

b This beam shall be included in the thermal analysis.

c This column shall be used in the thermal analysis.

The sponsor can adopt the principles given in Annex A for structural hollow sections. If this is the case, testing of the appropriate “I” or “H” sections in accordance with ISO 834-10 must be carried out.

In the case of board, slab, or mat protection where the fixing method for hollows differs from that of I or H sections or where a separate assessment of hollow sections is required, Table I.2 applies.

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table I.2 — Selection of test package for hollow sections where the fixing of boards is different to I and H sections

Scope	Test package	Loaded beams selected from I.2	Loaded columns selected from I.2	References sections	Short hollow beams	Short hollow columns	Total short sections	Correction procedures from Table B.2
Rectangular beams	1	✓		2	4		6	e)
Hollow columns	2		✓	2		6	6	f)

A test programme for unloaded sections is required to explore the relationship between fire resistance, protection thickness, and section factor. A typical programme will include at least six sections where a range of thickness is required.

I.2 Sections required for correction for stickability

To take into account the stickability performance of the fire protection product, the temperature data for the short sections is to be corrected against the loaded beams and loaded columns depending upon the selected test programme. The methodology for determining the stickability correction is dependent on the scope of the test package selected from Tables I.1 and I.2 and is described in this part of ISO 834.

Guidance for the selection of loaded sections for evaluating stickability is given in Tables I.3, I.4, and I.5.

Table I.3 — Selection of test specimens for evaluating stickability: Renderings

Loaded section	Protection thickness	Section factor	Minimum depth or width mm
Beam 1	Maximum	Maximum to suit scope of assessment	300
Beam 2	Minimum	Maximum to suit scope of assessment	300
Column 1	Maximum	Maximum to suit scope of assessment	200
Column 2	Minimum	Maximum to suit scope of assessment	200

Table I.4 — Selection of test specimens for evaluating stickability: Single-layer board/slab systems

Loaded section	Protection thickness	Section factor	Minimum depth mm
Beam 1	Maximum	Maximum to suit scope of assessment	300
Beam 2	Minimum	Maximum to suit scope of assessment	300
Column 1	Maximum	Maximum to suit scope of assessment	200
Column 2	Minimum	Maximum to suit scope of assessment	300

Table I.5 — Selection of test specimens for evaluating stickability: Multi-layer board/slab systems

Loaded section	Protection thickness	Section factor	Minimum depth mm
Beam 1	Maximum single layer	Maximum to suit scope of assessment	300
Beam 2	Maximum multi layer	Maximum to suit scope of assessment	300
Beam 3	Minimum single layer	Maximum to suit scope of assessment	300
Column 1	Maximum single layer	Maximum to suit scope of assessment	200
Column 2	Maximum multi layer	Maximum to suit scope of assessment	200
Column 3	Minimum single layer	Maximum to suit scope of assessment	200

Not all loaded sections will be required to demonstrate stickability; therefore, refer to I.1 for the selection of the tests required.

The methodology for determining the stickability correction is dependent on the scope of the test package selected from Table I.1 and Table I.2 and is described in Annex B.

Correction factors for single-layer systems shall apply only to thermal data from single layer testing.

Correction factors for multiple-layer systems shall apply only to thermal data from multiple layer testing

For multiple-layer systems tested on beams and columns, the section with the minimum protection thickness shall use two layers of the thinnest board, slab, or mat and the section with the maximum thickness shall use two or more layers of the maximum thickness board, slab, or mat. In the latter case, the outer layer of the board, slab, or mat may be replaced by a thinner layer to produce the maximum thickness to meet the scope of the assessment.

The location of the thinnest layer must be the same as in practice. For example, if the thinnest layer is tested as the outer layer of the system, then it must be the outer layer in practice.

I.3 Sections required for thermal analysis

I.3.1 Short I and H sections

The sections will be selected to cover the range of protection thickness, section factor, and fire resistance period and will include the short reference section equivalent to the loaded section. Tables I.6 and I.7 give the minimum number of sections required. Additional sections can be tested to allow curve fitting as described in the graphical assessment (Annex C).

Additional short sections will be required for the analysis of hollow sections similarly chosen to cover the range of protection thickness, section factor, and fire resistance period.

The selection of the specimens will be determined by the scope of the assessment required for the product. This will be on the basis of section factor range (maximum and minimum) and thickness range (maximum and minimum) for each fire resistance period. The range factors will be 1,0 for maximum and 0,0 for minimum and will be determined by the manufacturer.

For short I or H sections, Table I.6 applies:

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table I.6 — Selection of specimens for thermal analysis: Short I or H sections

Section factor range (K_s)	**Thickness range factor (K_d)**			
	0,0 (d_{min})	0,2 – 0,5	0,5 – 0,8	1,0 (d_{max})
0,0 (s_{min})	✓	✓	✓	
	✓ptp			
0,2 – 0,5	✓		✓	✓
	✓ptp			
	✓ptp	✓ptp		✓ptp
0,5 – 0,8	✓	✓	✓	✓
		✓ptp	✓ptp	✓ptp
		✓ptp	✓ptp	✓ptp
1,0 (s_{max})		✓	✓	✓

Notes to Table I.6:

a) Table I.6 applies to beams and columns separately.

b) The above is an example – in any choice there must be at least three sections in each row and three sections in each column.

c) The loaded beam at maximum thickness must be in the section factor range (0,2-1,0).

d) The loaded beam at minimum thickness must be in the section factor range (0,2-0,8).

e) Actual section factor and thickness are calculated in accordance with Formulae (I.1) and (I.2).

f) The scope of the assessment will be limited to beams with a maximum depth equal to two times that of the tested loaded beam protected with the appropriate protection thickness.

g) The scope of the assessment will be limited to columns with a maximum depth equal to two times that of the tested loaded beam or loaded column up to a maximum of 600 mm.

h) Minimum total number of short sections is 13 for beams and 13 for columns. If the system uses less than four thicknesses in practice, these thicknesses are tested and each thickness must be tested at every range of section factor.

i) If only short columns are used to assess beams, then reference beams must also be included for both minimum and maximum loaded beam tests.

j) If only short columns are used to assess beams, then the maximum web depth will be limited to the web depth of the loaded beam plus 50 %.

k) If short I or H sections are to be used to assess the performance of hollow sections, then this shall be in accordance with Annex A.

l) The sections indicated in Table I.6 with a ptp reference are required as additional sections which are intermediate to the section factor ranges on either side when using a point-to-point graphical assessment for a particular nominal thickness line.

I.3.2 Hollow sections

If hollow sections are to be tested and assessed separately, then Table I.7 applies.

NOTE Additional specimens may be needed for heavier steel sections as identified by local needs.

Table I.7 — Selection of specimens for thermal analysis: Hollow sections

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})		✓	✓

Notes to Table I.7

a) Table I.7 applies to hollow beams and columns separately.

b) The above is an example – in any choice there must be at least two sections in each row and two sections in each column.

c) The loaded beam at maximum thickness must be in the section factor range (0,5-1,0).

d) The loaded hollow column at maximum thickness must be in the section factor range (0,5-1,0).

e) Actual section factor and thickness are calculated in accordance with Formulae (I.1) and (I.2).

f) Minimum total number of short sections is six for beams and six for columns = 12 in total. If the system uses less than three thicknesses in practice, these thicknesses are tested and each thickness must be tested at every range of section factor.

This lower number of sections than in Table I.5 only allows for a limited assessment, i.e. a fixed protection thickness for each section factor with no interpolation between the tested thickness ranges.

For a full assessment, then the same approach and number of sections given in Table I.5 shall be used.

The scope of the assessment will be limited to beams with a maximum depth equal to 1,5 times that of the tested loaded beam protected with the appropriate protection thickness.

The scope of the assessment will be limited to columns with a maximum depth equal to two times that of the tested loaded beam or loaded column up to a maximum of 600 mm.

For some fire resistance periods, the loaded section may not be the maximum section factor but it must be protected by the maximum thickness.

The actual values of the range factor may be derived from Formulae (I.1) and (I.2).

For thickness:

$$d_p = K_d \left(d_{max} - d_{min} \right) + d_{min} \tag{I.1}$$

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 1,2 mm

Then thickness for a K_s factor of 0,5 is [(1,2 – 0,2) × 0,5] + 0,2 = 0,7 mm.

For section factor

$$s_p = K_s \left(s_{max} - s_{min} \right) + s_{min} \tag{I.2}$$

where

s_p is thickness at factor K_s;

s_{max} is maximum thickness at K_s factor of 1;

s_{min} is minimum thickness at K_s factor of 0.

Then section factor for a K_s factor of 0,5 is [(300 - 60) × 0,5] + 60 = 180 m^{-1}.

The section factor may be determined by the manufacturer subject to the selection of the actual test profile by the test laboratory.

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