BS EN 13381-4:2013

BSI Standards Publication

Test methods for determining the contribution to the fire resistance of structural members

Part 4: Applied passive protection to steel members

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National foreword

This British Standard is the UK implementation of EN 13381-4:2013. It supersedes DD ENV 13381-4:2002 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee FSH/22/-/12, Fire resistance tests For Protection Systems.

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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Compliance with a British Standard cannot confer immunity from legal obligations.

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

Méthodes d'essai pour déterminer la contribution à la résistance au feu des éléments de construction - Partie 4 : Protection passive appliquée aux éléments en acier

Prüfverfahren zur Bestimmung des Beitrages zum Feuerwiderstand von tragenden Bauteilen - Teil 4: Passive Brandschutzmaßnahmen für Stahlbauteile

This European Standard was approved by CEN on 10 February 2013.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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Foreword

This document (EN 13381-4:2013) has been prepared by Technical Committee CEN/TC 127 “Fire safety in buildings”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by November 2013, and conflicting national standards shall be withdrawn at the latest by November 2013.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes ENV 13381-4:2002.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

With respect to the previous version, the following changes have been made:

— A change has been made to the test method to introduce of a means allowing loaded beams to reach a deflection of L/30.

— In addition the graphical assessment method now includes a point to point method of constructing lines and a new virtual data point related to furnace temperature.

This document is compatible with EN 13381-8 and specifically deals with the testing and assessment of passive fire protection systems (sprays, renderings, mat products and boards) designed to protect structural steel.

This document is part of the EN 13381 series with the general title *Test methods for determining the contribution to the fire resistance of structural members*. Other parts of this series are:

— *Part 1: Horizontal protective membranes*;

— *Part 2: Vertical protective membranes*;

— *Part 3: Applied protection to concrete member*;

— *Part 4: Applied passive protection to steel members* (the present document);

— *Part 5: Applied protection to concrete/profile sheet steel and composite members*;

— *Part 6: Applied protection to concrete filled steel composite members*;

— *Part 7: Applied protection to timber members*;

— *Part 8: Applied reactive protection to steel members*.

CAUTION — The attention of all persons concerned with managing and carrying out this fire resistance test, is drawn to the fact that fire testing can be hazardous and that there is a possibility that toxic and/or harmful smoke and gases can be evolved during the test. Mechanical and operational hazards can also arise during the construction of test elements or structures, their testing and the disposal of test residues. An assessment of all potential hazards and risks to health should be made and safety precautions should be identified and provided. Written safety instructions should be issued. Appropriate training should be given to relevant personnel. Laboratory personnel should

ensure that they follow written safety instructions at all times. The specific health and safety instructions contained within this standard should be followed.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

This European Standard specifies a test method for determining the contribution made by applied passive fire protection systems to the fire resistance of structural steel members, which can be used as beams or columns. It considers only sections without openings in the web. It is not directly applicable to structural tension members without further evaluation. 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 bracing. This European Standard does not apply to solid bar or rod.

This European Standard covers fire protection systems that involve only passive materials and not to reactive fire protection materials as defined in this document.

The evaluation is designed to cover a range of thicknesses of the applied fire protection material, a range of steel sections, characterised by their section factors, a range of design temperatures and a range of valid fire protection classification periods.

This European Standard contains the fire test procedures, which specifies the tests which should be carried out to determine the ability of the fire protection system to remain coherent and attached to the steelwork, and to provide data on the thermal characteristics of the fire protection system, when exposed to the standard temperature/time curve specified in EN 1363-1.

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

This European Standard also contains the assessment, which prescribes how the analysis of the test data shall be made and gives guidance on the procedures by which interpolation should be undertaken.

The assessment procedure is used to establish:

a) on the basis of temperature data derived from testing loaded and unloaded sections, a correction factor and any practical constraints on the use of the fire protection system under fire test conditions, (the physical performance);

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

The limits of applicability of the results of the assessment arising from the fire test are defined, together with permitted direct application of the results, to different steel sections and grades and to the fire protection system.

The results of the test and assessment obtained according to this European Standard are directly applicable to steel sections of I and H cross sectional shape and hollow sections.

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.

EN 12467, *Fibre cement flat sheets — Product specification and test methods*

EN 13162, *Thermal insulating products for buildings — Factory made mineral wool (MW) products — Specification*

EN 823, *Thermal insulating products for building applications — Determination of thickness*

EN 13501-1, *Fire classification of construction products and building elements — Part 1: Classification using data from reaction to fire tests*

EN 1363-1, *Fire resistance tests — Part 1: General requirements*

EN 1365-3, *Fire resistance tests for loadbearing elements — Part 3: Beams*

EN 1365-4, *Fire resistance tests for loadbearing elements — Part 4: Columns*

EN 1993-1-1, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings*

EN 1993-1-2, *Eurocode 3: Design of steel structures — Part 1-2: General rules - Structural fire design*

EN 10025-1, *Hot rolled products of non-alloy structural steels — Part 1: General technical delivery conditions*

EN ISO 13943, *Fire safety — Vocabulary (ISO 13943)*

ISO 8421-2:1987, *Fire protection — Vocabulary — Part 2: Structural fire protection*

ETAG 018-Part 3, *Guideline for European Technical Approval of Fire Protective Products — Part 3: Renderings and rendering kits intended for fire resisting applications*

ETAG 018-Part 4, *Guideline for European Technical Approval of Fire Protective Products — Part 4: Fire protective board, slab and mat products and kits*

3 Terms and definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1363-1, EN ISO 13943 and ISO 8421-2, and the following apply:

3.1.1
steel member
element of building construction which is loadbearing and fabricated from steel of the same type as is used in the testing

3.1.2
reactive fire protection material
reactive materials 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

3.1.3
passive fire protection material
materials, which do not change their physical form on heating, providing protection by virtue of their physical or thermal properties

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

3.1.4
fire protection system
fire protection material together with any supporting system including mesh reinforcement astested and with a specific primer and/or topcoat if applicable

3.1.5
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 exposure to fire

3.1.6
test specimen
steel test section comprising columns and beams plus the fire protection system under test

3.1.7
fire protection thickness
dry thickness of an applied protection material or a single layer fire protection system or the combined thickness of all layers of a multilayer fire protection system excluding the thickness of the supporting system or joint cover strips

3.1.8
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 its ability to provide fire protection is not significantly impaired

3.1.9
section factor

3.1.9.1
profiled fire protection systems
ratio of the fire exposed outer perimeter area of the steel structural member itself excluding the protection material, per unit length, to its cross sectional volume per unit length

Note 1 to entry: See Figure 1.

3.1.9.2
boxed fire protection systems
ratio of the sum of the inside dimensions of the smallest possible rectangle or square encasement which can be measured round the steel structural member times unit length, to its volume per unit length

Note 1 to entry: See Figure 1.

3.1.10
design temperature
temperature of a steel structural member for structural design purposes

3.1.11
characteristic steel temperature
temperature of the steel structural member which is used for the determination of the correction factor for stickability calculated as (mean temperature +maximum temperature)/2

3.1.12
steel temperature
overall mean temperature to be used as input data for the analysis is calculated:

— for I and H section beams as the mean of the upper flange plus the mean of the web plus the mean of the lower flange divided by three;

— for I, H and hollow section columns as the sum of the means of each measuring station divided by the number of measuring stations;

— for hollow section beams as the mean of the sides plus the mean of the bottom face divided by two

3.2 Symbols and units

Symbol	Unit	Description
LB		loaded beam section
UB		unloaded short beam section
LC		loaded 3 m column section
SC		unloaded short column section
p		fire protection material
a		steel
f		furnace
d		thickness
ρ		density
t_l	min	time for the loaded section to reach the design temperature
t_1	min	time for the reference section to reach the design temperature
S	m^{-1}	section factor of the loaded section
S_1	m^{-1}	section factor of the reference section
D	mm	the protection thickness for the loaded section
D_1	mm	protection thickness for the reference section
d_{max}	mm	maximum protection thickness of the loaded section
d_{min}	mm	minimum protection thickness of the loaded section
d_i	mm	protection thickness of the short section
k_{imax}		stickability correction factor at maximum protection thickness
k_{imin}		stickability correction factor at minimum protection thickness
k_i		stickability correction factor for the short section at thickness *d*i
A_m/V	m^{-1}	section factor of the unprotected steel section
A_p/V	m^{-1}	section factor of the protected steel section
A	m^2	cross sectional area of the steel section
V	m^3/m	volume of the steel section per unit length
V_v	m^3/m	volume of the fire protection material per unit length
H	mm	height of the steel column
h	mm	depth of the steel section
B	mm	breadth of the steel section
t_w	mm	thickness of the web of the steel section
t_f	mm	thickness of the flange of the steel section
t	mm	thickness of the wall of a hollow steel section
L_{exp}	mm	length of beam specimen exposed to heating
L_{sup}	mm	length of beam specimen between supports
L_{spec}	mm	length of beam specimen

d_{UB}	mm	thickness of fire protection material on an unloaded beam section
d_{SC}	mm	thickness of fire protection material on an unloaded column section
d_p	mm	thickness of fire protection material concerned
$d_{p(max)}$	mm	maximum thickness of fire protection material used
$d_{p(min)}$	mm	minimum thickness of fire protection material used
$\rho_{protection}$	kg/m^3	density of fire protection material
ρ_{UB}	kg/m^3	density of fire protection material on an unloaded beam section
ρ_{SC}	kg/m^3	density of fire protection material on an unloaded column section
ρ_{LB}	kg/m^3	density of fire protection material on a loaded beam
ρ_a	kg/m^3	density of steel (normally 7 850 kg/m3)
θ_{LB}	°C	characteristic steel temperature of a loaded beam
θ_{UB}	°C	characteristic steel temperature of a short unloaded reference beam
θ_{LC}	°C	characteristic steel temperature of a loaded column
θ_{SC}	°C	characteristic temperature of a short reference column.
$\theta_{c(UB)}$	°C	corrected mean temperature of an unloaded beam section
$\theta_{c(SC)}$	°C	corrected mean temperature of an unloaded column section
θ_t	°C	average temperature of the furnace at time *t*
θ_{at}	°C	average temperature of the steel at time *t*
$\Delta\theta_t$	°C	increase of furnace temperature during the time interval Δt
$\theta_{m(SC)}$	°C	modified steel temperature of an unloaded section
θ	°C	design temperature
K_d		range factor for thickness
K_s		range factor for section factor
c_a	J/(kgK)	temperature dependant specific heat capacity of steel as defined in EN 1993-1-2
c_p	J/(kgK)	temperature independent specific heat capacity of the fire protection material
μ		ratio of heat capacity of the fire protection material to that of the steel section
t	min	time from commencement of the start of the test
t_e	min	time for an unloaded section to reach an equivalent temperature to the loaded beam at time *t*
Δt	min	time interval
t_d	min	time required for a short section to reach the design temperature
λ_p	W/(mK)	effective thermal conductivity of the fire protection material
$\lambda_{char(p)}$	W/(mK)	characteristic value of effective conductivity of the fire protection material
$\lambda_{ave(p)}$	W/(mK)	mean value of λ_p calculated from all the short sections at a temperature θ
$\lambda_{\delta(p)}$		standard deviation of λ_p calculated from all the short sections at a temperature θ
K		constant applied to $\lambda_{\delta(p)}$

4 Test equipment

4.1 General

The furnace and test equipment shall conform to that specified in EN 1363-1.

4.2 Furnace

The furnace shall permit the dimensions of the test specimens to be exposed to heating, as specified in Clause 6 and their installation upon or within the test furnace to be as specified in Clause 7.

4.3 Loading equipment

Loading shall be applied according to EN 1363-1. The loading system shall permit loading to be applied to beams as specified in 5.2.1 and to columns as specified in 5.2.3.

5 Test conditions

5.1 General

A number of short steel, I or H or hollow test sections, protected by the fire protection system, are heated in a furnace according to the protocol given in EN 1363-1.

Loaded and unloaded beams or columns that are likewise heated provide information on the ability of the fire protection system to remain intact and adhere to the steel test sections (stickability).

The method of testing loaded beams in this part of the test method is designed to provide maximum deflection (span/30) under the influence of load and heating. If the rate of deflection exceeds that given in EN 1363-1, then it may not be possible to reach span/30.

It is recommended that the tests be continued until the steel temperature reaches the maximum value commensurate with application of the data.

Where several test specimens are tested simultaneously, care shall be taken that each is adequately and similarly exposed to the specified test conditions.

The procedures given in EN 1363-1 shall be followed in the performance of this test unless specific contrary instructions are given in this standard.

5.2 Support and loading conditions

5.2.1 Loaded beams

Each loaded beam test specimen shall be simply supported and allowance shall be made for free expansion and vertical deflection of the beam. The beam shall not be provided with additional torsional restraint except where deemed necessary as defined in 6.3.1. The simply supported span shall not be greater than the length exposed to heating by more than 400 mm at each end.

The loading shall be applied using either of the two methods described in Figure 2.

The ends of loaded beams outside the furnace shall be insulated with a suitable insulation material.

5.2.2 Unloaded beams

Each unloaded beam test specimen shall be supported as shown in Figure 3.

5.2.3 Loaded columns

For each loaded column, provision shall be made for the proper support, positioning and alignment of the column test specimen in the furnace in accordance with EN 1365-4 subject to any amended or additional requirements of this standard. An example is given in Figure 8.

5.2.4 Unloaded columns

Unloaded column sections shall be supported vertically within the furnace, either installed to the soffit of the furnace cover slabs, (see example in Figure 10), or stood on the furnace floor (directly or on plinths).

5.3 Loading

The loaded beam test specimens shall be subjected to a total load which represents 60 % of the design moment resistance, according to EN 1993-1-1, calculated using the actual steel yield strength from the batch certificate of conformity or an actual measured value.

The actual load applied shall be the calculated total load less the dead weight of the beam, concrete topping and fire protection material etc.

The method of loading shall be by a system which will produce a bending moment which is uniform over at least 20 % of the span of the beam around mid-span.

The loaded column shall be subjected to an applied test load which represents 60 % of the design buckling resistance, according to EN 1993-1-1, calculated using the actual steel yield strength from the batch certificate of conformity or an actual measured value. Details of the calculation made to define the test loads shall be included in the test report.

Loaded steel test sections shall be tested in accordance with EN 1365-3 or EN 1365-4 subject to any amended or additional requirements of this standard.

6 Test specimens

6.1 General

The test sections shall be chosen to suit the scope of the assessment and will include both loaded and unloaded sections. The testing of loaded and reference sections provides the basis for the stickability correction to be applied to the thermal data generated from the unloaded short sections. Depending upon the scope of the assessment, the principle of selecting the loaded and unloaded sections shall be based on the details presented in 6.6. The test sections shall be chosen from the tables in Annex F.

For each test involving a loaded beam or column, an equivalent unloaded reference beam or column section respectively shall be included and tested in the furnace at the same time whenever possible. Where it is not possible to test a loaded column and a reference column together in the furnace then the reference section shall be tested separately in the same furnace in the same position as the loaded column.

For both the maximum and the minimum thickness of the fire protection system, a loaded beam shall be tested to examine stickability during maximum deflection of the steel section around 550 °C, up to a maximum anticipated steel temperature. The two loaded steel beams do not have to be the same size.

It will be necessary to consider loaded tests on both beams and columns if the protection systems are different.

The data from the loaded and equivalent unloaded reference sections shall be used to determine the correction factors for stickability across the range of thickness in accordance with Annex D.

If the assessment is to be confined to four sided protection of columns, the loaded beam tests shall be replaced by loaded column tests. In this case, the unloaded reference beam sections are replaced by unloaded reference column sections.

6.2 Size of test specimens

6.2.1 Loaded beams

Loaded beams shall have an I or H cross sectional shape, or hollow rectangular section.

Each beam shall have a total length, which shall provide for a length exposed to heating of not less than 4 000 mm.

The supported length and specimen length shall be specified as follows:

The span between the supports [L_{sup}] shall be the exposed length plus up to a maximum of 400 mm at each end. The length of the specimen [L_{spec}] shall be the exposed length plus up to a maximum of 500 mm at each end (see Figure 9).

The additional length, required for installation purposes, shall be kept as small as practically possible.

6.2.2 Reference sections

Where practical, each unloaded reference section shall be taken from the same length of steel as its equivalent loaded section, thereby ensuring that it is of the same dimensions and characteristics. If this cannot be achieved the test laboratory should ensure that the reference section is of similar dimensions and characteristics.

For board systems, the minimum length of short beams and columns used as reference sections shall be (1 000 ± 50) mm and joints in the board protection should not be included unless the maximum board length is less than 1 000 mm.

6.2.3 Loaded columns

All loaded columns shall have a minimum height, exposed to heating, of 3 000 mm.

6.2.4 Short sections

The short beams and columns shall have a length of (1 000 ± 50) mm.

6.3 Construction of steel test specimens

6.3.1 Loaded beams

Steel test sections used in loaded beam tests shall be constructed according to Figure 9.

Where the span of the beam is such that additional restraint is required then additional restraint can be provided by installation of web stiffeners as follows, subject to agreement with the sponsor.

To give web stiffness and torsional restraint, the beams may be provided with:

a) Web stiffeners in the form of steel plates or triangular gussets, welded at each loading point. These shall be of thickness at least equal to the thickness of the web and of depth at least 10 mm less than the beam flange depth. Details are shown in Figure 9.

b) Web stiffeners in the form of steel plates or channels, welded at each support point. These shall be of thickness at least equal to the thickness of the web. Web stiffeners comprising steel plates shall be trapezoidal in shape to provide additional torsional restraint. Details are shown in Figure 9.

6.3.2 Unloaded beams

The unloaded beams shall be constructed according to Figure 3.

To minimise heat transfer at the ends of the unloaded beams, the ends shall be protected with insulation board or similar which at elevated temperatures is capable of providing equivalent or greater insulation than that of the fire protection material provided over the length of the test specimen (see Figure 3).

The size of the end protection shall be greater than the total overall dimensions of the fire protection.

6.3.3 Loaded columns

The loaded columns shall be constructed according to Figure 8.

6.3.4 Short columns

Short columns may be constructed according to Figures 13 and 14.

Short columns may be tested on the floor of the furnace or suspended from the ceiling or on plinths.

To minimise heat transfer at the ends of the steel column sections, the ends shall be protected with insulation board or similar, which at elevated temperatures is capable of providing equivalent or greater insulation than that of the fire protection material provided over the height of the column (see Figures 13 and 14).

The size of the end protection shall be greater than the total overall dimensions of the fire protection (see Figure 13).

6.3.5 Application of the fire protection system

The surface of the steel shall be prepared where appropriate and the fire protection system shall be applied to the beams and to the columns in a manner representative of practice. The method of application to columns shall not be different to that for beams, otherwise separate tests and assessment shall be needed incorporating loaded columns. Any variability of density of the fire protection system applied to the loaded and equivalent unloaded beams shall be within the limits specified in 6.5.3.

For board and slab fire protection systems, the loaded beams and loaded steel column section shall incorporate an example of any constructional or peripheral joint that may be used in practice.

In the case of beams, the fire protection system shall be supported from the steel test section or the concrete deck as appropriate. Where the fire protection system is to be fixed to the lightweight concrete deck by artificial means, e.g. bolting through, the assessment shall take into account the intended method of fixing to the supporting structure used in practice.

The fire protection material shall be applied to loaded steel test sections before the load is applied except in the case of loaded beams protected by boards or slabs. In the case of loaded beams protected by board or slab fire protection systems see 10.3 for additional guidance.

The fire protection material shall extend beyond the heated length and shall extend the full height of each column section. In addition and for loaded beams, sufficient clearance should be provided to ensure that the furnace walls cannot interfere with the protection material. This clearance is required to ensure that the fire protection material is not adversely affected when the beam deflects.

Where the fire protection system is of the box type, the ends of the cavity between the material and the steelwork shall be sealed at the point where the test specimen exits the furnace wall to prevent any flow of gases beyond the heated length of the specimen.

Care shall be taken to ensure that during installation of the test specimens into the furnace, or as a result of any movement of the test specimens during the test, the fire protection system is not subjected to any expansion or restraint stresses contrary to its use in practice.

6.4 Composition of steel sections

The grade of steel used shall be any structural grade (S designation) to EN 10025-1 (excluding S185). Engineering grades (E designation) shall not be used.

The dimensions and cross-sectional areas of the steel sections shall be measured, neglecting any internal and external radii. These values shall be used to determine the steel section factors, according to the formulae given in Figure 1.

6.5 Properties of fire protection materials

6.5.1 General

The composition of the fire protection system shall be specified by the sponsor and shall include, at least, its expected nominal density, and moisture content. Additional information may be required relative to the heat capacity for the purpose of assessment.

For confidentiality reasons, the sponsor may not wish detailed formulation or composition details to be reported in the test report. In this case, such data as required by ETAG 018-3 or ETAG 018-4 to characterise the fire protection sprayed coating or board, slab or matt shall be provided.

The dimensions for boards and slabs shall be determined in accordance with EN 13162 (for slabs) and EN 12467 (for boards) and be within the tolerances defined in these standards.

Similarly, the thickness for boards and slabs shall be determined in accordance with EN 823 (for slabs) and EN 12467 (for boards) and be within the tolerances defined in these standards.

The density, moisture content and thickness for sprayed coatings and boards shall be determined in accordance with Annex B.

The actual thickness, density and moisture content of the fire protection material shall be measured and recorded at the time of test for each test specimen. The properties of materials shall be determined on test materials or test samples conditioned as defined in Clause 8.

The procedures appropriate to different types of fire protection material are given in Annex B.

6.5.2 Thickness of protection material

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

The mean shall be the mean of all measurements in accordance with Annex B.

The thickness of sprayed renderings or coated passive fire protection materials shall be measured at the locations specified in Annex B. Thickness measuring points shall not be closer than 150 mm to web stiffeners in loaded beams.

The measurements shall be taken between 50 mm and 100 mm away from each of the thermocouple positions.

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

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

6.5.3 Density and moisture content of fire protection materials

The density and moisture content of the fire protection material (where appropriate) applied to each section shall be measured according to Annex B and recorded.

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

The mean density of fire protection material (or maximum density according to the above criteria for permitted deviation in density) applied to each loaded beam and to the loaded steel column section, where used shall be the same as that applied to its equivalent unloaded beam or short steel column section. The difference between the densities in each case shall not be greater than 10 % of the maximum mean value at that thickness. The test laboratory shall confirm equilibrium values of loaded and reference sections are within 10 % of each other.

6.5.4 Verification of the test specimens

An examination and verification of the test specimen for conformity to specification shall be carried out as described in EN 1363-1.

The properties of the fire protection materials used in the preparation of the test specimens shall be measured, using special samples where necessary, using the methods given in Annex B.

The sponsor shall be responsible for verification that the fire protection material has been applied correctly and in the case of sprayed coatings or renderings, to ensure, by methods appropriate to the material that it is of design composition and specification.

The gap between the internal face of a board or slab system and the steel section shall be recorded. Measurements shall be taken at approximately mid-span and at both ends of a beam casing and at approximately mid-height and at the top of a column casing.

6.6 Selection of test specimens

6.6.1 Principle of selection

The scope of the assessment will determine the selection of the test specimens. Table 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.

Loaded beam testing of a particular fire protection system is applicable also to columns using the same system. The same protection system is defined as a system that identically reflects the bottom half of the beam protection system. It shall 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 similar angles or channels shall be used in the column casing system. Otherwise, the two systems are regarded as different and a loaded column shall also be tested.

Fire protection systems that include a different number of layers of board, slab or matt shall be regarded as more than one system. Therefore, a single-layer system requires a separate package of tests and assessment from the multi-layer 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 a reinforcing mesh then mesh can be added in practice. If the mesh is used in the tested system it shall be used in practice.

Table 1 applies to boards, slabs or mats and sprayed coatings. In the case of boards, slabs or matts the column and beam fire protection systems shall be the same for the combined columns and beams option (test packages 3 and 4).

Table 1

Scope	Test Package	Loaded beams selected from 6.6.2	Loaded columns selected from 6.6.2	RB [b]	RC [e]	SIB [c]	SIC [d]	Total Short Sections	Correction Procedures from Table D.1
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		11	13	26	c)

[a] I represents both I and H shapes.

[b] RB=Reference Beam. This beam shall be included in the thermal analysis.

[c] SIB=Short I-section Beams.

[d] SIC= Short I-section Columns.

[e] RC=Reference Column. This column shall be included 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 this document shall be carried out.

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

Table 2

Scope	Test Package	Loaded beams selected from 6.6.2	Loaded columns selected from 6.6.2	Reference sections	Short Hollow Beams	Short Hollow Columns	Total Short Sections	Correction Procedures from Table D.1
Rectangular Beams	1	✓		2	4		6	e)
Hollow Columns	2		✓	2		4	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.

6.6.2 Sections required for correction for stickability

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

Table 3 — Renderings

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

Table 4 — Boards/Slab/Matt

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

Not all loaded sections will be required to demonstrate stickability therefore refer to 6.6.1 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 1 and Table 2 and is described in Annex D.

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 matt and the section with the maximum thickness shall use two or more layers of the maximum thickness board, slab or matt. In the latter case one of the layers of board, slab or matt 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 shall be the same as in practice. For example, if the thinnest layer is tested as the outer layer of the system, then it shall be the outer layer in practice.

6.6.3 Sections required for thermal analysis

6.6.3.1 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 5 and 6 give the minimum number of sections required. Additional sections can be tested to allow curve fitting as described in E.2 (graphical approach).

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 short, unloaded test specimens for fire protection systems with joints shall not include joints unless the system would normally have joints at less than 1 m centres.

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 5 applies:

Table 5

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

The table applies to beams and columns separately.

The above is an example: in any choice there shall be at least 3 sections in each row and 3 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 (0,2 to 1,0).

The loaded beam at minimum thickness shall be in the section factor range (0,2 to 0,8).

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

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.

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 shall be tested at every section range factor.

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 %.

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.

The sections indicated in Table 5 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.

6.6.3.2 Hollow sections

If hollow sections are to be tested and assessed separately, i.e. when Annex A is not being used, then Table 6 applies:

Table 6

Section Range Factor (K_s)	Thickness Range factor (K_d)		
	0,0 (d_{min})	**0,4 to 0,6**	**1,0 (d_{max})**
0,0 (s_{min})	✓	✓	
0,4 to 0,6	✓		✓
1,0 (s_{max})		✓	✓

The table applies to hollow beams and columns separately.

The above is an example: in any choice there shall be at least 2 sections in each row and 2 sections in each column.

The loaded beam at maximum thickness shall be in the section factor range (0,5 to 1,0).

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

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

Minimum total number of short sections is 6 for beams and 6 for columns (12 in total). If the system uses less than three thicknesses, in practice these thicknesses are tested and each thickness shall be tested at every section range factor.

This lower number of sections than in Table 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 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 2 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 shall be protected by the maximum thickness.

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

For thickness

$$d_p = K_d\ (d_{max} - d_{min}) + d_{min} \quad (1)$$

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.

For example: thickness range 10 mm to 50 mm.

Then thickness for a K_s factor of 0,5 is ((50 - 10) x 0,5) + 10 = 30 mm.

For section factor

$$s_p = K_s\ (s_{max} - s_{min})\ ) + s_{min} \quad (2)$$

where

s_p is section factor at factor K_s;

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

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

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

Then section factor for a K_s factor of 0,5 is ((300 - 60) x 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 F.

7 Installation of the test specimens

7.1 Loaded beam

Lightweight or aerated concrete slabs shall be provided for the beam topping which are bolted to the beam using 12 mm diameter bolts. Only the two sides and the soffit of the beams are exposed to heating, as shown in Figures 2, 11 and 12. The slabs shall have the following properties;

a) The width measures across the beam shall be (600 ± 100) mm.

b) The thickness shall be within the range 150 mm to 200 mm.

c) The maximum length shall be 625 mm.

d) The nominal density of aerated slabs shall be 500 kg/m$^{3.}$

e) The nominal density of lightweight concrete slabs shall be 1 500 kg/m$^{3.}$

f) The concrete slabs shall have a gap between them sufficient to allow the beam to bend.

There shall be a layer of compressible insulation material placed between the concrete slabs and the top surface of the beam. This insulation material shall be a Class A1 insulation material determined in accordance with EN 13501-1 and have an operating temperature of at least 1 000 °C. It will have an uncompressed thickness of 30 mm ± 5 mm and a nominal density of (125 ± 25) kg/m^3. This insulation shall have a width equal to the width of the top surface of the steel beam (see Figure 2).

Each element of the concrete topping shall be secured by at least two fixings. The gap between the elements of the concrete topping shall be filled with fire resistant packing.

At the commencement of the test, the soffit of the concrete topping to the loaded beam shall be nominally flush with the soffit of the adjacent furnace cover slabs.

Arrangements, appropriate to laboratory practice, shall be made to ensure that the gap between the concrete topping to the loaded beam and the adjacent furnace cover slabs is sealed to prevent escape of furnace gases, especially when the beam is subject to deformation during the test. The loaded beam shall be installed, with special attention taken to insulate the bearings of the beam from the influence of heat.

In addition, the ends of the loaded beam outside the furnace should be insulated and sufficient clearance should be provided between the underside of the protection system and the furnace walls to prevent interference.

7.2 Unloaded beams

Each reference beam shall be bolted to the soffit of the furnace cover slabs comprising the same concrete as that used as topping to the loaded beam. All other short section beams shall have an aerated concrete topping. There shall be a suitable steel plate beneath the locking nut.

Each specimen shall be provided with a similar layer of compressible insulation material placed between the soffit and the top flange of the beam as specified in 7.1 for the loaded beam and Figure 3.

The ends of each beam shall be insulated with a layer of rigid or flexible insulation material; an example is given in Figure 3.

7.3 Loaded columns

A loaded column test specimen shall be installed as given in Figure 8 and described in 5.2.3.

7.4 Unloaded columns

Short columns shall be either fixed to the soffit of the furnace cover slabs as shown in Figure 10, or stood on the furnace floor (directly or on plinths).

Sufficient insulation material as specified in 7.1 for the loaded beam and Figure 12 shall be used between all contact surfaces of the steelwork and the cover slab or the furnace floor or plinth to avoid heat transfer via the ends of the sections.

The size of the end protection shall be greater than the total overall dimensions of the fire protection.

7.5 Test specimen installation patterns

For each test involving a loaded beam or column, an equivalent unloaded beam or column section respectively shall be included and tested in the furnace at the same time; otherwise refer to 6.1.

For each loaded beam, the equivalent reference beam shall be positioned parallel to and at mid span of the loaded beam.

Each loaded column and its equivalent short unloaded reference column section shall be installed within the furnace at the same time and tested together wherever possible.

The sections should be positioned within the furnace to ensure the sections are not shielded or affected by furnace walls, other test specimens and other obstacles. A minimum distance of separation of 300 mm is required or a distance equal to the depth of the web if the beam depth is greater than 300 mm. Sections should be placed to avoid direct impact from the furnace burner ports.

A typical test specimen installation pattern useable in a 4 m by 3 m furnace is given in Figure 10.

7.6 Furnace load

In order to ensure that the specified furnace temperature/time relationship is complied with, it may be necessary to control the amount of steel sections within the furnace and their location.

Typically, a furnace of size 4 m by 3 m by about 2 m deep is an example and can accommodate up to 45 kg/m^3 without adverse affect.

8 Conditioning of the test specimens

All test specimens, their components and any test samples taken for determination of material properties shall be conditioned in accordance with EN 1363-1.

9 Application of instrumentation

9.1 General

The instrumentation for measurement of temperature, furnace pressure, applied load and deformation shall comply with the requirements of EN 1363-1.

9.2 Instrumentation for measurement and control of furnace temperature

9.2.1 General

Plate thermometers, of the type specified in EN 1363-1, shall be provided to measure and control the temperature of the furnace and shall be uniformly distributed, as given in EN 1363-1, to give a reliable indication of the temperature in the region of the test specimens. They shall not be placed in positions were they are unable to measure the furnace temperature correctly because they are obstructed by test specimens.

It is likely that the test series will involve at least one test where only short sections are included.

9.2.2 Furnace temperature in the region of loaded beam test specimens

The furnace temperature in the region of each loaded beam test specimen shall be measured by plate thermometers, placed at locations at $^{1}/_{5}$, $^{2}/_{5}$, $^{3}/_{5}$ and $^{4}/_{5}$ of the heated length of the loaded beam, there being two plate thermometers at each location, one on each side of the beam. The plate thermometers shall be positioned at a distance of 500 mm below the soffit as shown in Figure 11.

The plate thermometers shall be oriented so that for half their number side ‘A’ faces the floor of the furnace and for the other half, side ‘A’ faces the longer side walls of the furnace. The distribution of the different orientations shall be such that there shall be equal numbers facing the floor and the wall on each side of the beam.

9.2.3 Furnace temperature in region of loaded column test specimens

Where a loaded column is tested in isolation, the furnace temperature in the region of the column section shall be measured using two plate thermometers placed, on two opposite sides of the column at ¼, ½ and ¾ column height and at a distance of 100 mm from the column.

The plate thermometers shall be oriented so that side ‘A’ faces the side walls of the furnace. The insulated parts shall face towards the column.

At the commencement of the test, the hot junctions of these thermocouples shall be positioned as specified in EN 1363-1.

9.2.4 Furnace temperature in the region of unloaded test specimens

9.2.4.1 Columns on furnace floor with or without a loaded beam

In the case where short columns are included in the same furnace as a loaded beam or a loaded column and they are placed on the floor of the furnace, the furnace temperature in the region of each column section shall be measured using one plate thermometer placed, on one side of the column, at a distance of 0,5 m from the base of column and shall be used to control the furnace temperature as given in EN 1363-1. These thermometers shall be placed as evenly as possible taking into account the location and number of test specimens.

The plate thermometers shall be oriented so that side ‘A’ faces the side walls of the furnace. The insulated parts shall face towards the column.

At the commencement of the test, the hot junctions of these thermocouples shall be positioned as specified in EN 1363-1.

Short columns on plinths (height > 500 mm) are equivalent to the fixing at the ceiling and therefore do not require additional plate thermometers.

9.2.4.2 Short sections fixed to furnace roof with a loaded beam

Where the short beams or short columns are included in the same furnace as a loaded beam and they are fixed to the roof of the furnace, the temperature shall be measured using the plate thermometers positioned as given in 9.2.2.

9.2.4.3 Short sections fixed to furnace roof without a loaded beam

It is likely that the test series will include at least one test where only short sections are installed in the furnace. In such tests, the furnace temperature will be measured by plate thermometers situated in the same position as if a loaded beam was installed as given in 9.2.2.

9.3 Instrumentation for measurement of steel temperatures

9.3.1 General

Thermocouples for measurement and recording of steel temperatures, of the type and fixing given in Annex C, shall be located at measurement stations as specified below (see 9.3.2 to 9.3.5) in the orientation shown in Figures 4 to 7:

a) I or H sections:

   The thermocouples on the flanges shall each be fixed mid-way between the toe of the flange and the web; the thermocouple on the web shall be fixed mid-way between the two flanges.

b) Rectangular hollow columns and beams:

   The thermocouples on the appropriate face shall each be fixed mid-way between the adjacent corners.

c) Circular hollow columns:

   The thermocouples at each measuring station shall each be fixed equidistant around the circumference.

9.3.2 Loaded beams

For each loaded beam there shall be three measurement stations each consisting of five thermocouples for I and H sections and three thermocouples for hollow sections at $^{1}/_{4}$, $^{1}/_{2}$ and $^{3}/_{4}$ of the length of the beam exposed to heating.

For I and H sections two thermocouples shall be attached to the lower flange, on alternate sides of the web at a distance of 250 mm from the central measuring station. For hollow beams these additional thermocouples shall be on the lower face.

Temperature measuring points shall be separated from loading points by at least 150 mm and shall not be closer than 150 mm to web stiffeners where fitted. The thermocouples on the web shall be positioned on alternate sides of the web.

9.3.3 Unloaded beams

For each unloaded beam there shall be three measurement stations, at $^{1}/_{3}$, $^{1}/_{2}$ and $^{2}/_{3}$ of the length of the beam each consisting of three thermocouples. Thermocouples on the web and flanges shall be positioned on alternate sides for adjacent measuring stations for I or H sections.

Similarly, for hollow sections, the thermocouples shall be at similar measuring stations and at the centre of each face.

9.3.4 Loaded columns

For each loaded column there shall be a measurement station consisting of five thermocouples located at a distance of 200 mm from the top of the column and also at, $^{1}/_{3}$ and $^{2}/_{3}$ of the heated length of the column.

Thermocouples on the web shall be positioned on alternate sides of the web.

Similarly, for hollow sections, the thermocouples shall be at similar measuring stations and at the centre of each face.

9.3.5 Unloaded short columns

For each short I or H column there shall be a measurement station consisting of five thermocouples located at a distance of 200 mm from the top of the column and a measuring station consisting of four thermocouples located at mid-height of the column. Thermocouples on the web and flanges shall be positioned on alternate sides for adjacent measuring stations for I or H sections.

For hollow section columns there will be four thermocouples at each measuring station.

9.4 Instrumentation for the measurement of pressure

Equipment for measuring pressure within the furnace shall be provided, located and used as specified in EN 1363-1.

9.5 Instrumentation for the measurement of deformation

For loaded beams, the vertical deformation at mid-span relative to the supports, and for loaded steel columns the axial deformation shall be measured as specified in EN 1363-1.

9.6 Instrumentation for the measurement of load

Instrumentation for the measurement of applied load shall be provided and used as specified in EN 1363-1.

10 Test procedure

10.1 General

Assemble the required number of loaded and unloaded sections forming the testing package appropriate to the scope of the assessment as detailed in Clause 6.

Incorporate these in several tests according to the capacity of the furnace and the criteria of Clause 7.

Carry out checks for thermocouple consistency and establish data points for temperature as specified in EN 1363-1 before commencement of the test and the procedures defined in 10.2 to 10.7.

10.2 Furnace temperature and pressure

Measure and record the furnace temperature in the region of the test specimens using the plate thermometers defined in 9.2.1 and the furnace pressure in accordance with EN 1363-1.

The location of plate thermometers to be used to control the furnace temperature is dependent upon the specimens incorporated within the furnace.

The plate thermometers as specified in 9.2.2 to 9.2.4 will be use to control the furnace to the criteria of EN 1363-1.

10.3 Application and control of load

10.3.1 Loaded beams

Using the procedures of EN 1363-1, apply a constant load to the loaded beam, of magnitude derived in accordance with 5.3, throughout the test period until a deformation of $L_{sup}/30$ is reached or when the rate of deflection exceeds that given in EN 1363-1, at which point, the load shall be removed.

$L_{sup}/30$ shall be reached in the range 500 °C to 600 °C. If this is not achieved after reaching 575 °C then the load shall be increased gradually and carefully until $L_{sup}/30$ is reached. The temperature used shall be the mean of the bottom flange temperatures.

In the case of board protection, it is possible that applying the required load to an already protected beam may lead to disruption of the protection material. Therefore up to 50 % of the required test load shall be applied to the beam prior to the installation of the fire protection.

In the case of the maximum thickness, loaded beam $L/30$ shall be reached within 85 % of the maximum fire resistance period within the scope of the assessment.

10.3.2 Loaded columns

Where a loaded column is tested, apply a constant load of magnitude calculated in accordance with 5.3 throughout the test period until the point of maximum elongation is reached and the column has returned to its original height at which point the load shall be removed.

In the case of the maximum thickness loaded column this shall be reached within 85 % of the maximum fire resistance period within the scope of the assessment.

10.4 Temperature of steelwork

Measure and record the temperature of the loaded and unloaded sections using the thermocouples attached to the steelwork as specified in 9.3 at intervals not exceeding 1 min.

10.5 Deflection

Identify an initial deflection datum point, relative to the supports, before application of the test load. Then, using the procedures of EN 1363-1, apply the test load, measure the zero point for deformation and monitor the deflection of the loaded steel beam and the axial contraction of the loaded steel column section, if used, continuously throughout the test, at intervals not exceeding 1 min.

10.6 Observations

Monitor the general behaviour of each of the specimens throughout the test and record the occurrence of cracking, fissuring, delamination or detachment of the fire protection material and similar phenomena as described in EN 1363-1.

10.7 Termination of test

All tests should provide thermal data up to the maximum temperature required for the scope of the assessment.

For tests that include loaded specimens and when the load has been removed it may be necessary to continue the test until the mean temperature recorded on all the steel sections exceeds the maximum temperature, and the duration of the test exceeds the maximum time period for which the sponsor requires approval. Otherwise terminate the test when one or more of the reasons for termination which are specified in EN 1363-1 occur.

11 Test results

11.1 Acceptability of test results

It is possible that within any test package apparently erroneous results may occur through failure of thermocouples, incorrect assembly of the test specimen. If any results are to be disregarded, i.e. become invalid the laboratory, in consultation with the sponsor, shall justify this and apply the following rules:

Loaded I or H section beams:

- from the 6 thermocouples on the upper flange at least 4 results shall be valid;
- from the 3 thermocouples on the web at least 2 results shall be valid;
- from the 8 thermocouples on the lower flange at least 6 results shall be valid.

Unloaded I or H section beams:

- from the 3 thermocouples on the upper flange at least 2 results shall be valid;
- from the 3 thermocouples on the web at least 2 results shall be valid;
- from the 3 thermocouples on the lower flange at least 2 results shall be valid.

Loaded I or H section columns:

- from the 15 thermocouples on the column at least 9 results shall be valid, with at least 3 valid results at each temperature measurement station.

Unloaded short I or H section columns:

- from the 3 thermocouples on the each flange at least 2 results shall be valid;
- from the 3 thermocouples on the web at least 2 results shall be valid.

Loaded hollow beams:

- from the 11 thermocouples on the beam at least 9 results shall be valid, with at least 2 valid results at each temperature measurement station.

Unloaded hollow beams:

- from the 9 thermocouples on the beam at least 7 results shall be valid, with at least 2 valid results at each temperature measurement station.

Loaded hollow columns:

- from the 12 thermocouples on the column at least 9 results shall be valid, with at least 3 valid results at each temperature measurement station.

Unloaded hollow columns:

- from the 8 thermocouples on the column at least 6 results shall be valid, with at least 2 valid results at each temperature measurement station.

11.2 Presentation of test results

The following shall be reported within the test report:

a) the results of measured dimensions and actual material properties, especially the thickness, density and moisture contents of the fire protection together with those values to be used in the assessment, according to 6.5;

b) the individual results of all furnace temperature measurements and the mean of all individual furnace temperature measurements, taken as specified in EN 1363-1, graphically presented and compared with the specified requirements and tolerances given in EN 1363-1;

c) the individual results of all furnace pressure measurements and the mean of all individual furnace pressure measurements, taken as specified in EN 1363-1, graphically presented and compared with the specified requirements and tolerances given in EN 1363-1;

d) the individual results and the mean steel temperature of each of the flanges, the mean of the web and the overall mean determined as given in 3.1.12 and all individual results of all steel temperature measurement thermocouples at the locations given in 9.3, all graphically presented. Evidence of compliance with the validity criteria of 11.1;

e) the deflection measurements on loaded beams specified in 10.5, all graphically presented. If the load is removed according to 10.3.1, the time at which this occurred;

f) the individual results of the axial contraction measurements on loaded columns specified in 10.5, all graphically presented. If the load is removed according to 10.3.2, the time at which this occurred;

g) observations made and times at which they occur shall be reported.

The results b) to f) may be presented as a selection of the measured data sufficient to give a history of the performance of the test specimen according to EN 1363-1.

The results b) to f) may also be prepared and printed in tabular form and/or presented on computer media. In the latter case, this should be prepared in an appropriate, secure “read only” format to prevent alteration. Only data maintained in the laboratory files shall be used in the assessment,

12 Test report

The test report shall include the following statement:

“This report provides the constructional details, the test conditions, the results obtained and the interpolated data obtained when the specified fire protection system described herein was tested following the procedures of EN 13381-4. Any deviation with respect to thickness and density of fire protection material and constructional details, loads, stresses, edge or end conditions other than those allowed under the field of application could invalidate the test result”.

In addition to the items required by EN 1363-1, the following shall also be included in the test report:

a) the generic description and accurate details of the fire protection system;

b) the name of the manufacturer of the product or products and the manufacturer or manufacturers of the construction;

c) full details of the test specimens including assembly and preparation details including surface preparation, application method, number of layers;

d) description of the fabrication of the test construction and description of the conditioning of the test construction and its installation onto the test furnace;

e) the results of the measurements obtained using the measurement devices in 11.2 a) to f) during the tests presented in graphical format (and any other optional format), as required in 11.2;

f) if possible, a description of significant behaviour of the test specimen observed during the test period, including observations of the time(s) and magnitude of any detachment of fire protection material;

g) the magnitude of the load applied to each test specimen, as a function of time, and if removed (loaded beams and columns), the time at which this occurred;

h) the reason, on the basis of 10.7 of this test method, for the termination of the test and the time elapsed when the test was terminated;

i) details of the calculations used to determine the test load.

13 Assessment

13.1 General

The temperature data obtained from the loaded and unloaded 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 thickness of fire protection of the loaded section column is less than the equivalent short reference section, the time to reach the design temperature is corrected in accordance with Annex D.

The section factor and applied material thickness of the reference sections shall be within ± 10 % of their equivalent loaded sections. The analysis of data shall be made on the basis of an assessment of the test data where the predicted performance satisfies the acceptance criteria given in 13.5 and is fully defined in the assessment report.

The method of analysis shall be selected from the methods given in Annex E. It will be incumbent upon the test laboratory, in consultation with the manufacturer, to utilise the most appropriate of the methods to provide the best relationship of the predicted performance with the test data.

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

This document defines test packages to suit the scope of the assessment determined in accordance with the principles given in Clause 6.

13.2 Temperature data

The steel temperature for assessment purposes shall be the overall mean temperature of each section calculated in accordance with 3.1.12.

13.3 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 D and linear interpolation will be applied to correct the time to reach the design temperature for all the short sections.

The characteristic steel temperature derived in accordance with 3.1.11 shall be used to determine the correction factors.

13.4 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 it shall satisfy the criteria for acceptability and limitations given in 13.5 and Clause 15 respectively.

A minimum number of short sections shall be tested as given in Clause 6. If further data points are required, additional specimens shall be tested.

13.5 Acceptability of the assessment method used and the resulting analysis – criteria for acceptability

The acceptability of the analysis within the range of steel section temperature (as defined by 10.7 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 in minutes to reach the design temperature calculated to one decimal place shall not exceed the corrected time by more than 15 %.

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

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

d) The results of the analysis which satisfy a) to c) above shall also 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 fire resistance time increases the temperature increases.

    4) As thickness increases temperature decreases.

    5) As section factor increases the temperature increases.

    6) As section factor increases thickness increases.

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

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

14 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);

c) the 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) reason for the omission of any test data;

f) general description of the test specimens forming the basis of the assessment including the dimensions of the test specimens, the composition and measured properties of the components required to be determined from 6.5 and their method of determination;

g) the assessment method used;

h) the mean steel temperatures used in the analysis in accordance with 13.2;

i) the corrected times used in the analysis determined in accordance with Annex D;

j) the values of all thermal data required to be calculated by the chosen assessment method;

k) for all methods of analysis the ability of the method to satisfy the criteria for acceptability as specified in 13.5;

l) the thermal analysis shall produce a series of tables and graphical presentations relating to fire resistance 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 needs and different design temperature limits and intervals of section factor may be used. Whatever the presentation interpolation is only allowed over a maximum range of 50 ºC and 10 m^{-1};

m) 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, thicknesses, time periods, three or four sided protection, etc;

n) the report shall include tables of corrected and predicted times.

15 Limits of the applicability of the results of the assessment

The results from this test method and the assessment procedure are applicable to 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.

For an assessment to be valid for any fire resistance period, the loaded sections protected with the maximum protection thickness shall achieve a load bearing capacity performance as defined in 10.3.1 and 10.3.2 within 85 % of this period.

The results of the analysis for columns can be applied to beams exposed on all four sides up to the maximum (fire) protection thickness predicted from the appropriate loaded beam test. The fire protection 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 and as given in EN 10025-1 as specified in 6.1 and with the limitations given therein. The results of the assessment may also applicable to fabricated sections.

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

The maximum depth of a column, (h) shall be limited to the depth of the loaded beam or loaded column plus 100 %. This is subject to a maximum permitted depth of 600 mm for boxed fire protection systems. The assessment is applicable to the method of application used in the test specimen preparation.

The distance of boards/slabs of the fire protection system from steel members shall be as follows;

Tested distance: - 5mm to + 50 mm with no change of fixing.

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 situations 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 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 and channels and T's.

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) The web depth – for large web depths a different support system may be needed.

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

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

Permitted protection thickness for beams

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

Minimum permitted protection thickness: up to 5 % below the minimum tested on a loaded beam.

Permitted protection thickness for columns

Maximum permitted protection thickness: up to 5 % above the maximum thickness tested on a loaded column. if no loaded column is tested and only loaded beams the maximum permitted thickness will be that of the loaded beam.

Minimum permitted protection 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.

Permitted section factor for beams

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

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

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

Permitted section factor for columns

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

Minimum permitted section factor: up to 10 % below up 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 shall be applied.

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

Table 7 — Example of tabulated data

Fire Resistance Period – 30 min								
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								

The temperature range above is an illustration only. The actual range is to be determined by the scope of the assessment.

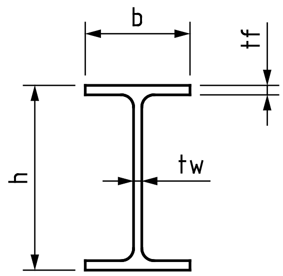
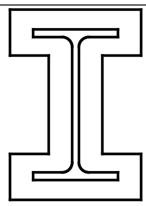
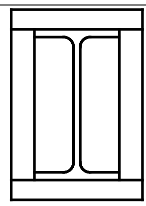
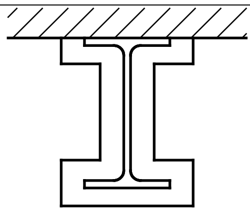
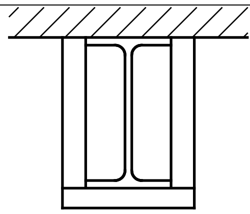
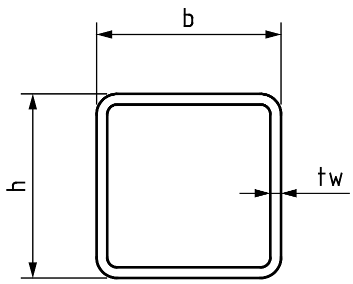
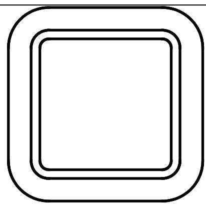
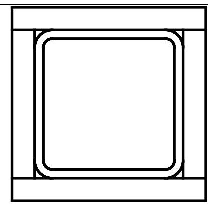
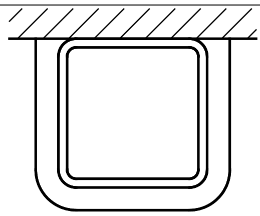
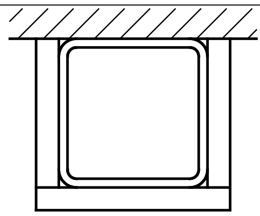
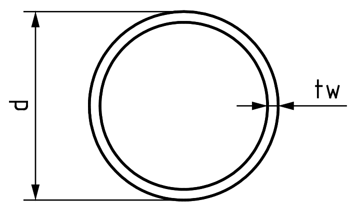
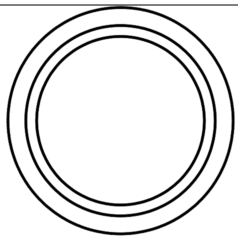
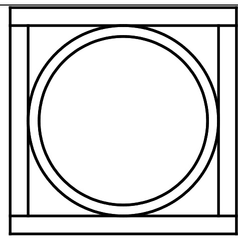
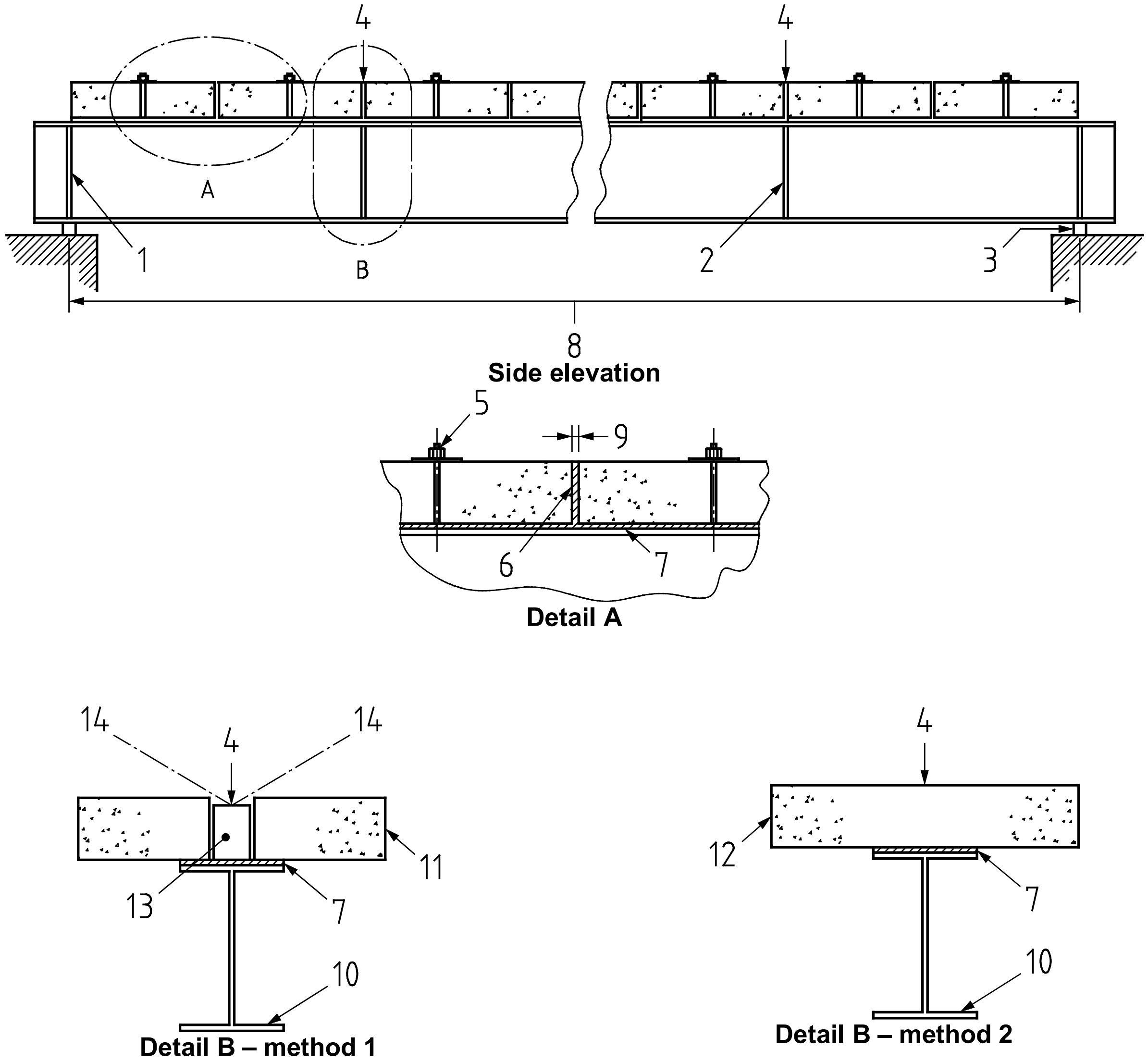
Steel section	Perimeter (P) - Profiled		Perimeter (P) - Boxed	
I or H section 	4 sides P = 4b + 2h - 2tw		4 sides P = 2b + 2h	
Cross section area = tw (h-2tf) + 2(b x tf)	3 sides P = 3b + 2h - 2tw		3 sides P = b + 2h	
Square or rectangular sections 	4 sides P = 2b + 2h		4 sides P = 2b + 2h	
Cross section area = 2b x tw (h-2tw) x (2tw)	3 sides P = b + 2h		3 sides P = b + 2h	
Circular hollow sections 	3 sides P = πd		3 sides P = πd	
$= \pi(d \div 2)^2 - \pi[(d-2tw) \div 2]^2$	Section factor = Perimeter ÷ cross sectional area			

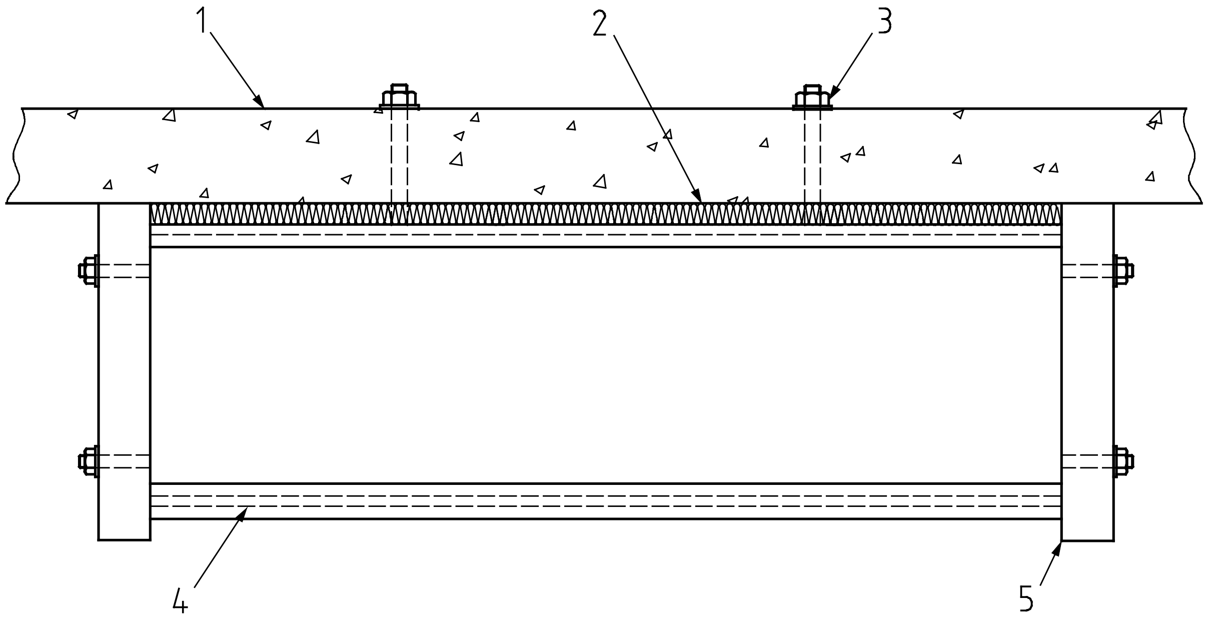
Figure 1 — Section factor



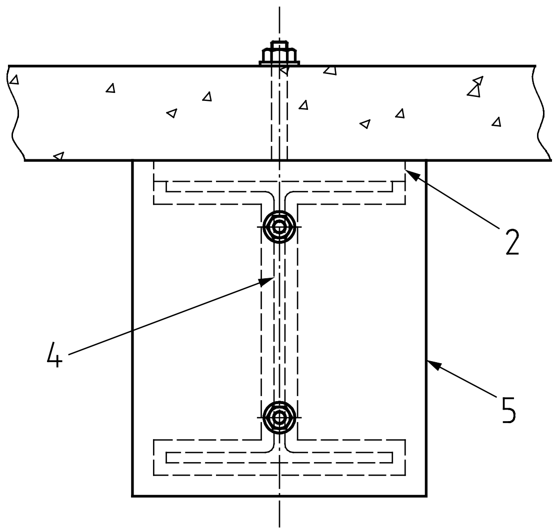
Key

A detail A – fixing of beam topping
B detail B – beam loading method 1 or 2
1 web stiffener at end bearing – I or H section
2 web stiffener at load points – I or H section
3 provide sufficient clearance to ensure furnace lining does not interfere with protection
4 load applied centrally to top of beam via load spacer 13 or to concrete slab 12
5 stud / plate / locking nut
6 fibre insulation or equivalent
7 compressible fibre insulation to width of beam, see 7.1
8 span
9 gap to be sufficient to ensure beam is able to bend without being restricted by the slab
10 steel beam - I section shown, hollow beam similar
11 aerated concrete slab sections of nominal density 500 kg/m^3 retained as 7.1. Nominal size of slabs 600 mm (± 100 mm) width x 625 mm maximum length x 150 mm to 200 mm thick
12 lightweight concrete slab section of nominal density 1 500 kg/m^3 retained as 7.1. Nominal size of slabs as 11
13 load spacer
14 additional bracing to prevent rotation of beam if necessary

Figure 2 — Loaded beam typical construction — I or H section, hollow beam similar



Side elevation



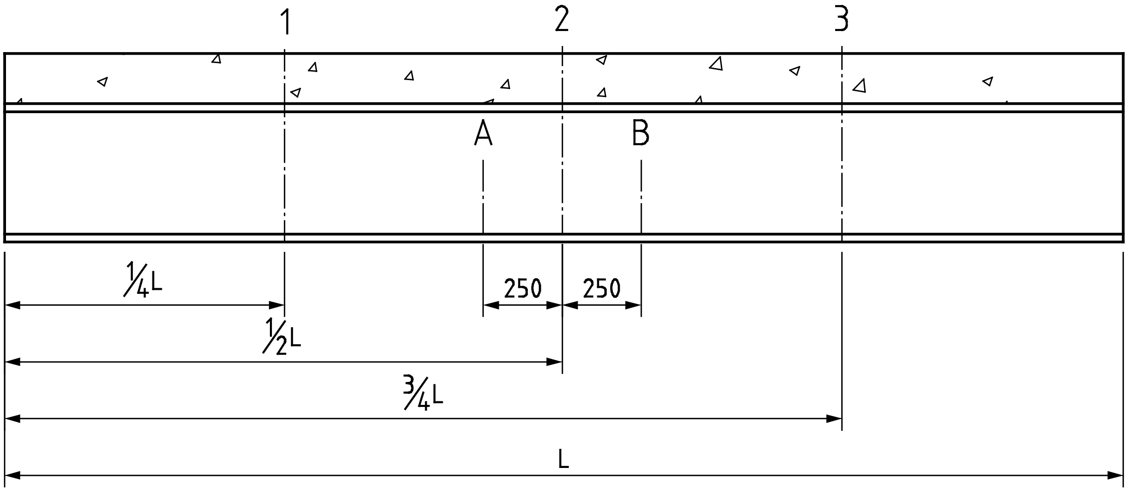
End elevation

Key

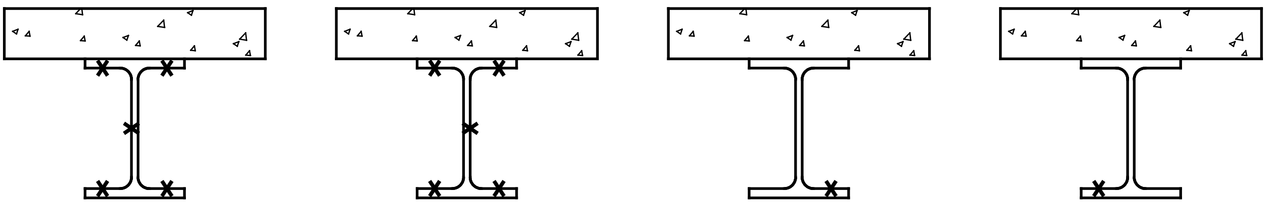
1 cover slab (same as loaded beam for reference beam, other beams to be aerated concrete)
2 insulation board
3 stud / plate / locking nut
4 steel section
5 insulation board – end cap

Figure 3 — Unloaded beam — Typical construction

All dimensions are in mm



Loaded beam side elevation



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

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

Position 1 to 3 | **Positions A and B**

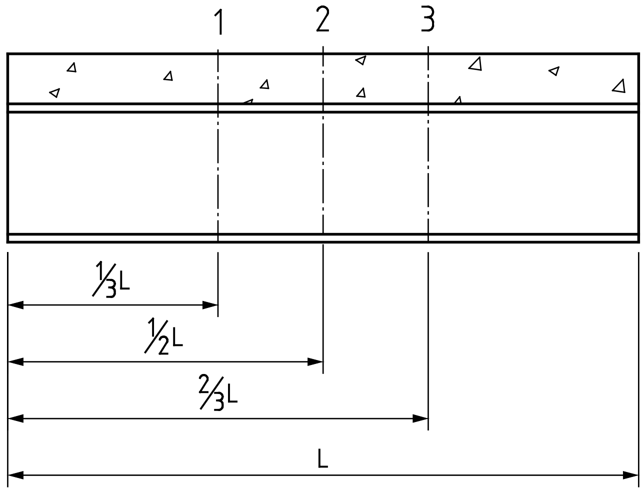
Thermocouple locations applicable to loaded hollow section beams (11 in total)

Key

1 position 1
2 position 2
3 position 3
A position A
B position B
L span of beam

Figure 4 — Thermocouple locations/orientation for loaded beams

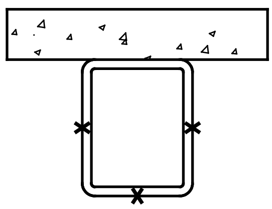
All dimensions are in mm



Short beam side elevation

Positions 1 and 3 **Position 2**

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



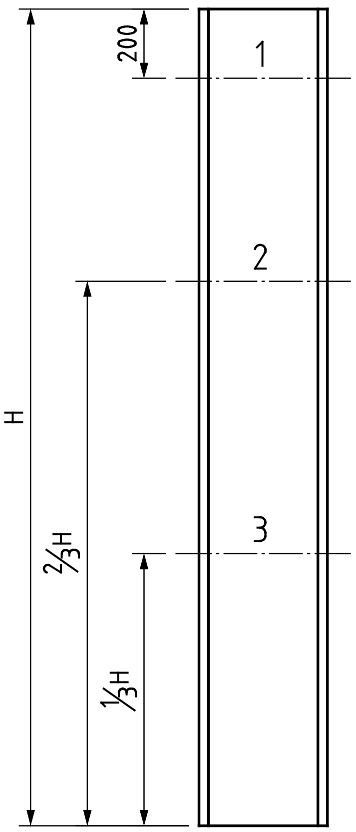
Thermocouple locations applicable to short hollow section beams (9 in total)

Key

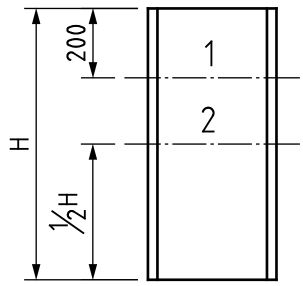
1 position 1
2 position 2
3 position 3
L span of beam

Figure 5 — Thermocouple locations / orientation for short beams

All dimensions are in mm



Loaded column elevation



Short column elevation

Positions 1 and 2 **Position 2** **Position 1** **Position 2**

Thermocouple locations applicable to loaded columns (15 in total)

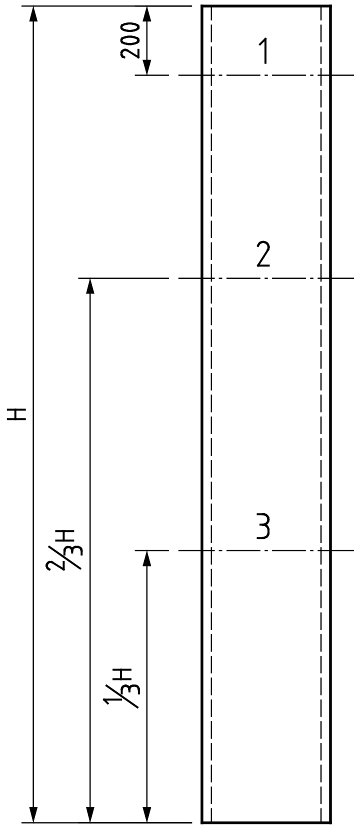
Thermocouple locations applicable to short columns (9 in total)

Key

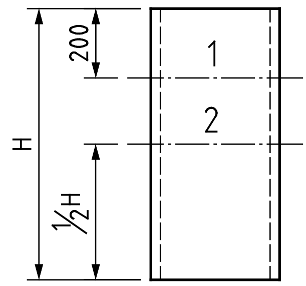
1 position 1
2 position 2
3 position 3
H height

Figure 6 — Thermocouple locations / orientation for 'I' of 'H' columns

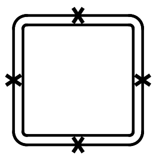
All dimensions are in mm



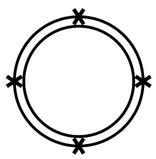
Loaded column elevation



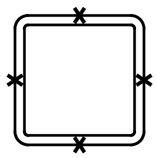
Short column elevation



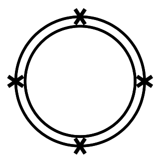
Positions 1 and 2



Positions 1 to 3



Positions 1 to 3



Positions 1 to 3

Thermocouple locations applicable to loaded columns (12 in total)

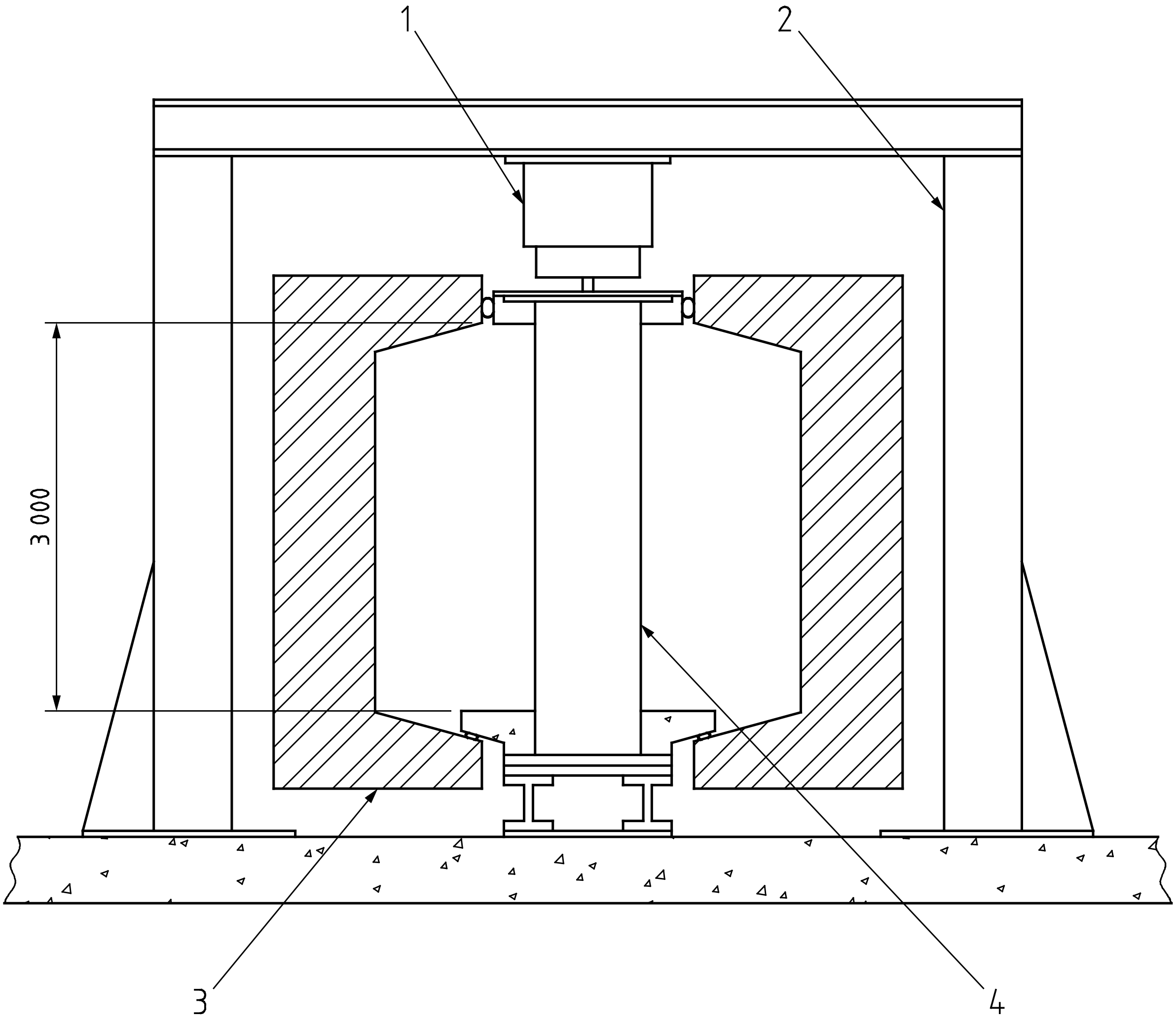
Thermocouple locations applicable to short columns (8 in total)

Key

1 position 1
2 position 2
3 position 3
H height

Figure 7 — Thermocouple locations / orientation for hollow sections

All dimensions are in mm

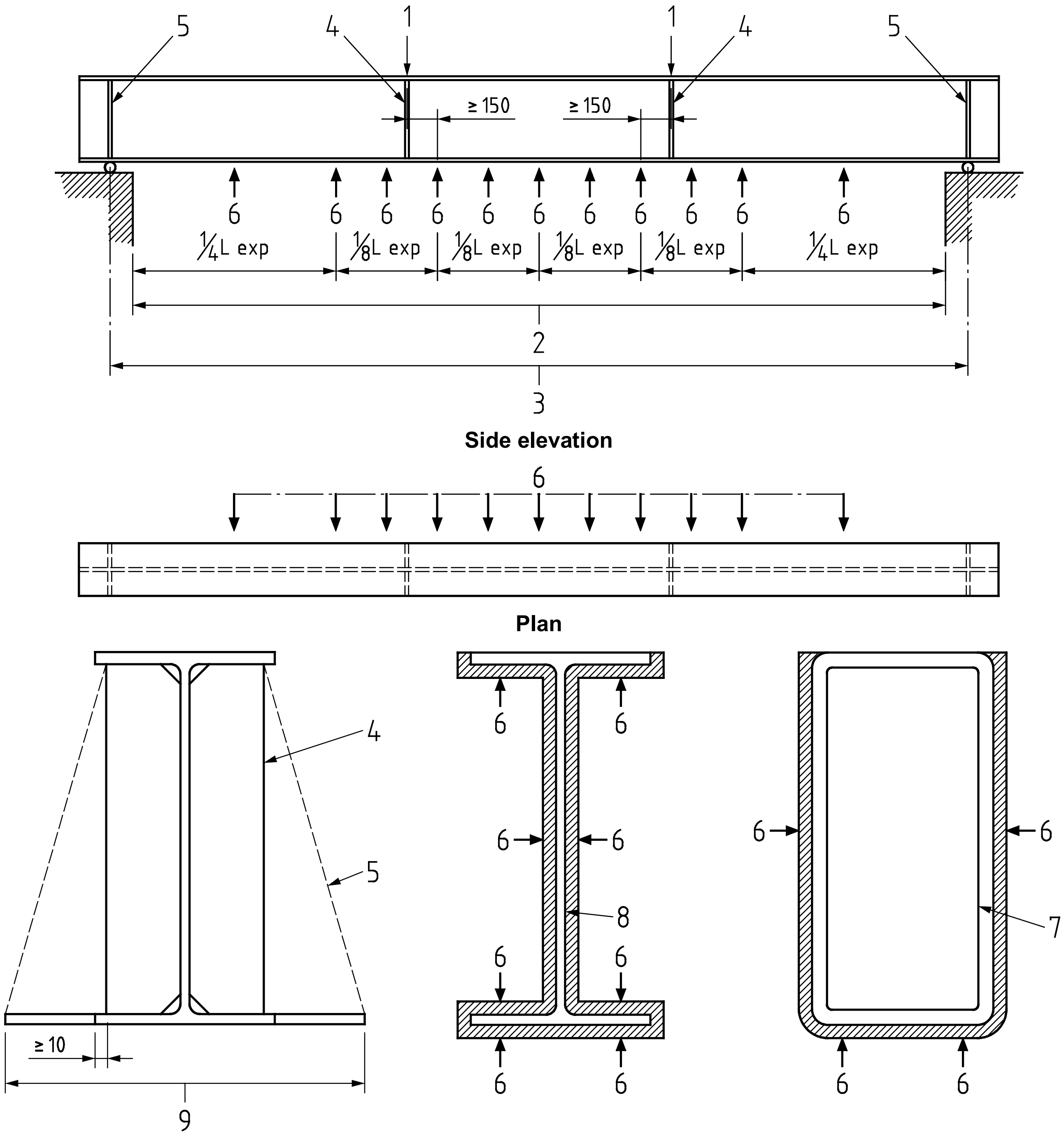


Key

1 hydraulic jack
2 loading frame
3 furnace
4 loaded column – eccentricity based on EN 1365-4

Figure 8 — Loaded column — Example of general test arrangement

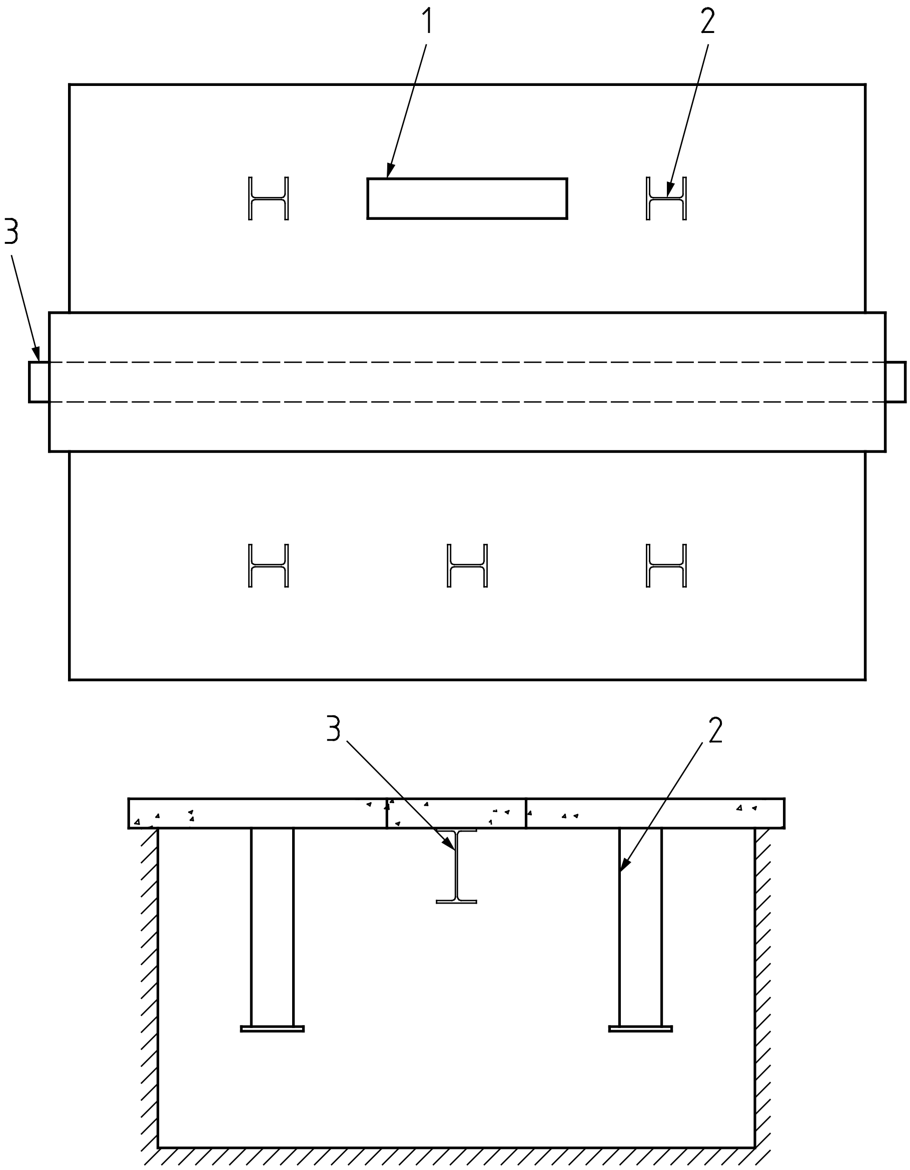
All dimensions are in mm



Key

1 load
2 exposed length L exp.
3 span
4 web stiffener at load points if required – I or H section
5 web stiffener at bearing positions if required – I or H section
6 measuring points for sprayed coating
7 hollow section beam
8 I or H section beam
9 2 x bottom flange

Figure 9 — Loaded beam stiffeners and thickness measuring points

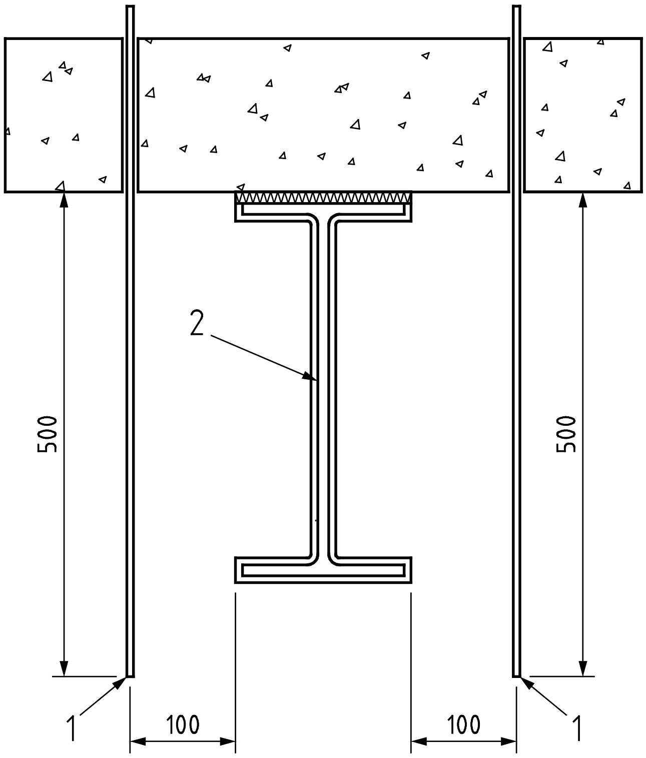


Key

1 position of unloaded short reference beam (parallel to loaded beam)
2 unloaded short column
3 loaded beam

Figure 10 — Typical test specimen installation pattern

All dimensions are in mm

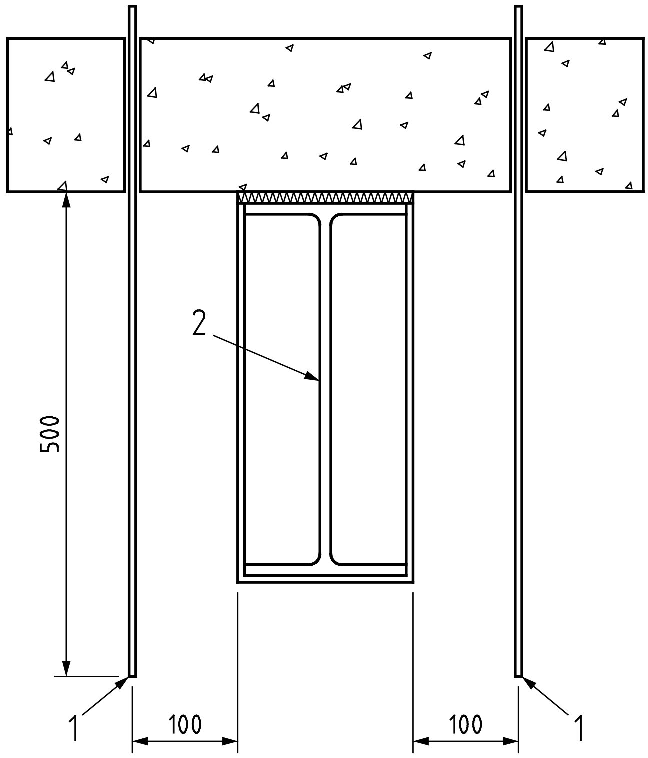


Key

1 plate thermometer
2 beam I or H section shown, hollow beam similar

Figure 11 — Location of furnace control thermocouples for loaded beams with profiled protection

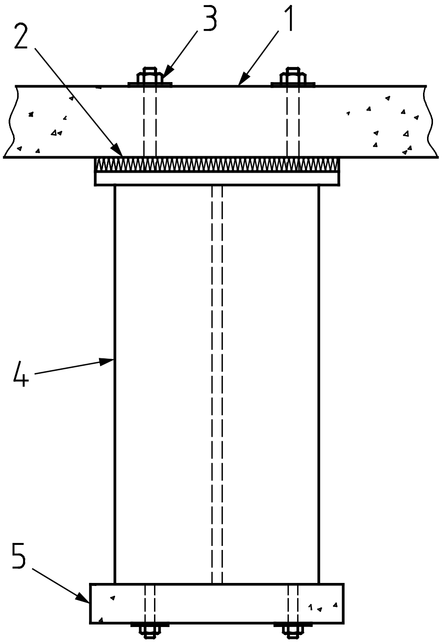
All dimensions are in mm



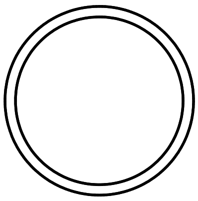
Key

1 plate thermometer
2 beam I or H section shown, hollow beam similar

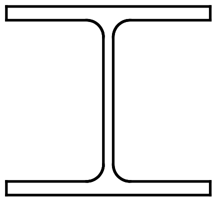
Figure 12 — Location of furnace control thermocouples for loaded beams with boxed protection



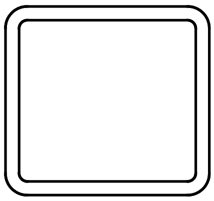
Column elevation



Column circular Hollow section



Column I or H section

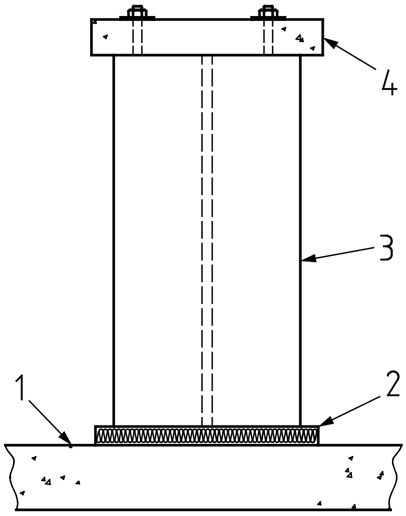


Column square and rectangular hollow sections

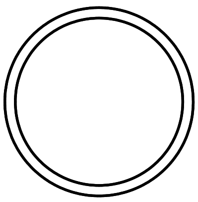
Key

1 furnace cover
2 insulation board
3 stud / plate / locking nut
4 short column
5 insulation board – end cap

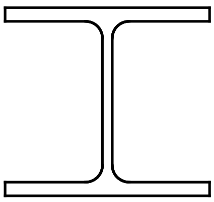
Figure 13 — Unloaded columns — Thermal isolation, installation to cover slabs



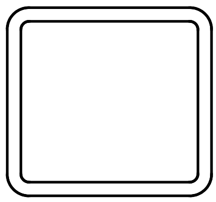
Column elevation



Column circular Hollow section



Column I or H section



Column square and rectangular hollow sections

Key

1 furnace floor or plinth
2 insulation material sufficient to prevent heat transfer via end of section
3 short column
4 insulation board – end cap

Figure 14 — Unloaded columns — Thermal isolation, installation onto furnace floor or on plinths

Annex A
(normative)

The applicability of the results of the assessment to sections other than I or H sections

A.1 Structural hollow sections - General

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 analyzed for rectangular, square and circular sections to establish comparability with respect to fire protection thickness, section factor and fire resistance performance. The approaches in A.2, A.3 and A.4 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 this document to obtain more suitable data if required.

A.2 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.3 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 mm 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:

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

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

$$\text{Modified thickness} = 1{,}25\ d_p \quad \text{(A.2)}$$

A.4 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.

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 Clause 6.

A.5 Limitations

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

The rules outlined in this annex may be used providing 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)

Measurement of properties of fire protection materials

B.1 Introduction

Determination of the thickness, density and moisture content of the fire protection materials and other materials used in fire resistance tests is important to the accurate prediction of required fire protection thicknesses from the test result.

The methods used to establish these properties shall, therefore, be consistent and this annex gives guidance on appropriate procedures to be used.

Any special test samples used to determine thickness, density, specific heat and moisture content shall be conditioned with the actual fire test specimen under the conditions described in Clause 8.

Any specific product standard existing for the measurement of such properties shall be followed.

The procedures given in EN 1363-1 shall be followed together with those referred to in B.2, B.3 and B.4.

B.2 Thickness of fire protection materials

B.2.1 Measurement

For board or slab/mat fire protection materials, the nominal thickness of each material shall be measured in accordance with EN 12467, EN 13162 or EN 823.

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

The design thickness used in the assessment shall be as described in 6.5.2.

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

The number and location of thickness measurement points shall be as given B.2.2.

The design thickness used in the assessment shall be as defined in 6.5.2.

For sprayed fire protection materials, of thickness very much greater than 5 mm, (i.e. where the mean thickness of the fire protection is greater than 15 % of the height of the test member), the mean thickness shall be given by Formula (B.1):

$$d_{av} = -A_p + \_\frac{(A_p + 16V_p)}{8} \quad \text{(B.1)}$$

where

A_p is the area of fire protection material per unit length;

V_p is the volume of area of fire protection material per unit length.

For sprayed fire protection materials and coatings of thickness less than 5 mm applied to the surface of steel beam and column test members, the material thickness shall be determined directly upon the test member, once the coating is fully dried.

The thickness shall be measured using an instrument employing either the electro-magnetic induction principle or the eddy current principle with a probe contact diameter of at least 2,5 mm.

The number and location of thickness measurement points shall be as described in B.2.2. The design thickness used in the assessment shall be as described in 6.5.2.

B.2.2 Measuring positions for renderings

The number and location of thickness measurement points (which shall be regarded as the minimum required) shall be:

Loaded beams:

A minimum number of 88 measurements should be taken on I beams and 66 measurements for hollow beams spread evenly over the measuring stations indicated in Figure 4 and Figure 9.

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

Unloaded beams:

A minimum number of 24 measurements at positions on I beams and 18 measurements on hollow beams (web and flanges or faces of hollow beams see Figure 5) at locations in the proximity of:

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

Loaded columns:

A minimum number of 50 measurements should be taken on I columns and 20 measurements on hollow columns spread evenly over the measuring stations indicated in Figures 6 for I or H sections and Figure 7 for hollow sections.

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

Unloaded short columns:

A minimum number of 20 measurements should be taken on I columns and 8 on hollow columns spread evenly over the measuring stations indicated in Figures 6 for I or H sections and Figure 7 for hollow sections.

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

B.3 Density of applied fire protection materials

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

For board or panel passive fire protection materials, the density can be obtained from values of mass, mean thickness (from nine measurements) and area measured either on the actual materials during assembly or on a representative special test sample, the minimum linear dimensions of which shall be 300 mm x 300 mm. The mass of the board shall be obtained using a balance having an accuracy equivalent to 0,1 % of the total mass of the sample being weighed or 0,1 g (the sample size shall be sufficient such that the minimum sample mass is 100 g), whichever is the greater.

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

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

The depth of the trays shall be the same as the design thickness of the fire protection material.

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

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

— one at the centre (one total);

— two along each centre to corner axis, equidistant from each other, the centre and the corner (eight in total).

The mass of the fire protection within the tray shall be obtained using a balance having an accuracy equivalent to 0,1 % of the total mass of the sample being weighed or 0,1 g (the sample size shall be sufficient such that the minimum sample mass is 100 g) whichever is the greater.

The design density used in the assessment shall in all cases be as described in 6.5.3

B.4 Moisture content of applied fire protection materials

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

For board or slab passive fire protection materials, special test samples shall be taken measuring minimum 300 mm x 300 mm and of each thickness of the material used. They shall be weighed and dried in a ventilated oven, using the temperatures and techniques specified in EN 1363-1. The moisture content of the specimen shall be calculated as a percentage of its moisture equilibrium weight.

For spray applied passive fire protection materials, the moisture content of the material shall be determined from oven drying of one of the sample trays referred to in B.3, for each thickness tested. They shall be weighed and dried in a ventilated oven, using the temperatures and techniques specified in EN 1363-1. The moisture content of the specimen shall be calculated as a percentage of its moisture equilibrium weight.

Annex C
(normative)

Fixing of thermocouples to steel work and routing of cables

C.1 Introduction

The accurate measurement of steel temperatures is fundamental to the assessment methodology. The type of thermocouple and the method of attachment and routing, protection and connection to suitable compensating cables or extensions shall therefore, be considered carefully. This annex offers guidance on suitable procedures.

C.2 Types of thermocouples

Several different kinds of thermocouple wire are suitable, including types ‘T’, ‘N’, ‘K’ and ‘J’ as specified in EN 60584-1.

Mineral-insulated stainless steel sheathed thermocouples with an isolated hot junction may be used if desired. The overall diameter over the sheath shall be at least 1,5 mm. Other thermocouples may be used subject to consultation between the laboratory and the test sponsor regarding their suitability. Suitable thermocouples shall be provided with individual wires at least 0,5 mm in diameter and be provided with insulation between the two wires and between each wire and any external conducting material such that there is no failure during test.

C.3 Fixing of thermocouples

The hot junction of the thermocouple shall be attached to the steelwork by peening or other methods that do not affect the response or accuracy of the thermocouple. Mechanical attachment using screws or bolts shall not be permitted.

Irrespective of the fixing methodology, it is essential that the thermocouples do not make contact beyond the hot junction which shall be in or at the steel surface; a thermocouple hot junction shall always be made at the position which creates the shortest loop between it and the cold junction. The thermocouple shall be fixed to ensure that it remains at that position.

C.4 Routing of thermocouple wires

Every attempt shall be made, whenever possible, to ensure that the wire from the hot junction follows a route to the cold junction which does not expose it to a temperature in excess of the hot junction temperature. The wires shall be routed behind the fire protection material and out of the furnace without passing through the furnace environment.

It shall be remembered that the claimed temperature performance of the thermocouple insulation material will relate to the thermocouple being in an environment where the wires are not subjected to movement or other strain.

It is possible that thermocouple wires will need to be supported to ensure that failure of the insulation material does not occur.

C.5 Connection of thermocouples

No connections shall be made between the thermocouple wire and any extension or compensating cable within any region of high temperature.

Compensating leads shall always be of a type appropriate to the thermocouple wire.

C.6 Thermocouple failures

Thermocouple failures are not always easily identifiable. Failure may be caused by a break within the wires or by failure of the electrical insulation between wires, thereby short circuiting the hot junction.

Obvious signs of failure, however, are:

- a sudden decrease of indicated temperature from that previously recorded;
- a sudden increase in indicated temperature to a value representing the maximum range of the recording device;
- a ‘floating or wandering’ indicated temperature inconsistent with anticipated values.

A common sign of electrical insulation failure may be the observation of an indicated temperature value inconsistent with that of the furnace.

Annex D
(normative)

Correction of data/Nominal thickness

D.1 Correction of data

D.1.1 Procedure

To take into account the stickability performance of the product, the data for the short sections is to be corrected against the loaded beams, loaded columns depending upon the selected test programme given in Tables 5 and 6. The correction procedures required for the test packages given in Table 1 are listed in Table D.1.

Table D.1

Ref	Correction procedures required for the test packages listed in Tables 1 and 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

The short section data is corrected for 'stickability' against the loaded sections. This is carried out by comparing the time for the loaded section to reach the design temperature with that for the equivalent short reference section. In all cases, the temperature is calculated as the characteristic temperature defined in 3.1.11.

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

D.1.2 Method

The loaded section 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 section using Formula (D.1).

$$t_c = t_1 \text{x} (S_1/S) \text{x} (D/D_1) \quad \text{(D.1)}$$

where

t_c is the corrected time;

t_1 is the time for the reference section to reach the design temperature;

S is the section factor of the loaded section;

S_1 is the section factor of the reference section;

D is the protection thickness for the loaded section;

D_1 is the protection thickness for the reference section.

The correction factor k is calculated using Formula (D.2).

Correction factor:

$k = t_1/t_c$

where

t_l is the time for the loaded section to reach the design temperature.

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

The times for the short sections to reach the specified temperatures are corrected using the appropriate correction factor and the corrected times are used as input data in the analysis. An example is given in Table D.2.

Table D.2

Section Type	**Thickness mm**	**Section Factor (m^{-1}) A_m/V**	**Time to reach design temp minutes**	**Corrected time for thickness and section factor minutes t_c**	**Correction factor ($k=t_l/t_c$)**
Loaded Beam (*LB*)	45,0 (*D*)	158 (*S*)	128 (t_l)	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 minimum and maximum protection thickness.

The correction factor for short sections with thicknesses within the range is obtained by linear interpolation using Formula (D.2):

$$k_i = \left[\frac{k_{max} - k_{min}}{d_{max} - d_{min}}\right](d_i - d_{min}) + k_{min} \qquad \text{(D.2)}$$

where

k_i is correction factor for the short section at thickness i;

k_{imax} is correction factor at maximum protection thickness;

k_{imin} is correction factor at minimum protection thickness;

d_i is protection thickness of the short section in mm;

d_{min} is the minimum protection thickness of the loaded section in mm;

d_{max} is the maximum protection thickness of the loaded section in mm.

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

An example calculation is given in Table D.3:

Table D.3

Section Type	**Thickness mm**	**Section Factor (m^{-1}) A_m/V**	**Time to reach design temp minutes**	**Corrected time for thickness and section factor minutes t_c**	**Correction factor *k***
LB d_{max}	45,0	158	128	144,2[a]	0,89 (k_{max})
Ref *B* d_{max}	46,1	161	145		
LB d_{min}	8,5	155	69	69,9[a]	0,99 (k_{min})
Ref *B* d_{min}	8,1	154	67		

Key

LB loaded beam

Ref *B* equivalent short beam

d_{max} maximum thickness

d_{min} minimum thickness

[a] This is the time that the short beam would have achieved if its protection thickness and section factor were the same as that of the equivalent loaded beam.

An example is given in Table D.4.

Table D.4

Short section	**Thickness (d_i) mm**	**Time to design temperature minutes**	**Factor k_i**	**Modified time minutes**
short beam	25,5	85	0,943	80,2

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

Short unloaded sections shall be corrected in accordance with Table D.1.

The correction factors for all design temperatures above the temperature at which the loaded section fails loadbearing capacity as defined in EN 1363-1 will be based on a lowest value derived as follows:

- determine the factor at a temperature equal to 100 °C below that at which loadbearing capacity failure occurred as above;
- determine factors for intermediate temperatures at intervals of 10 °C in the same way;
- select the lowest value and use for data correction for design temperatures above that at which loadbearing capacity failure occurred.

D.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 D.1 on a pro-rata basis of nominal and actual thickness. An example follows:

EXAMPLE Assuming linear behaviour and a plot of nominal thickness 50,0 mm and a data point of 52,3 mm actual thickness with a time of 64 min use 50,0/52,3 × 64, i.e. 61 min for this data point.

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

Annex E
(normative)

Methods of Assessment of Fire Protection System Performance

E.1 General

This annex includes methods of analysis which may be used to assess the performance of passive fire protection systems. For all methods, the calculated section factor for the test specimens shall be used in the analysis; see Figure 1.

For each assessment method, the results shall be presented as the protection thickness (determined in accordance with 3.1.7) to be applied to the steel member and given as function of section factor, design steel temperature and fire resistance period.

The input data shall be the time to reach the design mean steel temperature for all sections tested as required by Tables 5 and 6. The data shall be corrected in accordance with the principles given in Annex D.

In the case where only short columns have been tested in conjunction with loaded beams, the data may also apply to beams.

E.2 Graphical Approach

E.2.1 General

The following stepwise methodology, steps 1 to 7, shall be performed:

Step 1 : Determination of nominal thickness

Step 2 : Preparation of graphs

Step 3 : Methods for plotting lines or curves

Step 4 : Application of criteria for acceptability

Step 5 : Derivation of intercepts

Step 6 : Linear interpolation

Step 7 : Reporting of results

E.2.2 Input Data

- the design temperatures as defined in 13.5 which shall have at least three steps of 50 ºC;
- the corrected times to reach the design temperatures;
- the calculated section factor for the steel members;
- the mean material thickness of the protection only.

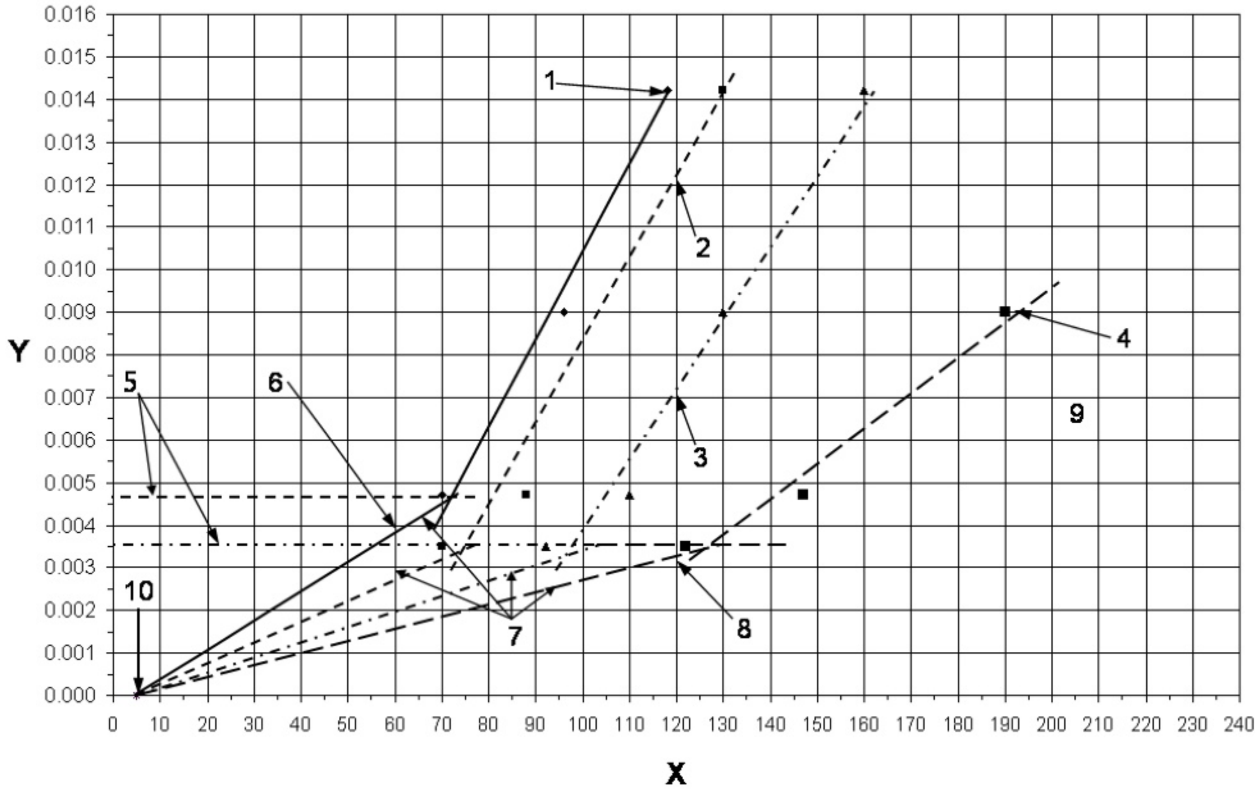
E.2.3 Step 1 – Nominal Thickness

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

E.2.4 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 corrected time to reach the steel design temperature as shown in Figure E.1. An additional conservative 'virtual' data point[1)] represented by the coordinates V/A_m of 0,0 m and the time taken to reach each design temperature taken as specified from the standard heating curve in EN 1363-1 can be used for all design temperatures. This virtual data point can be used in constructing each nominal thickness line.

1) The virtual data point (see E.2.4) represents a conservative data point for protected steel. It is a data point provided by the standard furnace temperature/time relationship defined in EN 1363-1 for the design temperature. It is appropriate to all section factors within the scope of the assessment since the steel section cannot be higher in temperature than the furnace temperature. This facilitates the drawing of a line from this point to the intersection of the horizontal line by the straight line or curve.



Key

X adjusted corrected time minutes

Y inverse section factor (V/A_m) m

1 the line for thickness d_{min} cannot be extrapolated to 120 min. The intercept is derived by plotting time against thickness for a constant section factor and interpolating to 120 min. See Figure E.3.

2 intercept for d_1 at 120 min, i.e. 82 m^{-1}

3 intercept for d_2 at 120 min, i.e. 137 m^{-1}

4 no greater than 15 % for all points

5 a horizontal line is drawn at the lowest inverse section factor for each nominal thickness line to intersect with the nominal thickness line

6 an intercept at 60 min

7 straight lines drawn from the intersections to the virtual data point

8 intercept for d_{max} at 120 min, i.e. 286 m^{-1}

9 use all data points for each thickness to draw a best fit straight line on the basis of least squares

10 'Virtual data point' at V/A of 0,0 m and 4,5 min (time to reach a furnace temp of 550 °C

◆ d_{min}

▴ d_{max}

■ d_1

▲ d_2

Figure E.1 — Steel temperature 550 °C

E.2.5 Step 3 – Line Plotting

The plots may be drawn as best fit straight lines 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 5 and 6. For each set of data points of the same nominal material 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 E.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 shall be accommodated within the minimum data set from Tables 5 and 6. The curve shall be a parabolic least squares fit and may 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 5 and 6 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 decrease. Points which do not meet this requirement shall be omitted.

E.2.6 Step 4 – Compliance with 13.5

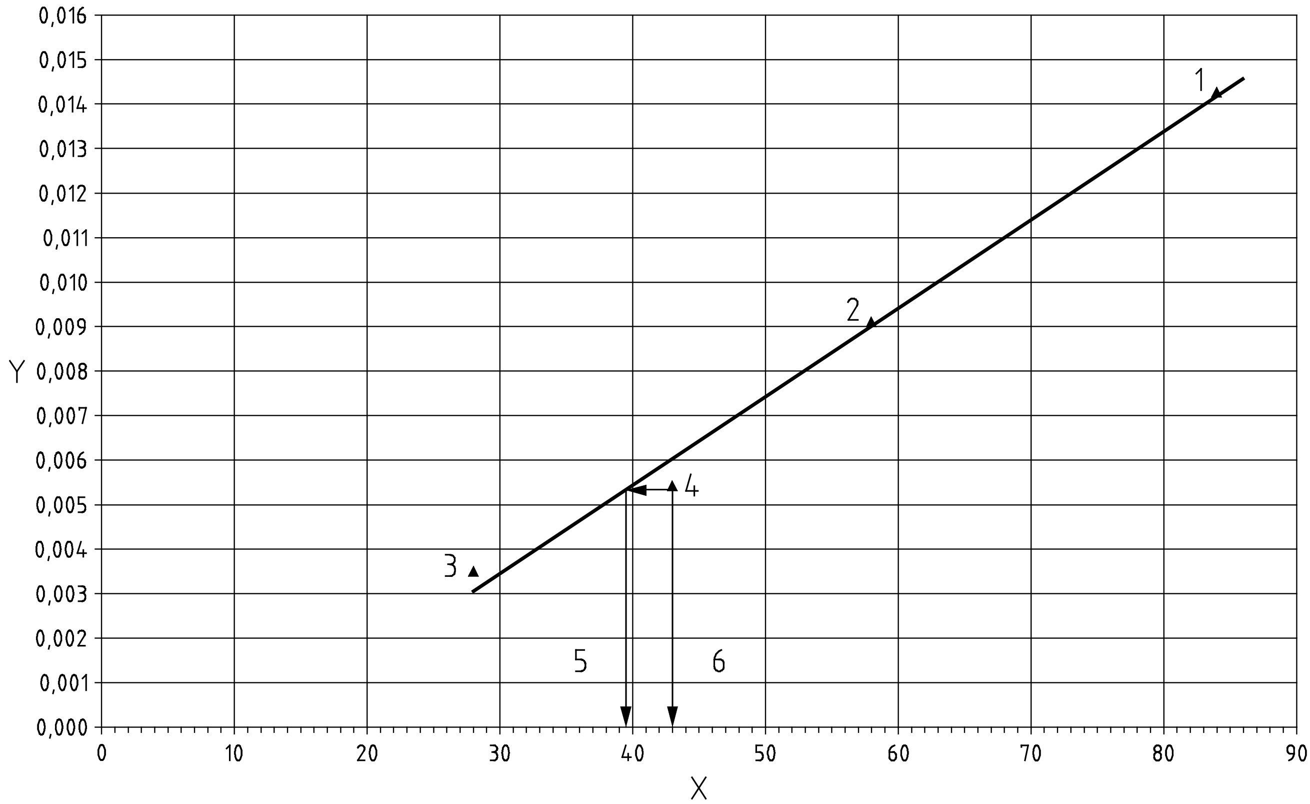
Apply the three criteria given in 13.5 a), b) and c) for each design temperature as shown in the example given in Figure E.2, which shows a plot of inverse section factor against the predicted time and “adjusted corrected time for an “average thickness of a nominal thickness range” at a particular design temperature.

The data for this example is given in Table E.1. If, for any line, criteria a) is not met then the line in question shall 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 i.e. nearest to the actual data point. After each move of a line, the smallest unconservative prediction is redetermined and the process is repeated until the criteria are met.

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.



Key

X time in minutes
Y inverse section factor (*V/A*$_m$) m
1 data point
2 data point 2
3 data point 4
4 data point 3
5 predicted time is 39,5 min
6 adjusted corrected time is 43 min

▲ d – linear (d)

Figure E.2 — Comparison of Predicted time against Adjusted corrected time

Table E.1

Data point	**Section factor** m^{-1}	**Inverse Section factor m**	**Time to design temperature min**
1	70	0,0142 86	84
2	110	0,0090 91	58
3	185	0,0054 05	43
4	285	0,0035 09	28

Considering data point 3, the predicted value is given by the intercept with the plot line and a corresponding predicted 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.

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

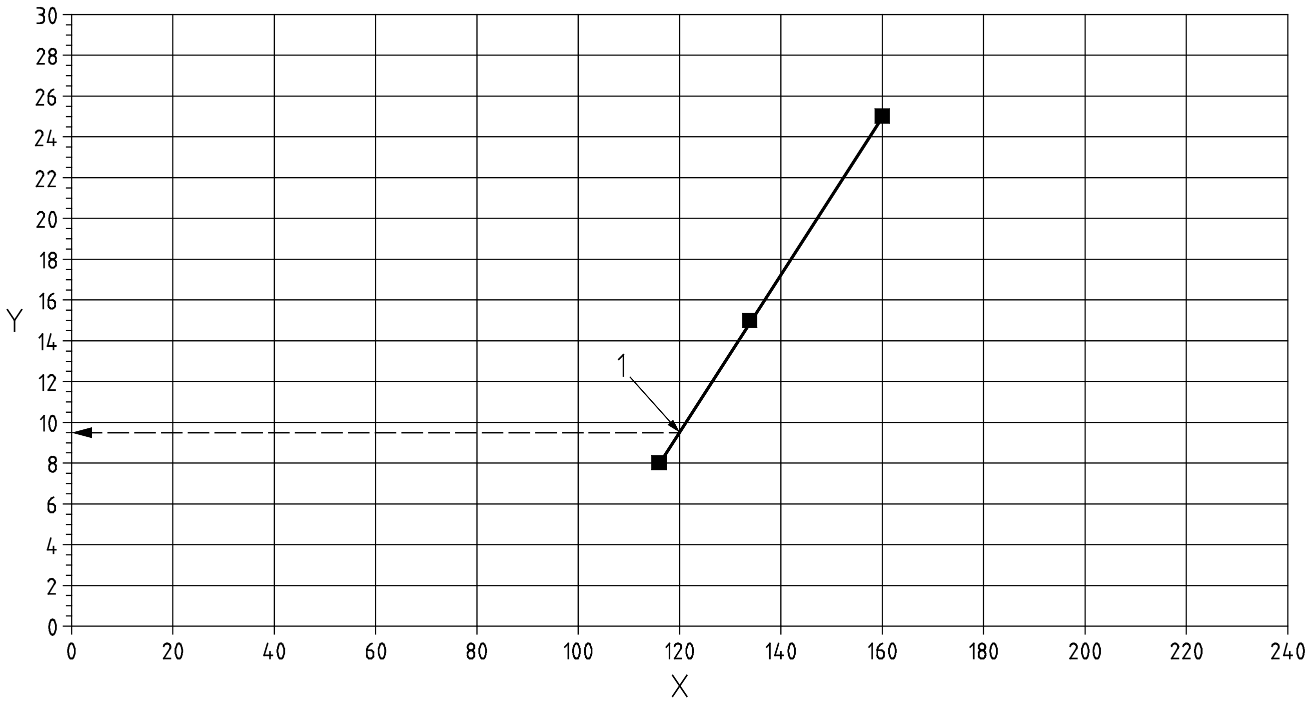
Table E.2

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

E.2.7 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 E.1.

Where a nominal thickness line does not intersect a fire resistance period, as shown on Figure E.1 for the minimum thickness and 60 min, an intercept may be derived by interpolation by plotting an additional graph of nominal thickness against adjusted corrected time for a constant section factor. An example plot is shown in Figure E.3 which is based on a hypothetical minimum thickness of 8 mm and intermediate thicknesses of 15 mm and 25 mm.



Key

X time in minutes

Y thickness in mm

1 intercept is now determined as 70 m^{-1} and 9,5 mm

Figure E.3 — Intercepts for 550 °C/70 m^{-1}

E.2.8 Step 6 – Linear Interpolation

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

The number of thickness steps required between the maximum and minimum thicknesses are given in Table E.3.

Table E.3

Maximum thickness – Minimum thickness (mm)	Number of thickness steps
up to 40	4
> 40 up to 75	5
> 75	6

E.2.9 Step 7 – Reporting of Results

Report the results of the assessment according to Clause 14.

E.3 Differential Formula Analysis (variable λ approach) Methodology

E.3.1 General

The following stepwise methodology, Steps, 1 to 11, shall be performed:

a) Step 1: Basic formula;

b) Step 2: Input data;

c) Step 3: Preparation of input data;

d) Step 4: Determination of Moisture plateau;

e) Step 5: Determination of elementary variable conductivities from each short section;

f) Step 6: Determination of the temperature of protective material;

g) Step 7: Transformation of conductivities;

h) Step 8: Determination of average variable conductivities for the protective material;

i) Step 9: Check on criteria of acceptability;

j) Step 10: Adjustment of characteristic variable conductivities;

k) Step 11: Presentation of the results;

l) Step 12: Reporting of the results.

E.3.2 Step 1 – Basic formula

The basic differential formula is as follows:

$$\Delta\theta_{a,t} = \left[\frac{\lambda_{p,t}/d_p}{c_a\rho_a}\times\frac{A_m}{V}\times\left(\frac{1}{1+\phi/3}\right)\times(\theta_t-\theta_{a,t})\Delta t\right]-\left[\left(e^{\phi/10}-1\right)\Delta\theta_t\right] \quad \text{(E.1)}$$

where $\phi = \frac{c_p\rho_p}{c_a\rho_a}\times d_p\times\frac{A_m}{V}$

where

$\Delta\theta_{a,t}$ is the steel temperature rise over time step Δt, in degrees Kelvin;

$\Delta\theta_t$ is the furnace temperature rise over time step Δt, in degrees Kelvin;

d_p is the dry film thickness of reactive product, in metres;

c_a is the temperature dependant specific heat capacity of steel at θ_a, in joules per kilogram per kelvin;

ρ_a is the density of steel, in kilograms per cubic metre;

A_p/V is the steel section factor, in m^{-1};

θ_t is the furnace temperature in degrees Celsius;

$\theta_{a,t}$ is the steel temperature, in degrees Celsius;

Δt is the time step, in seconds;

$\lambda_{p,t}$ is the thermal conductivity of the protective material at time t and for d_p thickness of protective material, in watts per metre per degree Kelvin.

with

$$\Delta\theta_{a,t} \geq 0 \quad and \quad \Delta t \leq 30\,s$$

If the calculated Δt is higher than 30 s, then 30 s 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 Formula (E.2):

$$\Delta t = 0{,}8\times\frac{c_a\times\rho_a}{\lambda_{p,t}/d_p}\times\frac{V}{A_p} \quad \text{(E.2)}$$

where

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

c_a and ρ_a are known steel material properties according to EN 1993-1-2;

d_p is the initial dry film thickness of the reactive product only.

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

c_p = 1 000 J/(kg·K)

ρ_p = 100 kg/m^3

E.3.3 Step 2 – Input data

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

— the design temperatures as defined in 13.5 which shall have at least three steps of 50 °C;

— the corrected times to reach the design temperatures;

— the uncorrected average steel temperatures;

— the calculated section factor for the steel members;

— the mean dry film thickness of the reactive coating only i.e. excluding primer and top coat.

E.3.4 Step 3 – Preparation of input data

For each specimen, the average temperature between 2 time increments shall not decrease. If it does decrease then the lower, intermediate temperature is discarded and replaced with a temperature linearly interpolated between the temperature at the start of the first time increment and the temperature at the end of the second time increment.

E.3.5 Step 4 - Determination of Moisture plateau

Determine a smooth curve of moisture plateau length (D_p) versus fire protection material thickness (d_p) as follows and as in formula (E.3):

$$D_p = C \times d_p^3 \qquad (E.3)$$

C is given by Formula (E.4):

$$C = \left[\frac{\sum_{i=1}^{n} d_p^3 \times D_p}{\sum_{i=1}^{n} d_p^6} \right] \qquad (E.4)$$

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).

E.3.6 Step 5 – Determination of elementary variable conductivities from each short section

For each short section, basic Formula (E.1) provides the thermal conductivity of the protective material versus time.

$$\lambda_{p,t} = d_p \times \frac{V(1+\phi/3)}{A_p} \times c_a \times \rho_a \times \frac{1}{(\theta_t - \theta_{a,t}) \times \Delta t} \times \left[\Delta\theta_{a,t} + \left(e^{\phi/10} - 1\right)\Delta\theta_t\right] \quad (E.5)$$

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

E.3.7 Step 6 – Determination of the temperature of protective material

For each short section and for each time interval, determine the protective material temperature $\theta_{p,t}$ from Formula (E.6):

$$\theta_{p,t} = \left[(\theta_{t-1} + \theta_t)/2 + (\theta_{a,t-1} + \theta_{a,t})/2 \right] / 2 \quad (E.6)$$

E.3.8 Step 7 – Transformation of conductivities

Transform the (λ_p vs. t) $\lambda_{p,t}$ values to (λ_p vs. $\theta_{p,t}$) λ_{p,θ_p} values.

E.3.9 Step 8 – Determination of average variable conductivities for the protective material

E.3.9.1 General

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

Values of thermal conductivity calculated between the start and finish of the moisture plateau are not used in this process.

The test program includes at least three sections with the nominal minimum amount of fire protection and three sections with the nominal maximum amount of fire protection.

For minimum thickness, the $\lambda_{mean}(\theta_p)$ relevant to short non-loaded sections protected with minimum thickness shall be considered.

For maximum thickness, the $\lambda_{mean}(\theta_p)$ relevant to short non-loaded sections protected with maximum thickness shall be considered.

For each nominal thickness, the procedure is as follows:

— from the elementary variable conductivities $\lambda_p(\theta_p)$, a mean variable conductivity $\lambda_{mean}(\theta_p)$ of the protective material shall be determined according to Step 8a;

— then an average variable conductivity $\lambda_{ave}(\theta_p)$ and corresponding standard deviation shall be determined according to Step 8b.

E.3.9.2 Step 8a

For the sections protected with minimum thickness and sections protected with maximum thickness, from each elementary variable conductivity $\lambda_p(\theta_p)$, calculate the arithmetical mean values of $\lambda_{mean}(\theta_p)$ 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 range considered. eg, at 375 °C, 425 °C, 475 °C, etc.

E.3.9.3 Step 8b

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

For the sections protected with maximum thickness, the average variable thermal conductivity and corresponding standard deviation shall 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 °C to 1 000 °C at 50 °C intervals and from each arithmetical mean values of $\lambda_{mean}(\theta_p)$, calculate the arithmetical average values of $\lambda_{ave}(\theta_p)$ and the standard deviation $\sigma(\theta_p)$ associated, for θ_p from 0 °C to 1 000 °C at 50 °C intervals; i.e. for 21 values.

E.3.10 Step 9 – Verification of the fitness of average variable conductivities

E.3.10.1 General

Using the thermal conductivities calculated in 8b, the temperature time curves for each section are computed and the computed times to reach the design temperatures are compared with the measured times.

E.3.10.2 Step 9a

For each short element, recalculate the steel temperature by using Formula (E.7) and with $\lambda_{\text{ave}}(\theta_{\text{p}})$ for θ_p from 0 °C to 1 000 °C at 50 °C intervals.

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

For temperature θ_p higher than 1 000 °C, use value of $\lambda_{ave}(\theta_p)$ determined for 20[th] range [950,1 000] °C.

When the steel temperature reaches 100 °C, the time to reach 100 °C is increased by the length of the moisture plateau, Dp, and the processed continued.

The value of $\lambda_{ave}(\theta_p)$ is related to d_p and shall be calculated by linear interpolation between the $\lambda_{ave}(\theta_p)$ calculated for minimum and maximum thicknesses of protective material, as described in Step 8b.

E.3.10.3 Step 9b

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

E.3.10.4 Step 9c

Compare all the t_{recal} versus t_{exp}, according to the acceptability criteria as defined in 13.5.

If the three criteria are satisfied, the average variable conductivities $\lambda_{ave}(\theta_p)$ for θ_p from 0 °C 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.

Then, proceed to Step 11.

If not, the average variable conductivities $\lambda_{ave}(\theta_p)$ shall be modified in order that the three acceptability criteria are satisfied. Proceed to Step 10.

E.3.10.5 Step 10 – Adjustment of characteristic variable conductivities

In order to meet the three acceptability criteria, the average conductivities for minimum thickness $\lambda_{ave,\min}(\theta_p)$ and the average conductivities for maximum thickness $\lambda_{ave,\max}(\theta_p)$ shall be modified by using Formula (E.8):

$$\lambda_{char}(\theta_p) = \lambda_{ave}(\theta_p) + K \times \sigma(\theta_p) \tag{E.8}$$

The value of *K* shall be the lowest possible. The same value shall be used for both minimum and maximum thicknesses of protective material.

The value of *K* may be found iteratively or, alternatively, by increasing the value in small steps.

Then, proceed again Step 8 by using $\lambda_{char}(\theta_p)$ instead of $\lambda_{ave}(\theta_p)$, until the three acceptability criteria are satisfied.

If not, increase *K* and repeat Step 9.

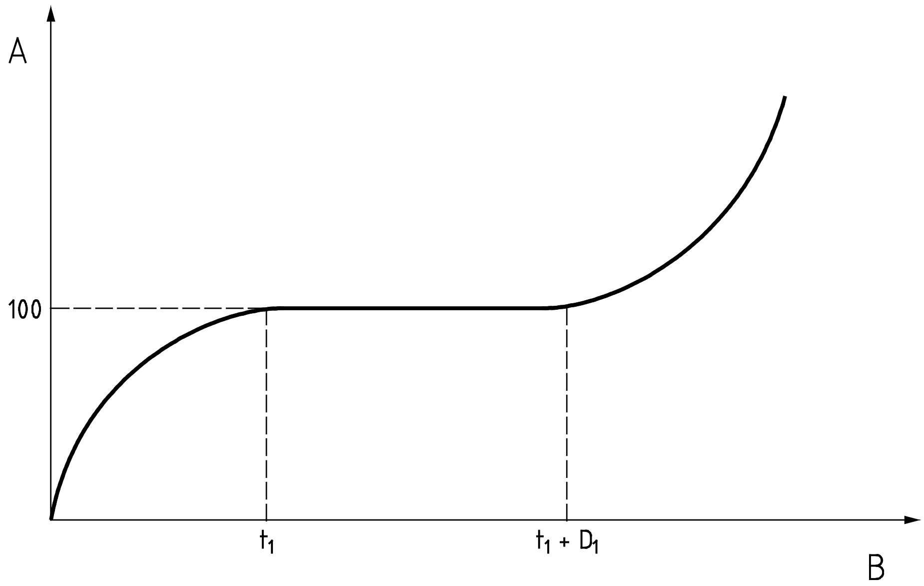
E.3.11 Step 11 − Presentation of the results

Use the relevant $\lambda_{ave}(\theta_p)$ or $\lambda_{char}(\theta_p)$ conductivities issued from Step 9c or from Step 10, as well as Formula (E.7) 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 13.5.

Use these steel temperatures to be presented in the report of the assessment as required in Clause 14.

E.3.12 Step 12 – Reporting of the results

Report the results and their assessment according to Clause 14.



Key

A temperature °C
B time (min)

Figure E.4 — Introduction of moisture plateau

E.4 Differential Formula Analysis (constant λ approach) Methodology

E.4.1 General

The following stepwise methodology, Steps, 1 to 7, shall be performed:

e) Step 1: Use of input data from test results.

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

g) Step 3: Linear regression.

h) Step 4: Verification of criteria of acceptability.

i) Step 5: Modification of c_0.

j) Step 6: Presentation of results.

k) Step 7: Reporting of the results.

E.4.2 Step 1 – Use of input data from test results – Input Data

— the design temperatures as defined in 13.5;

— 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 each short section, evaluate the moisture plateau length D_p, as shown in Figure E.5 and according to the instructions below:

— the moisture plateau length, D_p, 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/time 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 / $t_{115°C}$] and [200 °C / $t_{200\ °C}$].

For the determination of the moisture plateau, the steel temperature of each short section is calculated as defined in 3.1.12.

— the corrected times taking account the moisture plateau to reach the design temperatures, i.e. corrected time as defined in D.1 minus the moisture plateau length D_p. This value will be used for the determination of the λ as prescribed in Steps 2 and 3.

E.4.3 Step 2 – Determining the λ for a defined design steel temperature

Formula (E.9) provides a relationship of the steel temperature against time. All variables except λ are known. For each short section, determine λ using Formula (E.9) 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.9):

$$\Delta\theta_{a,\,t} = \left[\frac{\lambda_{p,\,t}/d_p}{c_a\rho_a} \times \frac{A_m}{V} \times \left(\frac{1}{1+\phi/3}\right) \times (\theta_t - \theta_{a,\,t})\Delta t\right] - \left[\left(e^{\phi/10} - 1\right)\Delta\theta_t\right] \quad \text{(E.9)}$$

where

$$\phi = \frac{c_p\rho_p}{c_a\rho_a} \times d_p \times \frac{A_m}{V}$$

where

$\Delta\theta_{a,t}$	[K]	steel temperature rise over time step Δt (shall always be > 0);
$\theta_{a,t}$	[K]	steel temperature at time t;
d_p	[m]	mean thickness of the protection material;
c_a	[J/kgK]	specific heat of steel at ϑ_a;
ρ_a	[kg/m^3]	density of steel;
c_p	[J/kgK]	temperature independent specific heat of the protection material. If this value is not available, then a value of 1 000 kJ/kg °C shall be used;
ρ_p	[kg/m^3]	mean density of protection material;
A_m/V	[m^{-1}]	calculated steel section factor;

θ_t	[ºC]	furnace temperature associated to each short column;
θ_a	[ºC]	steel temperature;
Δt	[s]	time step (shall be ≤ 30 s);
$\Delta\theta_t$	[K]	furnace temperature rise over time step Δt.

E.4.4 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 following formula:

$$\lambda = c_0 + c_1 \, x \, A_m/V + c_2 \, x \, d_p \qquad \text{(E.10)}$$

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

E.4.5 Step 4 – Verification of criteria for acceptability

Determine a smooth curve of moisture plateau length (D_p) versus fire protection material thickness (d_p) as in Formula (E.11) and as in Figure E.6:

$$D_p = C \times d_p^3 \qquad \text{(E.11)}$$

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

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.10). Use the basic Formula (E.9) 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.7.

— Calculate θ_a using Formula (E.9) 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 with Formula (E.9).

Determine whether the results meet the acceptability criteria of 13.5 a), b) and c).

E.4.6 Step 5 – Modification of c_0

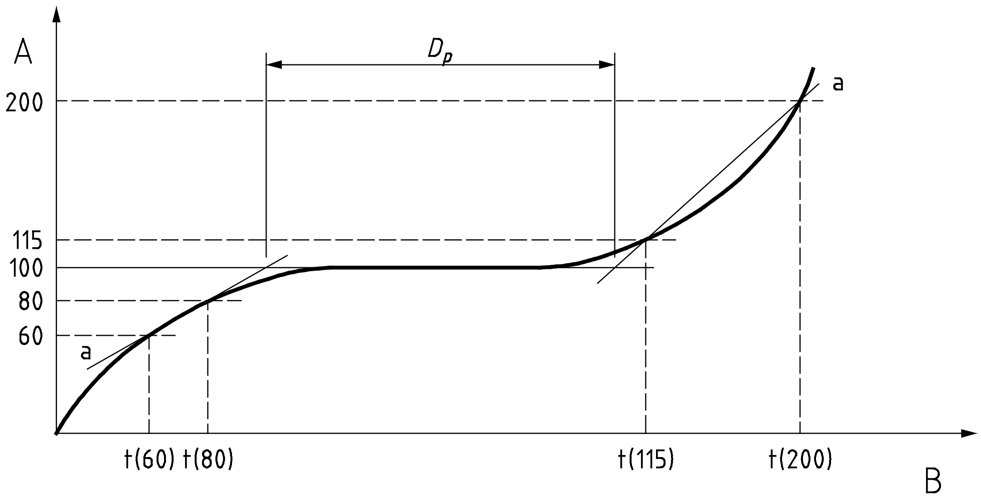
If the acceptability criteria are not met initially, repeat Step 4 with modified c_0 until the acceptability criteria of 13.5 a), b) and c) are met. The outcome of the analysis is the combination of regression coefficients c_0 (modified if appropriate), c_1 and c_2.

E.4.7 Step 6 – Presentation of the results

Use the regression coefficients c_0, c_1 and c_2 as well as Formula (E.9) and (E.10), taking into account the moisture plateau as defined in Step 4, to determine the information to be presented in the report of the assessment as required in Clause 14.

E.4.8 Step 7 – Reporting of the results

Report the results and their assessment according to Clause 14.



Key

A temperature °C
B time (min)

Figure E.5 — Evaluation of length of moisture plateau

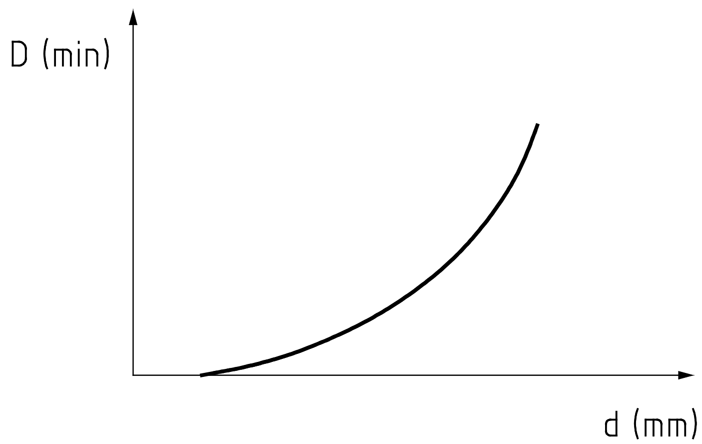
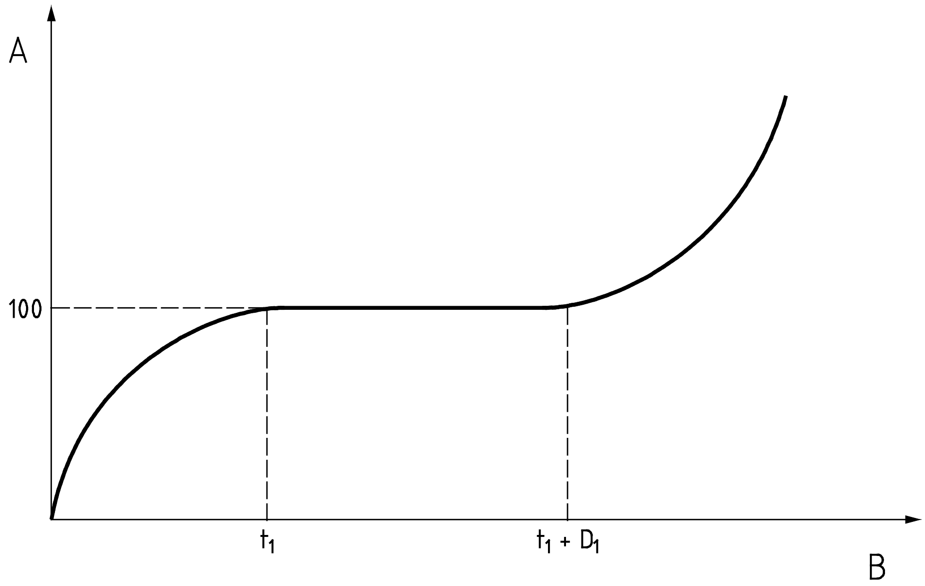


Figure E.6 — Evaluation of the moisture plateau vs. fire protection material thickness



Key

A temperature °C
B time (min)

Figure E.7 — Introduction of moisture plateau

E.5 Numerical Regression Analysis

E.5.1 General

The following stepwise methodology, steps 1 to 6 shall be performed:

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

— Step 6: Reporting of the results.

E.5.2 Input Data

— the design temperatures as defined in 13.5;

— the corrected times to reach the design temperatures;

— the calculated section factor for the steel members;

— the thickness of the protection material only.

E.5.3 Basic Formula

The multiple linear numerical regression analysis is conducted using Formula (E.12):

$$t = a_0 + a_1 d_p + a_2 \frac{d_p}{A_m / V} + a_3 \theta_a + a_4 d_p \theta_a + a_5 d_p \frac{\theta_a}{A_m / V} + a_6 \frac{\theta_a}{A_m / V} + a_7 \frac{1}{A_m / V} \quad \text{(E.12)}$$

where

t is the time to design temperature (minutes);

d_p is the thickness of protection material (mm);

A_m/V is the measured section factor (m^{-1});

a_o to a_7 are the regression coefficients;

θ_a is the steel temperature (°C).

E.5.4 Steps 1 to 5: Use of input data from test results

E.5.4.1 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.

E.5.4.2 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.

E.5.4.3 Step 3

Compare the predicted times to reach each design temperature with the corrected measured times and determine whether the results meet the criteria of 13.5 a), b) and c).

E.5.4.4 Step 4

If necessary, determine for each of the three acceptance criteria a simple linear modification factor ‘x’, where ‘x’ $\leq$ 1,0, which, when applied to all the regression constants, causes the predicted times to just meet the acceptance criteria.

E.5.4.5 Step 5

Use the modified regression coefficients to determine the information to be presented in the report of the assessment as required in Clause 14. This will require the transposition of Formula (E.12) to determine the thickness required for a given section factor for each required fire resistance period and for each steel temperature. Formula (E.13) should be used to determine the thickness.

$$d_p = \frac{t - a_0 - a_3\theta_a - \left(\frac{a_6\theta_a}{A_m/V}\right) - \left(\frac{a_7}{A_m/V}\right)}{a_1 + a_4\theta_a + \left(\frac{a_2}{A_m/V}\right) + \left(\frac{a_5\theta_a}{A_m/V}\right)} \qquad \text{(E.13)}$$

where

t is the time to design temperature (minutes);

d_p is the thickness of protection material (mm);

A_m/V is the measured section factor (m^{-1});

a_o to a_7 is the regression coefficients;

θ_a is the steel temperature (°C).

E.5.4.6 Step 6

Report the results and their assessment according to Clause 14.

Annex F
(normative)

Tables of Section Sizes

Table F.1 — Tables of Profiled I and H Shape Beam Sections

UK Beam Section Size mm × mm × kg/m	Nominal Profiled Section Factor m^{-1}	Euro Beam Section Size mm × mm × kg/m	Euro Beam Designation	Nominal Profiled Section Factor m^{-1}
914 × 419 × 388	60	814 × 303 × 317	HEM 800	63
610 × 305 × 238	70	900 × 300 × 291	HEB 900	73
610 × 305 × 179	90	540 × 300 × 166	HEA 550	95
254 × 254 × 89	110	240 × 240 × 83	HEB 240	116
457 × 152 × 82	130	500 × 200 × 91	IPE 500	141
356 x 171 x 67	140			
533 x 210 x 92	140			
406 × 178 × 67	155	400 × 180 × 66	IPE 400	164
610 x 229 x 101	145			
406 × 178 × 60	175	330 × 160 × 49	IPE 330	188
406 × 178 × 54	190	300 x 150 x 42	IPE 300	200
356 × 171 × 45	210	240 × 120 × 31	IPE 240	223
356 x 127 x 39	215			
254 × 146 × 31	230	200 × 100 × 22	IPE 200	253
305 × 102 × 28	245	180 × 91 × 19	IPE 180	268
254 × 102 × 22	275	160 × 82 × 16	IPE 160	287
305 x 102 x 25	285	140 × 73 × 13	IPE 140	306
102 × 44 × 7.4	320	120 × 64 × 10.4	IPE 120	331
		100 x 55 x 7.8	IPE 100	360
			IPE 80	390

Table F.2 — Tables of Boxed I and H Shape Beam Sections

UK Beam Section Size mm × mm × kg/m	Nominal Bosed Section Factor m^{-1}	Euro Beam Section Size mm × mm × kg/m	Euro Beam Designation	Nominal Boxed Section Factor m^{-1}
914 × 419 × 388	45	814 × 303 × 317	HEM 800	49
610 × 305 × 238	50	900 × 300 × 291	HEB 900	58
610 × 305 × 179	70	540 × 300 × 166	HEA 550	67
254 × 254 × 89	70	240 × 240 × 83	HEB 240	71
457 × 152 × 82	105	500 × 200 × 91	IPE 500	107
356 x 171 x 67	105			
533 x 210 x 92	110			
406 × 178 × 67	115	400 × 180 × 66	IPE 400	121
610 x 229 x 101	110			
406 × 178 × 60	130	330 × 160 × 49	IPE 330	137
406 × 178 × 54	145	300x150x42	IPE 300	145
356 × 171 × 45	155	240 × 120 × 31	IPE 240	161
356 x 127 x 39	170			
254 × 146 × 31	160	200 × 100 × 22	IPE 200	184
305 × 102 × 28	200	180 × 91 × 19	IPE 180	194
254 × 102 × 22	215	160 × 82 × 16	IPE 160	207
305 x 102 x 25	225	140 × 73 × 13	IPE 140	221
102 × 44 × 7.4	260	120 × 64 × 10.4	IPE 120	239
		100 x 55 x 7.8	IPE 100	258
			IPE 80	277

Table F.3 — Profiled I and H Shaped Column Sections

UK Column Section Size mm × mm × kg/m	Nominal Profiled Section Factor m^{-1}	Euro Column Section Size mm × mm × kg/m	Euro Column Designation	Nominal Profiled Section Factor m^{-1}
356 x 406 x 634	30			
305 x 305 x 283	55	432 x 307 x 256	HEM 400	64
356 x 406 x 340	55			
305 x 305 x 198	75	270 x 248 x 157	HEM 240	76
		310 x 288 x 189	HEM 280	74
254 x 254 x 132	90	240 x 226 x 117	HEM 220	92
356 x 368 x 177	95	450 x 300 x 171	HEB 450	98
254 x 254 x 107	110	320 x 300 x 127	HEB 320	117
305 x 305 x 118	120	300 x 300 x 117	HEB 300	125
		390 x 300 x125	HEA 400	128
254 x 254 x 89	130	240 x 240 x 83	HEB 240	139
356 x 368 x 129	130	330 x 300 x 105	HEA 340	145
203 x 203 x 60	160	180 x 180 x 51	HEB 180	168
305 x 305 x 97	145	290 x 300 x 88.3	HEA 300	166
203 x 203 x 52	180	230 x 240 x 60	HEA 240	192
203 x 203 x 46	200	210 x 220 x 51	HEA 220	209
		190 x 200 x 42	HEA 200	229
152 x 152 x 30	235	152 x 160 x 34	HEA 160	253
		133 x 140 x 25	HEA 140	259
203 x 102 x 23	270	114 x 120 x 20	HEA120	290
		200 x 100 x 22.4	IPE 200	290
152 x152 x 23	300	180 x 91 x 19	IPE 180	307
178 x 102 x 19	305	160 × 82 × 16	IPE 160	329
			IPE 100	424
			IPE 80	450

Table F.4 — Boxed I and H Shaped Column Sections

UK Column Section Size mm × mm × kg/m	Nominal Boxed Section Factor m^{-1}	Euro Column Section Size mm × mm × kg/m	Euro Column Designation	Nominal Boxed Section Factor m^{-1}
356 x 406 x 634	20			
305 x 305 x 283	40	432 x 307 x 256	HEM 400	46
356 x 406 x 340	35			
305 x 305 x 198	50	270 x 248 x 157	HEM 240	53
		310 x 288 x 189	HEM 280	51
254 x 254 x 132	65	240 x 226 x 117	HEM 220	64
356 x 368 x 177	65	450 x 300 x 171	HEB 450	71
254 x 254 x 107	75	320 x 300 x 127	HEB 320	80
305 x 305 x 118	85	300 x 300 x 117	HEB 300	84
		390 x 300 x125	HEA 400	90
254 x 254 x 89	90	240 x 240 x 83	HEB 240	94
356 x 368 x 129	90	330 x 300 x 105	HEA 340	99
203 x 203 x 60	110	180 x 180 x 51	HEB 180	114
305 x 305 x 97	100	290 x 300 x 88.3	HEA 300	110
203 x 203 x 52	125	230 x 240 x 60	HEA 240	129
203 x 203 x 46	140	210 x 220 x 51	HEA 220	140
		190 x 200 x 42	HEA 200	153
152 x 152 x 30	160	152 x 160 x 34	HEA 160	169
		133 x 140 x 25	HEA 140	174
203 x 102 x 23	210	114 x 120 x 20	HEA120	194
		200 x 100 x 22.4	IPE 200	220
152 x152 x 23	205	180 x 91 x 19	IPE 180	233
178 x 102 x 19	230	160 × 82 × 16	IPE 160	250
			IPE 100	313
			IPE 80	339

Table F.5 — Rectangular Hollow Sections

Column Section* Size mm × mm × mm	Nominal Section Factor m^{-1}
400 x 400 x 20	55
200 x 200 x 16	70
200 x 200 x 12,5	85
200 x 200 x 10	100
200 x 200 x 8	130
160 x 160 x 8	135
90 x 90 x 8	140
200 x 200 x 6,3	165
150 x 150 x 5	210
100 x 100 x 4	260
90 x 90 x 3,6	290
80 x 80 x 3,6	295
100 x 50 x 3,2	330
50 x 50 x 2,5	425

Sections can also be selected from this table if testing rectangular beams. In this case, the section factor is calculated on the basis of three sided exposure.

Table F.6 — Circular Hollow Sections

Column Section Size mm(dia) × mm	Nominal Section Factor m^{-1}
244,5 x 25	45
323,9 x 25	45
355,6 x 20	55
219,1 x 12,5	85
219,1 x 10	100
219,1 x 8	130
168,3 x 8	130
168,3 x 6,3	165
139,7 x 5	205
219,1 x 5	205
114,3 x 3,6	285
88,9 x 3,2	325
42,4 x 2,6	410

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