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Fire-resistance tests — Elements of building construction —

Part 13: Requirements for the testing and assessment of applied fire protection to steel beams with web openings

Essais de résistance au feu — Éléments de construction —

Partie 13: Exigences pour les essais et l'évaluation de la protection contre l'incendie appliquée aux poutres en acier avec ouvertures dans l'âme

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Foreword

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

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 2, *Fire containment*.

A list of all parts in the ISO 834 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Background

Recent developments in steel construction have seen the introduction of cellular beams consisting of openings of various sizes and shapes cut in the web of the steel section. These offer a number of advantages over conventional beams without openings such as lighter/less steel required to provide the same structural performance and the ability to accommodate services within the depth of the section.

An opening in the web of a beam may be circular or rectangular but in reality can be any shape. Cellular beams may have a mixture of opening shapes and in some cases there may only be a single isolated opening.

Cellular beams can be fabricated from either hot rolled sections or welded steel plate. In the case of structural sections this involves cutting around the centre line of the web along the beams length and then welding the two halves together. Assymetric beams can be fabricated by welding together the two halves of different size sections. In the case of plate girders, asymmetry can also be achieved by using different plate thicknesses for the top and bottom flanges.

Beams with web openings behave differently to solid beams in that additional failure modes at the fire limit state (FLS) are possible as a result of the proximity of openings and web slenderness. Solid beams generally fail in bending but a beam with web openings can fail in one of several mechanisms which include:

— buckling of the web-post,

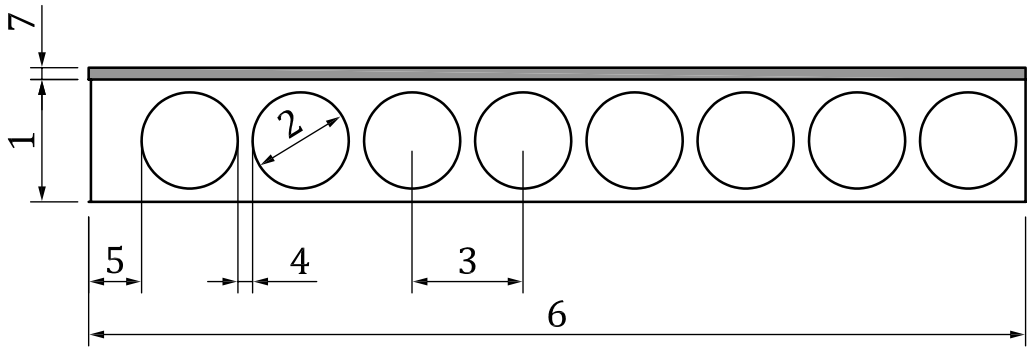
— shear at an opening,

— Vierendeel bending around the opening.

These failure modes generally occur at lower temperatures than for a solid beam at similar utilisation factors and therefore require greater thicknesses of fire protection.

Overview of structural geometry

A beam with circular web openings is illustrated in Figure 1. The figure also shows some of the important dimensions that will affect beam's performance in fire.

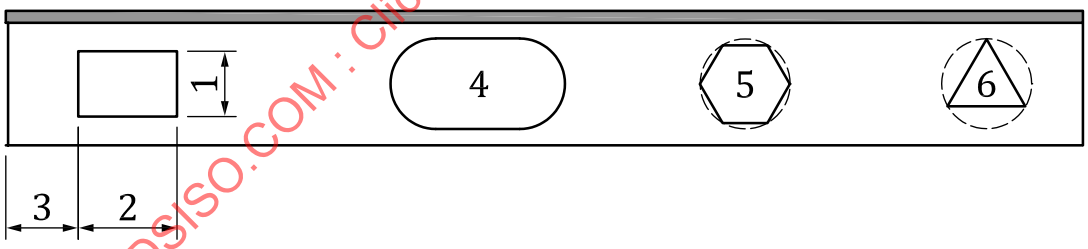


Key

1 steel beam
2 circular opening
3 spacing of openings
4 web post
5 end post
6 span
7 composite floor slab

Figure 1 — Beam with circular openings

Data generated from the tests in this document can be used for beams with circular openings, rectangular openings and elongated openings formed by joining two circular openings. The data can also be used conservatively to assess openings of other shapes by forming around the opening a circular, rectangular or elongated opening which just touches (circumscribes) the shape. Examples of this are shown in Figure 2. For non uniform shapes, the smallest circle is described touching the extreme tips around the shape.



Key

1 height of rectangular opening
2 width of rectangular opening
3 position of opening
4 elongated opening with circular ends
5 hexagonal opening inside a circle
6 triangular opening inside a circle

Figure 2 — Beam with mixed openings

Interaction with ISO 834-10 and ISO 834-11

In most cases, failure of the web will be critical to the overall performance of the beam but failure of the bottom flange may also occur.

Where the web is critical, its corresponding temperature can be used in conjunction with its relevant web reference modification factor to find the limiting steel web temperature. This temperature together

with its elemental web section factor and the product specific elemental re-analysis of ISO 834-10 test data, can be used to determine a product thickness to achieve the required fire resistance rating.

Where the bottom flange is critical, a similar approach (without the need for modification factors) is adopted using its limiting steel temperature, its corresponding elemental bottom flange section factor and the product specific elemental re-analysis of ISO 834-10 test data to determine a product thickness to achieve the required fire resistance rating.

Steel temperature distribution

A large number of fire resistance tests on fire protected beams have shown that if the temperatures of various parts of the web of a beam in the vicinity of web openings are compared with the temperature of the centre of the web away from any openings, the ratio of the temperatures is reasonably constant. Where the web temperature is measured at least 250 mm from the edge of the hole it can be assumed that the hole has no effect on this temperature measurement. This is referred to as the web reference temperature.

In this document, a relationship is provided to assess the temperature ratios for both a range of web post widths and a number of points around openings in relation to the web reference temperature.

The top flange steel temperature may be assumed to be 75 % of the temperature of an equal sized bottom flange.

Process to determine the thickness of fire protection material

In order to determine a thickness of fire protection material to protect a beam with web openings it is important to understand:

a) the structural failure mode at the fire limit state;

b) the web-post width at the point of failure (if failure is in the web);

c) the temperature of the web at failure;

d) the temperature of the bottom flange at failure.

The amount of fire protection required should be based on the thermal information derived from the testing in this document and a suitable structural calculation model.

In order to derive limiting temperatures for cellular beams one should make use of a structural model.

Any structural calculation model should provide a realistic anlaysis of the beam exposed to fire. It should be based upon fundamental physical behaviour in such a way as to lead to a reliable approximation of the expected behaviour of the relevant structural component under fire conditions. It is not within the scope of this document to define the detailed analysis methods of the structural model, however, the following modes of failure as a minimum should be accounted for at the fire limit state:

— global vertical shear;

— global bending moment;

— vertical shear at openings;

— bending moment at openings;

— Vierendeel bending moment at openings;

— web-post buckling;

— web-post bending;

— web-post horizontal shear.

In this document, three methods are described in the informative Annex A to determine the thickness of fire protection for beams with web openings:

a) analysis for any fire protection material;

b) iterative thickness analysis incorporating product specific fire protection data;

c) iterative steel temperature analysis incorporating product specific fire protection data.

Fire-resistance tests — Elements of building construction —

Part 13: Requirements for the testing and assessment of applied fire protection to steel beams with web openings

1 Scope

This document specifies a test and assessment method for determining the contribution made by fire protection systems to the fire resistance of structural steel beams, I and H sections, in the horizontal plane containing openings in the web which may affect the structural performance of the beam. It is applicable to beams subjected to three or four sided fire exposure.

For any cellular beam with a single web opening or where the web openings are considered to be of small diameter in relation to the web depth the applicability of this document is intended to be determined by a structural engineer

This document adopts the principle of establishing ratios of temperatures between and around openings in the web of a beam with the temperatures of a solid portion of that beam. This is with the intention that these data can be utilised within a structural model to derive the value and location of the associated limiting temperature of the beam at the fire limit state. The limiting temperature is then used in conjunction with data for the fire protection material determined from ISO 834-10 and ISO 834-11 to determine the necessary thickness of fire protection material for beams with web openings.

This document applies to fire protection materials that have already been tested and assessed in accordance with ISO 834-10 and ISO 834-11 and is not intended to be used in isolation. It covers fire protection systems that include both passive and reactive materials which follow the section profile as defined in this document.

This document includes the use of a multi-temperature analysis (MTA) derived from ISO 834-11 as the basis for determining the thickness of fire protection for beams with web openings.

This document contains an assessment method, which prescribes how the analysis of the test data should be made and gives guidance on the procedures that could be undertaken.

The assessment procedure can be used to establish:

a) The thermal response of the fire protection system on cellular beams, (the thermal performance) on the basis of the temperature data derived from testing unloaded steel sections.

b) The temperature ratio between the web post and the web reference temperature, which will vary depending on the web post width.

c) The temperature ratio between points around the web openings and the web reference area.

d) A structural model that can be used to derive limiting temperatures for cellular beams.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 834-6, *Fire-resistance tests — Elements of building construction — Part 6: Specific reqrements for beams*

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

ISO 834-11, *Fire resistance tests — Elements of building construction — Part 11: Specific requirements for the assessment of fire protection to structural steel elements*

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

ISO 13943, *Fire safety — Vocabulary*

ISO 15614-1, *Specification and qualification of welding procedures for metallic materials — Welding procedure test — Part 1: Arc and gas welding of steels and arc welding of nickel and nickel alloys*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
bottom flange temperature
average of the bottom flange temperatures

3.2
cellular beam
structural steel beams with openings in the web

3.3
elemental multi temperature analysis
outcome of an assessment carried out on data from ISO 834-11 based on a range of average temperatures of the web and flanges separately

3.4
elemental section factor
section factor of the web or bottom flange in isolation

3.5
fire protection system
fire protection material together with any supporting system including mesh reinforcement as tested

3.6
fire protection thickness
dry thickness of the fire protection system

Note 1 to entry: For reactive fire protection systems, the thickness is the mean dry film thickness of the coating excluding primer and top coat if applicable.

3.7
limiting temperature
temperature at a point within the beam at which structural failure of the cellular beam will take place

3.8
multi temperature analysis
outcome of an assessment carried out in accordance with ISO 834-11 based on a range of average temperatures of the whole steel section

3.9
passive fire protection material
sprayed coatings or renderings formulated with ingredients enabling the retention of their physical form upon heating while providing insulation to the substrate

3.10
plate girder dimensions
overall beam depth, by flange width, by flange thickness, by web thickness

Note 1 to entry: Plate girder dimensions are given in millimetres.

3.11
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

3.12
stickability
ability of a fire protection material to remain in position for a defined range of deformations, furnace and steel temperatures, such that its ability of the material to provide fire protection is not significantly impaired

3.13
test specimen
steel test section plus the fire protection system

3.14
Vierendeel bending
mechanism by which shear is transferred across the web opening and causes bending in the top and bottom, left and right, parts of the beam surrounding the opening

3.15
web post
portion of steel between the web openings

3.16
web post buckling
buckling that occurs when the web separating two openings is unable to transfer the required horizontal shear force and the shear stress is greater than the shear strength of the web

3.17
web post temperature
proportioned average temperature of the web post derived from thermocouples fixed across the web at mid-height

3.18
web reference temperature
mean temperature of a solid portion of the web without holes in close proximity

4 Symbols and abbreviated terms

Symbol	Unit	Description
b	m	width of beam flanges
d	m	depth of beam
t_w	m	web thickness
t_f	m	flange thickness
a	m	heated perimeter
v	m^2	cross section area

5 Test equipment

5.1 General

The furnace and test equipment as appropiate, shall conform to that specified in ISO 834-1.

5.2 Furnace

The furnace shall be designed to permit the dimensions of the test specimens to be exposed to heating as specified in 9.2 and their installation within the test furnace as specified in 7.2.

5.3 Test conditions

A number of short steel beams all containing web openings and protected by the fire protection system shall be heated in a furnace according to the protocol given in ISO 834-1.

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 ISO 834-1 shall be followed in the performance of this test unless specific contrary instructions are given.

6 Test specimens

6.1 General

The test sections should be chosen to suit the scope of the assessment.

There are specific test packages designed to suit a specified fire performance period as given in 6.5 and Tables 1, 2, and 3.

6.2 Precautions against erroneous results

In the event that there should be a loss of valid results from the package of short steel sections tested (through failure of thermocouples, abnormal behaviour of fire protection etc), then the conditions given in 10.1 shall be applied and a further number of short steel sections may be required to be tested.

6.3 Construction of steel test specimens

6.3.1 Cellular beam test sections

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

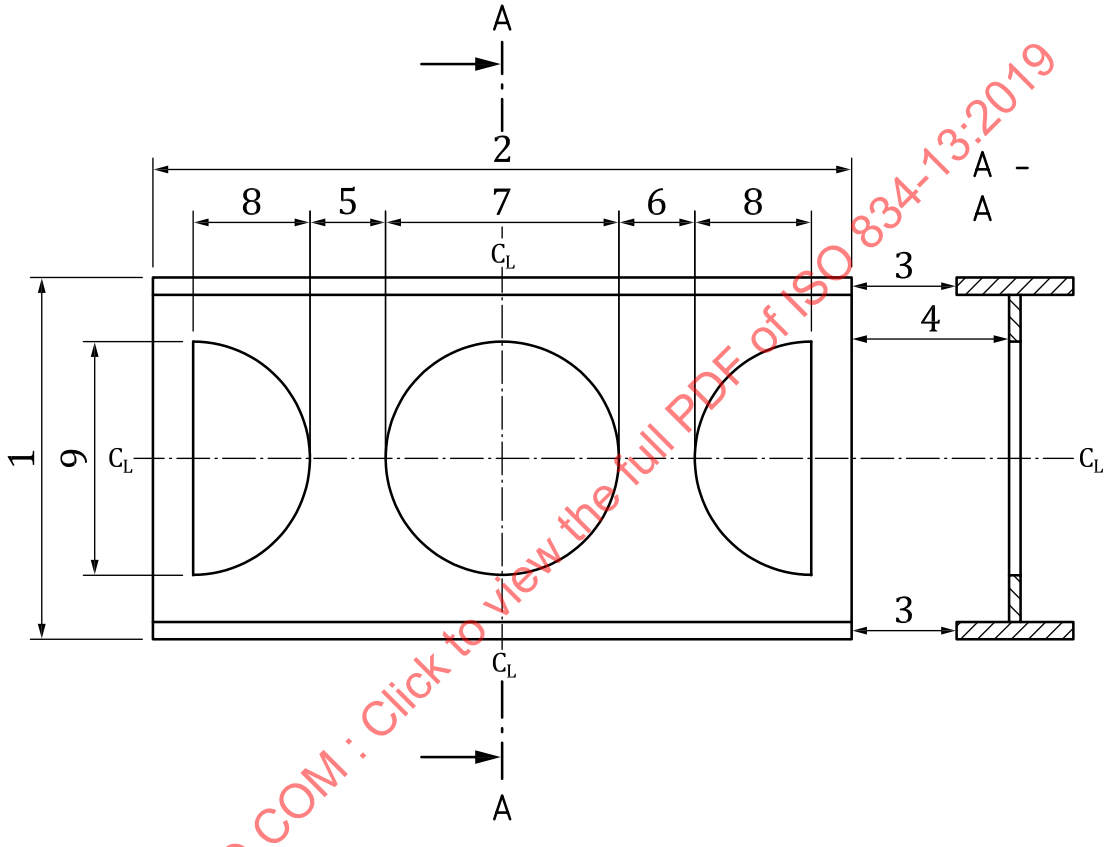
In each case the welding techniques shall be in accordance with ISO 15614-1.

The cellular beam sections shall have a length of 1 200 mm ± 50 mm and will have circular or rectangular openings cut out of the webs.

The cellular beam sections shall be constructed according to Figures 3, 4 and 5.

A Beam Reference Number is assigned to each construction. The Beam Reference Number is used to identify components of test packages described in 6.5 and Tables 1, 2 and 3.

Dimensions in mm

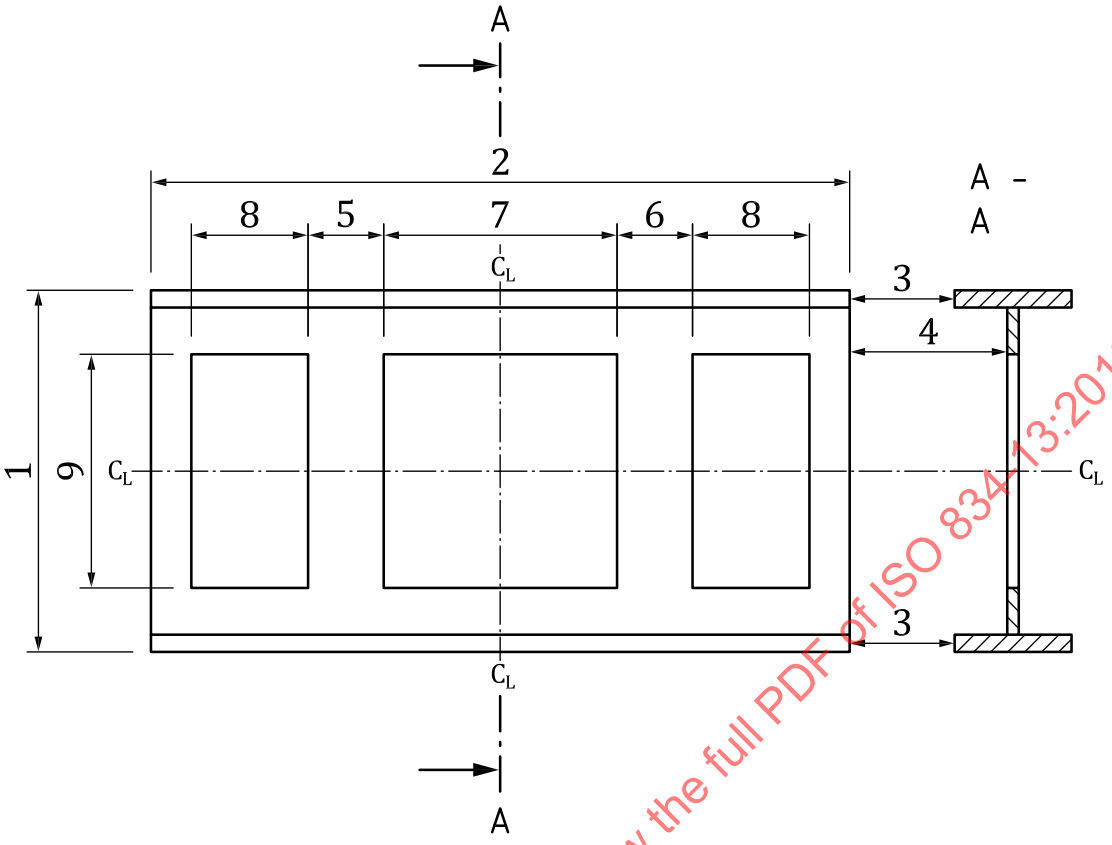


Key

Beam reference number	Dimensions of beam sections								
	1	2	3	4	5	6	7	8	9
1	600	1 200 ± 50	170 × 12	8 thick	130	160	400	200	400
2	600	1 200 ± 50	170 × 12	8 thick	160	225	400	200	400
3	600	1 200 ± 50	170 × 12	8 thick	130	225	400	200	400
6	600	1 200 ± 50	170 × 15	10 thick	130	160	400	200	400
7	600	1 200 ± 50	170 × 15	10 thick	160	225	400	200	400
8	600	1 200 ± 50	170 × 15	10 thick	130	225	400	200	400
11	600	1 200 ± 50	170 × 20	12 thick	130	160	400	200	400
12	600	1 200 ± 50	170 × 20	12 thick	160	225	400	200	400
13	600	1 200 ± 50	170 × 20	12 thick	130	225	400	200	400

Figure 3 — Beam sections with circular holes

Dimensions in mm

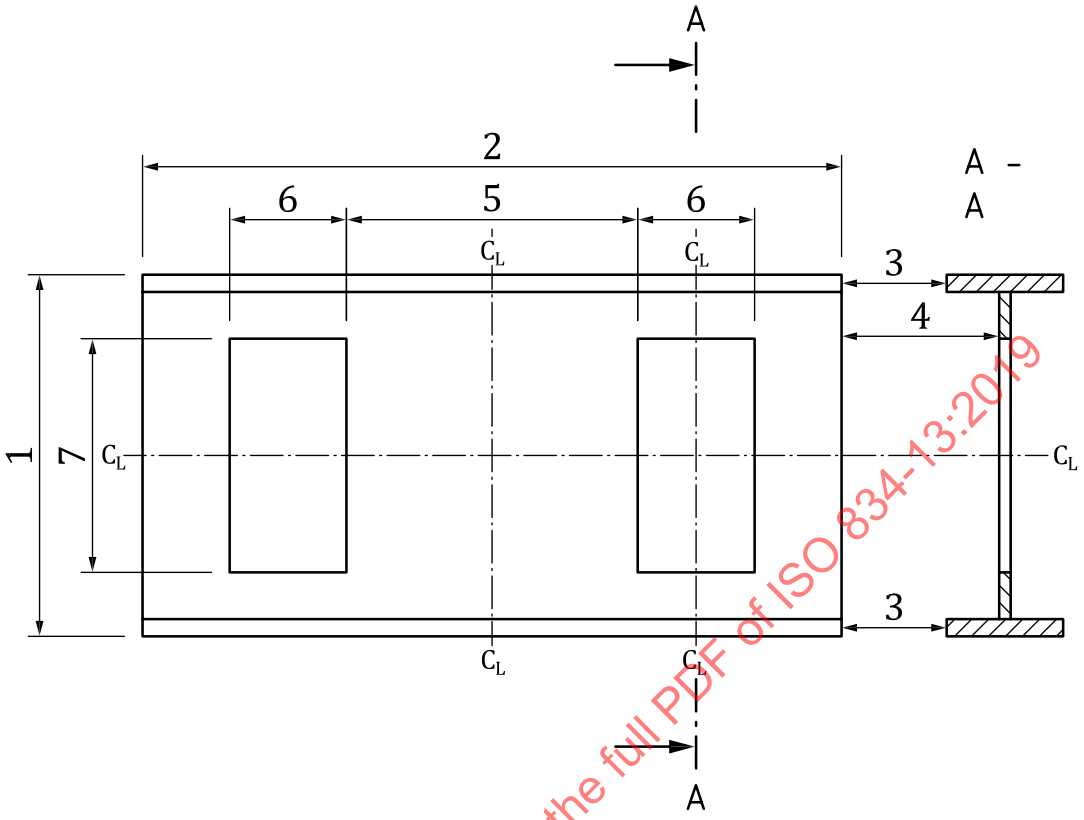


Key

Beam Reference Number	Dimensions of beam sections								
	1	2	3	4	5	6	7	8	9
5	600	1 200 ± 50	170 × 12	8 thick	130	225	400	200	400
10	600	1 200 ± 50	170 × 15	10 thick	130	225	400	200	400
15	600	1 200 ± 50	170 × 20	12 thick	130	225	400	200	400

Figure 4 — Test specimens with rectangular holes — Narrow web post

Dimensions in mm



Key

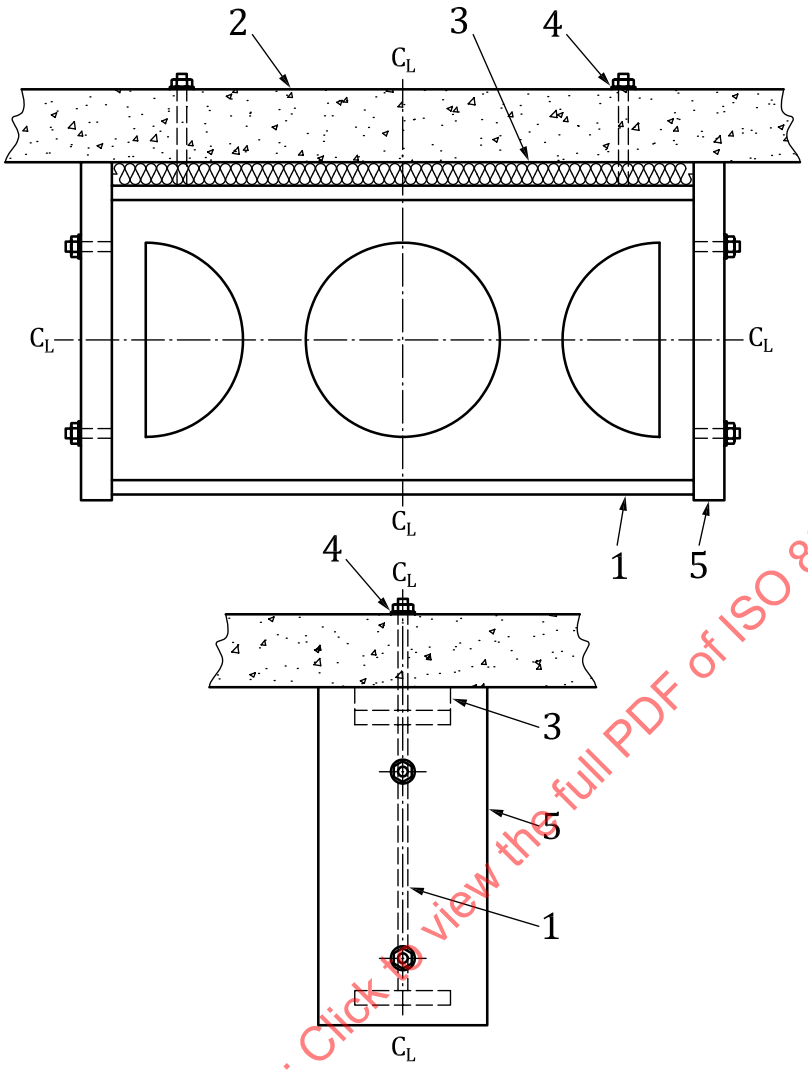
Beam Reference Number	Dimensions of beam sections						
	1	2	3	4	5	6	7
4	600	1 200 ± 50	170 × 12	8 thick	500	200	400
9	600	1 200 ± 50	170 × 15	10 thick	500	200	400
14	600	1 200 ± 50	170 × 20	12 thick	500	200	400

Figure 5 — Test specimens with rectangular holes — Wide web post

The 130 mm web post specified in Figures 3 and 4 may be replaced by a narrower web post if a wider scope is required by the sponsor.

To minimize heat transfer at the ends of the 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 6).

The linear dimensions of the end protection shall be greater than the total overall dimensions measured over the fire protected steel member.



Key

1 steel section
2 furnace cover
3 insulation board
4 stud / plate / locking nut
5 insulation board end cap

Figure 6 — Unloaded beam — Typical construction — Circular holes (Rectangular holes similar)

6.3.2 Application of the fire protection to the test sections

The surface of the steel shall be prepared in accordance with the manufacturers recommendations and the fire protection system shall be applied to the beams in a manner representative of practice.

6.4 Composition of test specimen component materials

6.4.1 Steel sections

The grade of steel used shall be any mild steel structural grade excluding engineering grades, that is used for load bearing members in building construction.

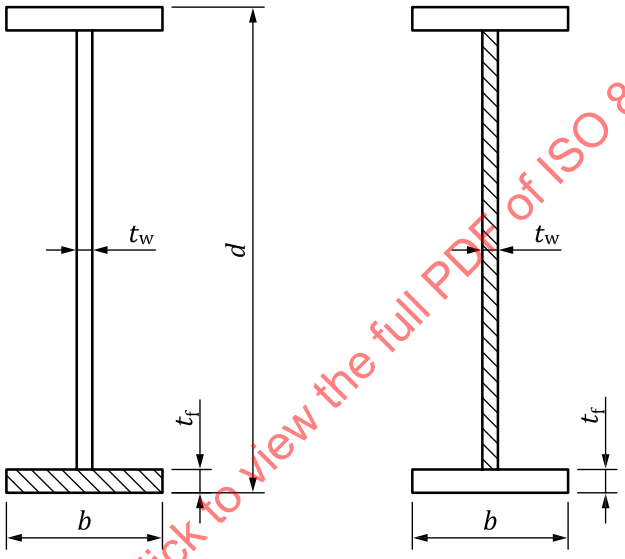
The dimensions of the steel sections shall be measured and these values shall be used to determine the elemental section factors (*a/v)*. The elemental section factors, (*a/v)*, shall be calculated in accordance with Figure 7.

$$\text{Elemental section factor} = \frac{a}{v}$$

where

a is the heated perimeter of the steel section in meters;

v is the cross-sectional area of the steel section in square meters.



	Lower flange	Web
Heated perimeter (*a*) meter	$(2b + 2\ t_f) - t_w$	$2d - 4\ t_f$
Area (*v*) square meter	$b \times t_f$	$(d - 2t_f) \times t_w$

Key

Section factor = $a/v(m^{-1})$

b width of beam flanges

d depth of beam

t_w thickness of web

t_f thickness of flanges

Figure 7 — Elemental section factor

All the steel sections shall be fabricated from steel plate to ensure a consistent approach in determining the thermal data.

6.4.2 Fire protection materials

The composition, dimensions, (including thickness), verification and properties of the fire protection materials shall be determined in accordance with the requirements of ISO 834-10.

The thickness of fire protection material applied to the inside edge of an opening may be less than the thickness tested on the main body beams in the test packages in 6.5 provided it is not less than the

minimum tested on a loaded beam in ISO 834-10. Other materials or combinations of different materials may not be used unless alternative fire test evidence is available that is not covered by this document.

6.4.3 Fire protection thickness requirements

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

Ten thickness measurements shall be taken on each face of each web post within an area 125 mm above and below the web centreline in accordance with Figures 8, 9 and 10.

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

In the case of the 500 mm web post, the thickness measurements are taken in an area within a 250 mm × 250 mm square around the four thermocouples (see Figure 10).

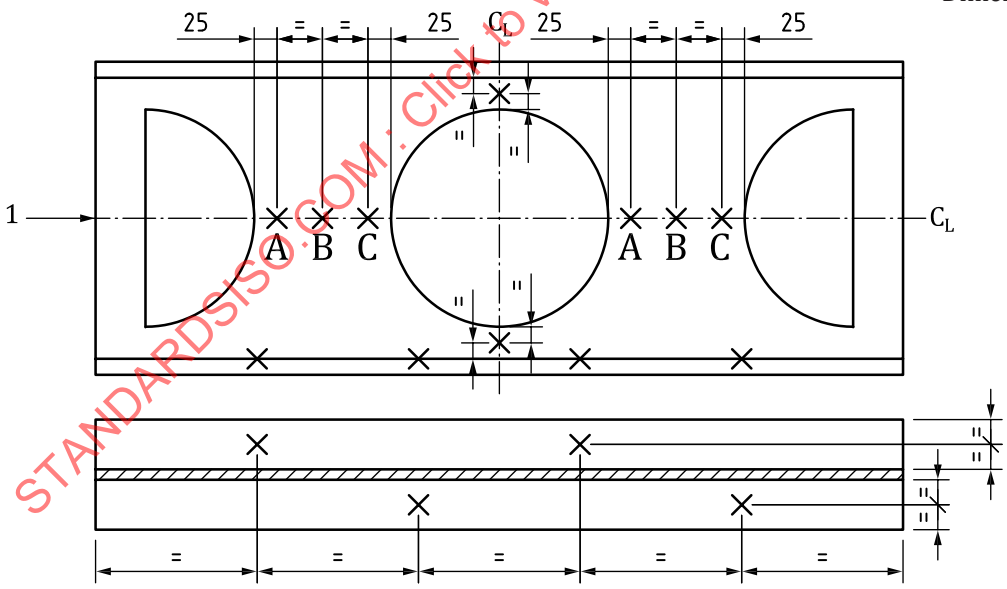
Twenty thickness measurements shall be taken on the underside bottom flange of each section and the mean thickness of fire protection material on the bottom flange is then determined.

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

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

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

Dimensions in mm



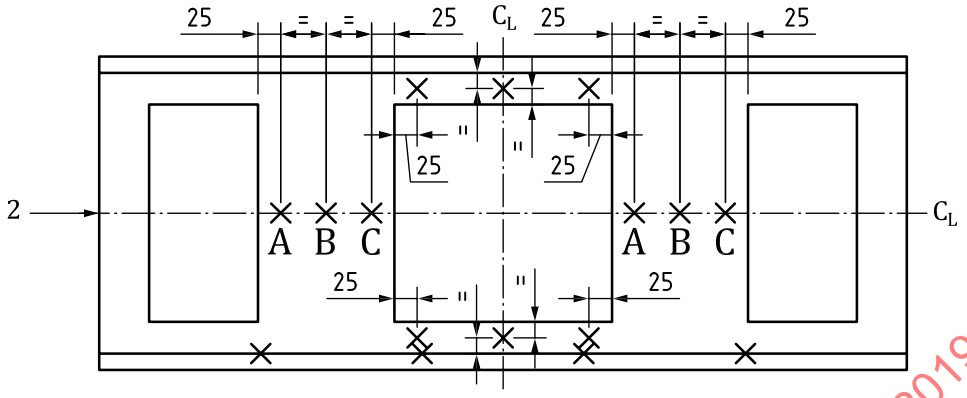
Key

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

E web post thermocouples for web reference temperature

Figure 8 — Locations of fire protection thickness measurements and thermocouple positions on beam with circular openings

Dimensions in mm



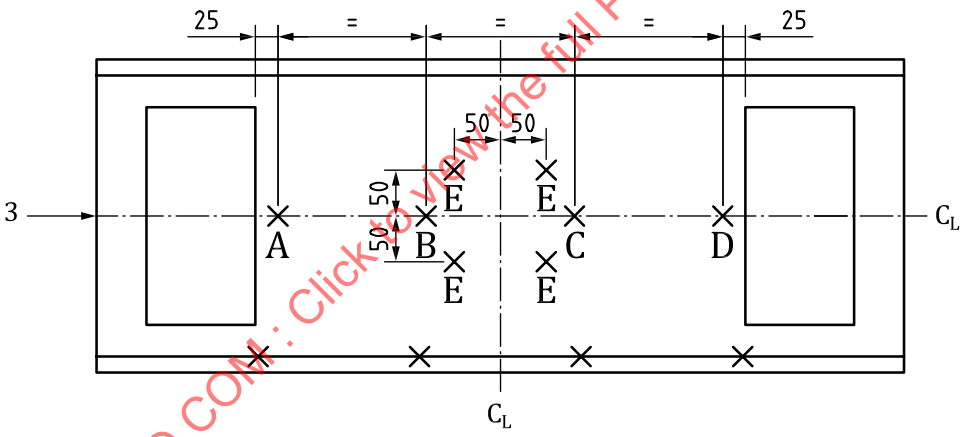
Key

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

E web post thermocouple for web reference temperature

Figure 9 — Locations of fire protection thickness measurements and thermocouple positions on beam with rectangular openings with web posts less than or equal to 225 mm

Dimensions in mm



Key

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

E web post thermocouple for web reference temperature

Figure 10 — Locations of fire protection thickness measurements and thermocouple positions on beam with rectangular openings with web posts greater than 225 mm

6.5 Selection of test specimens — Test packages

The scope of the assessment will determine the selection of the test specimens. Tables 1, 2 and 3 provide suitable test packages with specific section details for fire performance periods up to and including 240 min. Where the scope of the assessment is required to include web posts narrower than those listed in Tables 1, 2 and 3, then additional sections shall be tested, or, the 130 mm web posts can be replaced by 100 mm web posts.

Table 1 — Test package for protection up to 60 min fire resistance

Beam reference number	Plate girder dimensions (mm)	Web post width (mm)	Cell opening type
1	600 × 170 × 12 × 8	130	Circular
		160	Circular
2	600 × 170 × 12 × 8	160	Circular
		225	Circular
3	600 × 170 × 12 × 8	130	Circular
		225	Circular
4	600 × 170 × 12 × 8	500	Rectangular
5	600 × 170 × 12 × 8	130	Rectangular

Table 2 — Test package for protection up to 90 min fire resistance

Beam reference number	Plate girder	Web post width (mm)	Cell opening type
6	600 × 170 × 15 × 10	130	Circular
		160	Circular
7	600 × 170 × 15 × 10	160	Circular
		225	Circular
8	600 × 170 × 15 × 10	130	Circular
		225	Circular
9	600 × 170 × 15 × 10	500	Rectangular
10	600 × 170 × 15 × 10	130	Rectangular

Table 3 — Test package for protection up to 240 min fire resistance

Beam reference number	Plate girder	Web post width (mm)	Cell opening type
11	600 × 170 × 20 × 12	130	Circular
		160	Circular
12	600 × 170 × 20 × 12	160	Circular
		225	Circular
13	600 × 170 × 20 × 12	130	Circular
		225	Circular
14	600 × 170 × 20 × 12	500	Rectangular
15	600 × 170 × 20 × 12	130	Rectangular

7 Installation of test specimens

7.1 Fixing

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

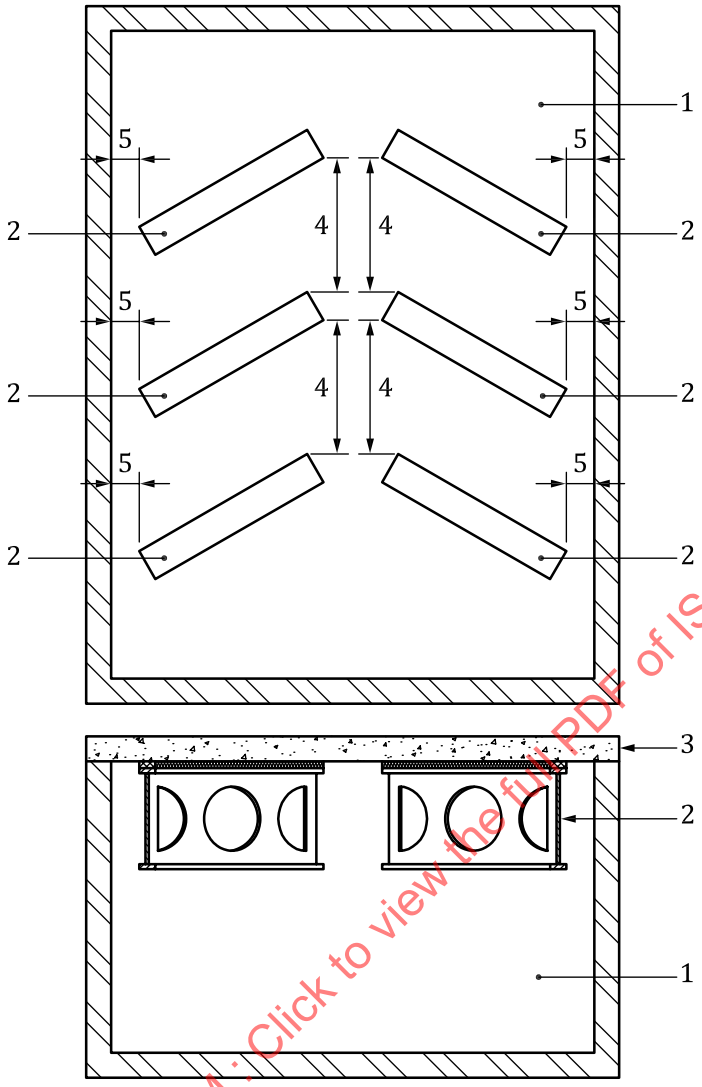
Each specimen shall be provided with a layer of ceramic fibre insulation board placed between the soffit and the top flange of the beam.

The insulation material shall have an uncompressed thickness of (30 ± 5) mm and a nominal density of (125 ± 25) kg/m^3. The insulation shall have a width equal to the width of the top flange of the steel beam (see Figure 11).

Alternative insulation materials of Class A1 determined in accordance with ISO 1182 and ISO 1716 may be used provided they have similar thermal properties and thickness to the specified ceramic fibre insulation.

7.2 Installation pattern

A typical test specimen installation arrangement for a 4 m by 3 m furnace is given in Figure 11. Beams shall have a spacing of a minimum 450 mm from flange toe to flange toe and be positioned such that they are at least 300 mm from the furnace wall as shown in Figure 11. Care shall be taken to eliminate direct burner impingement onto the test specimens.



Key

1 furnace area
2 unloaded beam specimen fixed to furnace cover slab as shown in Figure 6
3 furnace cover slab
4 minimum separation of 450 mm
5 minimum 300 mm

Figure 11 — Typical test specimen installation pattern

7.3 Furnace load

In order to ensure that the specified furnace temperature/time relationship is complied with and to avoid test specimens being affected by adjacent specimens and other obstacles it may be necessary to control the amount of steel within the furnace.

Typically a furnace of size 4 m by 3 m by approximately 2 m deep can accommodate up to 45 Kg/m^3 without adverse effects.

7.4 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 ISO 834-1.

8 Application of instrumentation

8.1 General

The instrumentation for measurement of temperature and furnace pressure shall comply with the requirements of ISO 834-1.

8.2 Instrumentation for measurement of furnace temperature

8.2.1 General

Plate thermometers, of the type specified in ISO 834-1, shall be provided to measure the temperature of the furnace and shall be uniformly distributed, as stated in ISO 834-1, to give a reliable indication of the temperature in the region of the test specimens.

8.2.2 Furnace temperature in the region of test specimens

The furnace temperature shall be measured by plate thermometers situated in the same position as if a loaded beam was installed as specified in ISO 834-10.

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

8.3 Instrumentation for measurement and determination of steel temperatures

Thermocouples for measurement and recording of steel temperatures shall be of the type and fixed as stated in ISO 834-10.

8.3.1 Location of thermocouples attached to the beams

Figures 8, 9 and 10 identify the locations of the thermocouples to be attached to the beams.

8.3.2 Location of web reference thermocouples

The web reference areas are located on sections 5, 10 and 15 as given in Tables 1, 2, and 3.

There are four thermocouples for each reference area positioned at the corners of a 100 mm square around a point on the centre of the web and 500 mm from the edge of the hole. See Figure 10 (key item E).

8.4 Instrumentation for measurement of pressure

Equipment for measuring pressure within the furnace shall be provided, located and used as specified in ISO 834-1.

9 Test procedure

9.1 General

Carry out checks for thermocouple consistency and establish data points for temperature as specified in ISO 834-1 before commencement of the test and the procedures defined in 9.2 to 9.5.

9.2 Furnace temperature and pressure

Measure and record the furnace temperature in the region of the test specimens using the plate thermometers defined in ISO 834-1 and the furnace pressure in accordance with ISO 834-1.

9.3 Temperature of steelwork

Measure and record the temperature of the sections using the thermocouples attached to the steelwork as specified in Figures 8, 9 and 10 at intervals not exceeding 1 min.

9.4 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 ISO 834-1.

9.5 Termination of test

Continue the test until the required fire performance period is reached. If the mean bottom flange temperature recorded on all the steel sections has not reached 575 °C then the test shall be continued until this occurs. If the maximum temperature in the scope of the MTA generated from ISO 834-11 is less than 575 °C then this shall be used instead of 575 °C for termination of the test.

10 Test results

10.1 Acceptability of test results

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

— From the thermocouples on each web post only 1 can be invalid.

— From the 4 thermocouples on the lower flange at least 3 results shall be valid.

— If one of the outer web post thermocouples fails then the other should be double counted when determining the weighted average.

10.2 Test report and presentation of test results

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 ISO 834-10.

Any deviation with respect to thickness and/or density of fire protection material and constructional details, 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 ISO 834-1, the following shall also be included in the test report:

a) The measured dimensions and actual material properties, especially the thickness, density and moisture contents of the fire protection where relevant together with those values to be used in the assessment, according to 7.4.

b) The individual results of all furnace temperature measurements and the mean of all individual furnace temperature measurements, taken as specified in ISO 834-1, graphically presented and compared with the specified requirements and tolerances given in ISO 834-1.

c) The individual results of all furnace pressure measurements and the mean of all individual furnace pressure measurements, taken as specified in ISO 834-1, graphically presented and compared with the specified requirements and tolerances given in ISO 834-1.

d) The weighted mean steel temperature of each web post as defined in 11.2 and the mean steel temperature of the bottom flange shall be tabulated.

e) The steel temperatures at all the additional thermocouple positions shall be tabulated.

f) The mean steel temperature of the web reference area shall be tabulated.

Observations of the behaviour of the test specimens shall be made and the time at which they occur shall be recorded.

Only data maintained in the laboratory files shall be used in the assessment.

11 Assessment

11.1 General

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

This document defines test packages to suit the required fire performance period as given in 6.5.

11.2 Determination of web post and web reference temperatures

11.2.1 Calculation of web post temperatures

Web post temperatures are dependent upon the web post width and calculated as follows, also see Annex B:

a) For web post width = 100 mm

$$\text{Web post temperature} = \frac{(\text{Temp at Position A} \times 37{,}5) + (\text{Temp at Position C} \times 37{,}5) + (\text{Temp at Position B} \times 25)}{100}$$

b) For web post width = 130 mm

$$\text{Web post temperature} = \frac{(\text{Temp at Position A} \times 45) + (\text{Temp at Position C} \times 45) + (\text{Temp at Position B} \times 40)}{130}$$

c) For web post width = 160 mm

$$\text{Web post temp} = \frac{(\text{Temp at Position A} \times 50) + (\text{Temp at Position C} \times 50) + (\text{Temp at Position B} \times 60)}{160}$$

d) For web post width = 225 mm

$$\text{Web post temp} = \frac{(\text{Temp at Position A} \times 50) + (\text{Temp at Position C} \times 50) + (\text{Temp at Position B} \times 125)}{225}$$

e) For web post width = 500 mm

$$\text{Web post temp} = \frac{(\text{Temp at Position A} \times 50) + (\text{Temp at Position D} \times 50) + (\text{Temp at Position B} \times 200) + (\text{Temp at Position C} \times 200)}{500}$$

11.2.2 Calculation of web reference temperature

The web reference temperature is calculated as the average of the four thermocouples referred to in 8.3.2.

11.3 Determination of web-post lines

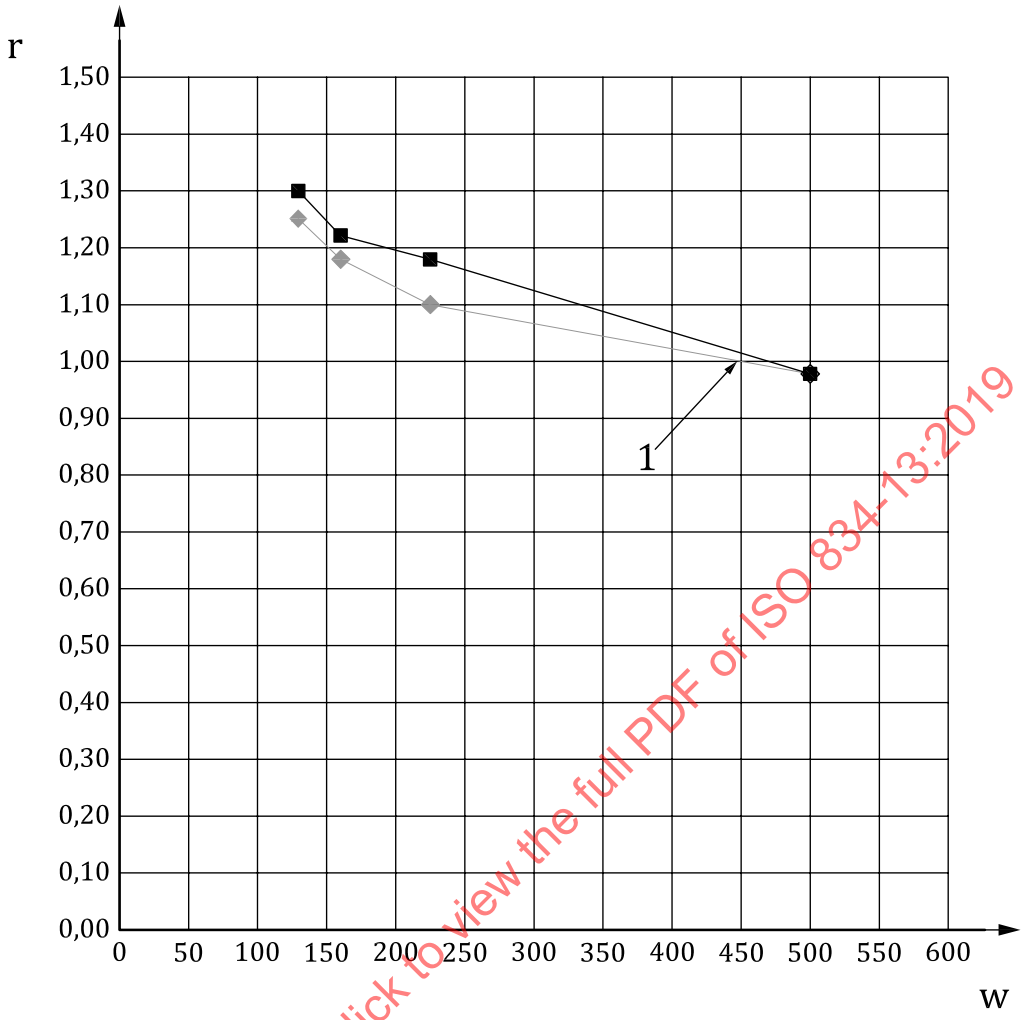
The web post line assessment shall be based on the ratio of the web post temperature to the web reference temperature, for the maximum required fire performance period.

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

Where there is more than one web post of the same width, then the mean of the individual ratios shall be determined. This ratio is then plotted against web post width (see Figure 12). If the web post ratio is less than 1, then the web post ratio for web posts greater than this shall equal 1. The web post ratio shall increase with a decrease in web post width. If any point does not satisfy this criteria then it shall be replaced by the ratio of the next highest web post width unless this point is the narrowest web post in which case it shall revert to the next highest web post ratio.

As a minimum requirement, the average bottom flange temperature shall not reach 575 °C before it is in within 15 % of the required period of fire performance. No upper limit has been set in this respect, as the web post to web reference temperatures will be taken when the bottom flange has reached 575 °C and not when the predicted period of fire performance has been reached. This will ensure that no benefit will be gained from over-application of the protection system.

A single fire test at maximum fire resistance period may be used to determine a web post line assessment for all fire resistance periods below by taking the worst case individual ratio of the mean web post temperature to the web reference temperature for each fire resistance period compared to the ratio of the mean web temperature to the web reference temperature at the maximum fire resistance period achieved.



Key

w web post width, expressed in mm

r ratio of web post temperature to web reference temperature

◆ circular holes

■ rectangular holes

1 the point where the line intersects with a ratio of 1,0. All greater web posts widths have a ratio of 1,0

Figure 12 — Example of web post lines

11.4 Additional thermal modification factors

Some structural models utilise a protection product specific temperature distribution across the section, and may therefore require additional temperature measurements at a number of locations on the steel section around the web openings. Therefore thermocouples in addition to those on the web post and web reference area may be included in the test specimens but their use is considered optional depending upon the requirements of the structural model. These additional thermocouples may be situated, but are not limited to, the top and bottom of the web posts and underneath openings.

For each of these additional temperature measurement positions, the equivalent temperatures across all sections in the test package should be averaged and reported. These mean values should be used to determine further modification factors calculated as the ratio of the mean values to the web reference value. These modification factors may be used as additional thermal information should they be required by the structural model.

The optional thermocouples are shown in Figures 8, 9 and 10.

11.5 Location of limiting temperatures

For any cellular beam design, there will be a weakest point along its length depending on the applied load and a number of geometrical variables.

A structural analysis of the beam containing web openings shall be conducted by a professional structural engineer to locate the weakest point related to the fire limit state. The structural analysis shall address each of the potential failure modes. The structural analysis shall be based on a model validated by fire test data on a loaded specimen whose size is in compliance with ISO 834-6.

NOTE A validation fire test has been conducted on an uncoated, unprotected beam where the fire exposure was controlled by a rate of temperature rise of 10°C/min.

11.6 Determination of the elemental multi-temperature analysis (EMTA)

The fire protection thickness applied to any cellular beam shall be sufficient to keep the beam below its limiting temperature as determined in 11.3.

The thickness required for each fire resistance period is determined from the EMTA generated by the assessment from ISO 834-11. Examples of the presentation of such tabulated information are given in Table 4.

The structural model will indicate whether failure is governed by the web or the bottom flange limiting temperatures so that the most appropriate elemental analysis can be used to determine the fire protection thickness.

The fire protection thickness applied to any cellular beam shall be sufficient to keep the beam below the temperatures derived from a structural analysis at elevated temperatures. Information on this process is presented in Annex A.

The web or bottom flange temperature for a given thickness of fire protection may be obtained by carrying out an assessment to ISO 834-11 for the web or bottom flange temperatures only. The web or bottom flange temperatures are analysed in the same way that average beam temperatures are analysed with the exception that the stickability correction factors used are those already used for the average beam temperature given in ISO 834-11:2014, Annex B. Where the assessment is based on short column testing only, the assessment shall be carried out using the mean of both flanges.

Conservatively, the web and bottom flange temperatures may be assumed to be equal and the section factors of the individual web and flange are calculated according to Figure 11. The fire protection thickness shall be that derived from an assessment in accordance with ISO 834-11.

Table 4 — Example of tabulated data base on the mean steel temperatures of the web of I-section beams

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 of web below design temperature**							
40								
50								
60								
70								
80								

Table 4 *(continued)*

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 of web below design temperature**							
90								
100								
110								
120								
130								
140								
150								
160								
170								
180								
190								
200								
210								
220								
230								
240								
250								
260								
270								
280								
290								
300								

Temperature and section factor ranges for illustration only. Actual range to be determined by the scope of the assessment.

12 Assessment report

The assessment report shall include the following:

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

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

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 dimensions of the test specimens; reason for the omission of any test data;

e) the composition and measured properties, of test specimen components required to be determined from 6.4;

f) the web post, the web reference, mean bottom flange temperatures, and the means of all the temperatures for all the additional thermocouples for each fire performance period;

g) where measured, the thermal modification factors calculated from any additional thermocouple data;

h) the thermal analysis shall produce a table of web post data points and a graphical representation of the ratio of the web post temperature to the web reference temperature against web post width;

i) a statement regarding the limits of direct application of the assessment procedure;

j) the elemental thermal data generated and reported in ISO 834-10 shall be reassessed and reported against elemental *a/v* for each fire resistance period in the format illustrated in Table 4.

13 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 systems over the range of fire protection material thicknesses tested and the values of steel section factor *a/v* tested in ISO 834-10.

The assessment is only applicable to the method of application or fixing method used in the test. Any change in the method of application and any reinforcement of material shall be re-assessed. This would normally require additional tests.

The results of the assessment are applicable to all other structural (non engineering) grades of steel to that tested and with the limitations therein.

The results from the testing of beams with circular and rectangular web openings may be used to determine limiting temperatures for beams with other shaped openings. This is achieved by the creation of a larger circular or rectangular opening that is circumscribed around the other shaped opening. The beam can then be treated as a beam with circular or rectangular openings in the web (see Introduction).

The assessment may be applied to both hot rolled sections and plated girders.

The thermal data generated giving web post modification factors applies to all web thicknesses.