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BSI Standards Publication

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

Part 9: Applied fire protection systems to steel beams with web openings

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National foreword

This British Standard is the UK implementation of EN 13381-9:2015.

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

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Test methods for determining the contribution to the fire resistance of structural members - Part 9: Applied fire protection systems to steel beams with web openings

Méthodes d'essai pour déterminer la contribution à la résistance au feu des éléments de construction - Partie 9: Systèmes de protection au feu appliqués aux poutres alvéolaires en acier

Prüfverfahren zur Bestimmung des Beitrages zum Feuerwiderstand von tragenden Bauteilen - Teil 9: Brandschutzmaßnahmen für Stahlträger mit Stegöffnungen

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CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

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Foreword

This document (EN 13381-9:2015) 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of an identical text or by endorsement, at the latest by December 2015, and conflicting national standards shall be withdrawn at the latest by December 2015.

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

This European Standard is one of a series of standards for evaluating the contribution to the fire resistance of structural members by applied fire protection materials. Other parts of this series are:

— *Part 1: Horizontal protective membranes*;

— *Part 2: Vertical protective membranes*;

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

— *Part 4: Applied passive protection to steel members*;

— *Part 5: Applied protection to concrete/profiled sheet steel composite member*;

— *Part 6: Applied protection to concrete filled hollow steel columns*;

— *Part 7: Applied protection to timber members* [currently at Enquiry stage];

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

The 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 this data can be utilized within a structural model to derive the value and location of the associated limiting temperature of the beam at the fire limit state. This can then be used in conjunction with data for the fire protection material determined from either EN 13381-4 or EN 13381-8, as appropriate to determine the necessary thickness of fire protection.

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Introduction

The European Committee for Standardization (CEN) draws attention to the fact that it is claimed that compliance with this document may involve the use of a patent concerning the method of designing a fire resistant structural beam.

CEN takes no position concerning the evidence, validity and scope of this patent right.

The holder of this patent right has ensured CEN that, through appropriate declaration, he/she agrees to publically disclose the relevant part of their patent in RT1356 or EN 13381-9 and renounce to challenge the same and all subsequent European standards on the basis of infringement of their patent. In this respect, the statement of the holder of this patent right is registered with CEN. Information may be obtained from:

Fabsec Limited

1st Floor Unit 3 Calder Close

Calder Business Park

Wakefield

WF4 3BA

United Kingdom

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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.

1 Scope

This European Standard specifies a test and assessment method for determining the contribution made by fire protection systems to the fire resistance of structural steel beam I and H members in the horizontal plane containing openings in the web which may affect the structural performance of the beam. This European Standard applies to beams subject to 3 or 4 sided fire exposure.

For any 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 European Standard needs to be determined by a structural engineer.

This European Standard applies to fire protection materials that have already been tested and assessed in accordance with EN 13381-4 or EN 13381-8. i.e. this European Standard cannot be used in isolation. Use of this European Standard requires the multi-temperature analysis (MTA) derived from EN 13381-4 or EN 13381-8 as the basis for determining thickness for beams with web openings. This MTA needs to be carried out on the web and bottom flange separately generating an elemental multi-temperature analysis (EMTA). The bottom flange EMTA may be used as the top flange EMTA when a beam is subject to 4 sided exposure.

This European Standard contains the fire test methodology, which specifies the tests which need to be carried out 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.

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

The assessment procedure is used to establish:

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

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) the elemental multi temperature analysis from either EN 13381-4 or EN 13381-8 needs to be reassessed and reported against elemental A/V for each fire resistance period;

e) a structural model needs to be used to derive limiting temperatures for cellular beams using the data from b), c) and d) above.

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 1363-1, *Fire resistance tests - Part 1: General Requirements*

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 1994-1-1, *Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings*

EN 1994-1-2, *Eurocode 4 - Design of composite steel and concrete structures - Part 1-2: General rules - Structural fire design*

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

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

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

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

EN 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 (ISO 15614-1)*

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

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
cellular beam(s)
structural steel beams with web opening(s)

3.1.2
fire protection material

3.1.2.1
reactive materials
materials that 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

3.1.2.2
passive materials
materials that 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 which, on heating evaporates to produce cooling effects. These may take the form of sprayed coatings, renderings, mat products boards or slabs.

3.1.3
fire protection system
fire protection material together with any supporting system including mesh reinforcement as tested

3.1.4
test specimen
steel test section plus the fire protection system under test

3.1.5
fire protection thickness
total dry film thickness of the fire protection material

3.1.6
stickability
ability of a fire protection material 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

3.1.7
bottom flange temperature
bottom flange temperature is the overall average of the bottom flange

3.1.8
web post
area of web between two web openings

3.1.9
web post temperature
proportioned average temperature of the web post derived from thermocouples fixed across the web at mid-height

3.1.10
web reference temperature
mean temperature of a solid portion of the web without holes in close proximity, that is at least 250 mm from the edge of a hole

3.1.11
web post buckling
web post buckling 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

3.1.12
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

3.1.13
limiting temperature
temperature at a point along the beam at which structural failure of the cellular beam will take place

3.1.14
elemental section factor
section factor of the web or bottom flange in isolation

3.1.15
plate girder dimensions
plate girder size which is stated as overall beam depth by flange width by flange thickness by web thickness given in millimetres

3.1.16
multi temperature analysis
outcome of an assessment carried out in accordance with either EN 13381-4 or EN 13381-8 based on a range of average temperatures of the whole steel section

3.1.17
elemental multi temperature analysis
outcome of an assessment carried out on data from EN 13381-4 or EN 13381-8 based on a range of average temperatures of the web and flanges separately

3.2 Symbols and units

Symbol	Unit	Designation
B	m	Width of beam flanges
D	m	Depth of beam
t_w	m	Thickness of web
t_f	m	Thickness of flanges

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 be designed to permit the dimensions of the test specimens to be exposed to heating, to be as specified in 6.2 and their installation within the test furnace to be as specified in Clause 6.

4.3 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 EN 1363-1 and Clause 7.

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.

5 Test specimens

5.1 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 5.4.4, Tables 1, 2, and 3.

5.2 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 9.1 shall be applied and a further number of short steel sections may be required to be tested.

5.3 Construction of steel test specimens

5.3.1 Cellular beam test sections

The beam 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 EN ISO 15614-1.

The short beams shall have a length of (1 200 ± 50) mm and will have circular or rectangular openings cut out of the webs.

The short beams shall be constructed according to Figures 1, 2 and 3.

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 4).

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

5.3.2 Application of the fire protection material 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.

5.4 Composition of test specimen component materials

5.4.1 Steel sections

The grade of steel used shall be any structural grade (S designation) to EN 10025-1 (excluding S 185). Engineering grades (E designation) shall not be used.

The dimensions of the steel sections shall be measured and these values shall be used to determine the elemental section factors. The elemental section factors shall be calculated in accordance with Figure 7.

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

5.4.2 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 EN 13381-4 or EN 13381-8.

The thickness of panel 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 it deviates by more than 15 % then the maximum thickness recorded shall be used in the assessment.

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 5.4.4 provided it is not less than the minimum tested on a loaded beam in EN 13381-4 or EN 13381-8 and that it is the same material. Other materials or combinations of may not be used unless alternative fire test evidence is available that is not covered by this European Standard.

5.4.3 Fire protection thickness requirements for sprayed materials

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 Figure 6.

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 x 250 mm square around the four thermocouples (see Figure 6).

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 manufacturers for details.

5.4.4 Selection of test specimens

The scope of the assessment will determine the selection of the test specimens. Tables 1, 2 and 3 provide 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 — Up to and including 60 min fire protection

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

Table 2 — Up to and including 90 min fire protection

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

Table 3 — Up to and including 240 min fire protection

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

NOTE In Tables 1, 2 and 3, it is acceptable to test additional specimens with a narrower web post if required.

6 Installation of the test specimens

6.1 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.

This insulation material shall have an uncompressed thickness of (30 ± 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 flange of the steel beam (see Figure 4)

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

6.2 Installation pattern

A typical test specimen installation pattern useable in a 4 m by 3 m furnace is given in Figure 5. Beams shall have a spacing of a minimum 450 mm from flange toe to flange toe and away from the furnace lining by a minimum of 300 mm as shown in Figure 5.

6.3 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 about 2 m deep can accommodate up to 45 kg/m^3 without adverse affect.

6.4 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 EN 1363-1.

7 Application of instrumentation

7.1 General

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

7.2 Instrumentation for measurement of furnace temperature

7.2.1 General

Plate thermometers, of the type specified in EN 1363-1, shall be provided to measure 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.

7.2.2 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 given in EN 13381-4 and EN 13381-8.

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.

7.3 Instrumentation for measurement and determination of steel temperatures

7.3.1 General

Thermocouples for measurement and recording of steel temperatures shall be of the type and fixed as given in EN 13381-4 and EN 13381-8.

7.3.2 Location of thermocouples attached to the Beams

Figure 6 shows the location of the thermocouples to be attached to the beams.

7.3.3 Location of web reference thermocouples

The web reference areas are located on sections 4, 9 and 14 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 6 (key item E).

7.4 Instrumentation for measurement of pressure

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

8 Test procedure

8.1 General

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 8.2 to 8.5.

8.2 Furnace temperature and pressure

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

8.3 Temperature of steelwork

Measure and record the temperature of the sections using the thermocouples attached to the steelwork as specified in Figure 6 at intervals not exceeding 1 min.

8.4 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 EN 1363-1.

8.5 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 and this shall be within 15 % of the required fire resistance period. If the maximum temperature in the scope of the multi-temperature analysis generated from EN 13381-4 or EN 13381-8 is less than 575°C then this shall be used instead of 575°C for termination of the test.

9 Test results

9.1 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 bottom 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.

9.2 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 EN 13381-4 or EN 13381-8.
>
> "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 EN 1363-1, 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 6.4;

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 weighted mean steel temperature of each web post as defined in 10.2 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.

10 Assessment

10.1 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 standard defines test packages to suit the required fire performance period as given in 5.4.4.

10.2 Determination of mean web post and web reference 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

$$\text{Web post temperature} = \frac{(\text{Temp at Position Ax}37.5) + (\text{Temp at Position Cx}37.5) + (\text{Temp at Position Bx}25)}{100}$$

b) for web post width 130 mm

$$\text{Web post temperature} = \frac{(\text{Temp at Position Ax}45) + (\text{Temp at Position Cx}45) + (\text{Temp at Position Bx}40)}{130}$$

c) for web post width 160 mm

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

d) for web post width 225 mm

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

e) for web post width 500 mm

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

Positions are shown in Figure 6

f) the web reference temperature is calculated as the average of the four thermocouples referred to in 7.3.3.

10.3 Determination of web post lines

The web post line 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 8. 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 lowest web post width, unless this point is the narrowest web post in which case you 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 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.

10.4 Additional thermal modification factors

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

For each of these additional temperature measurement positions on the webs, 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 Figure 6.

10.5 Determination of limiting temperature

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. At this point along the beam in fire the limiting temperature will be the lowest that leads to structural failure.

A structural model is developed in accordance with Annex A which shall adopt the principles of EN 1993-1-1 and EN 1993-1-2 and EN 1994-1-1 and EN 1994-1-2.

10.6 Determination of EMTA

The fire protection thickness applied to any cellular beam shall be sufficient to keep the beam below its limiting temperature as determined in 10.3.

The thickness required for each fire resistance period is determined from the EMTA generated by the assessment from EN 13381-4 or EN 13381-8. Examples of the presentation of such tabulated information are given in Tables 4 and 5.

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 shall be obtained by carrying out an assessment to EN 13381-4 or EN 13381-8 for the web or bottom flange temperatures only. The web or bottom flange temperatures are analyzed in the same way that average beam temperatures are analyzed with the exception that the stickability correction factors used are those for already used for the average beam temperature (EN 13381-4:2013 or EN 13381-8:2013, Annex D). 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 7. The fire protection thickness shall be that derived from an assessment in accordance with EN 13381-4 or EN 13381-8.

11 Report of the assessment

The report of the assessment shall include the following:

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

b) the name(s) and address(es) of the sponsor(s). The name of the 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 5.4;

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) the report shall also include a statement regarding the limits of direct application of the assessment procedure.

j) the elemental thermal data generated and reported in EN 13381-4 and EN 13381-8 shall be reassessed and reported against elemental A/V for each fire resistance period in the format illustrated in Tables 4 and 5.

12 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 tested in EN 13381-4 and EN 13381-8.

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 grades of steel to that tested and as given in EN 10025-1 as specified in 5.4.1 and with the limitations given 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. This beam can then be treated as a beam with circular or rectangular openings in the web, see Annex A.

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.

Table 4 — Example of tabulated database on the mean steel temperature 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								
90								
100								
110								
120								
130								
140								
150								
160								
170								
180								
190								
200								
210								
220								
230								
240								
250								
260								
270								
280								
290								
300								

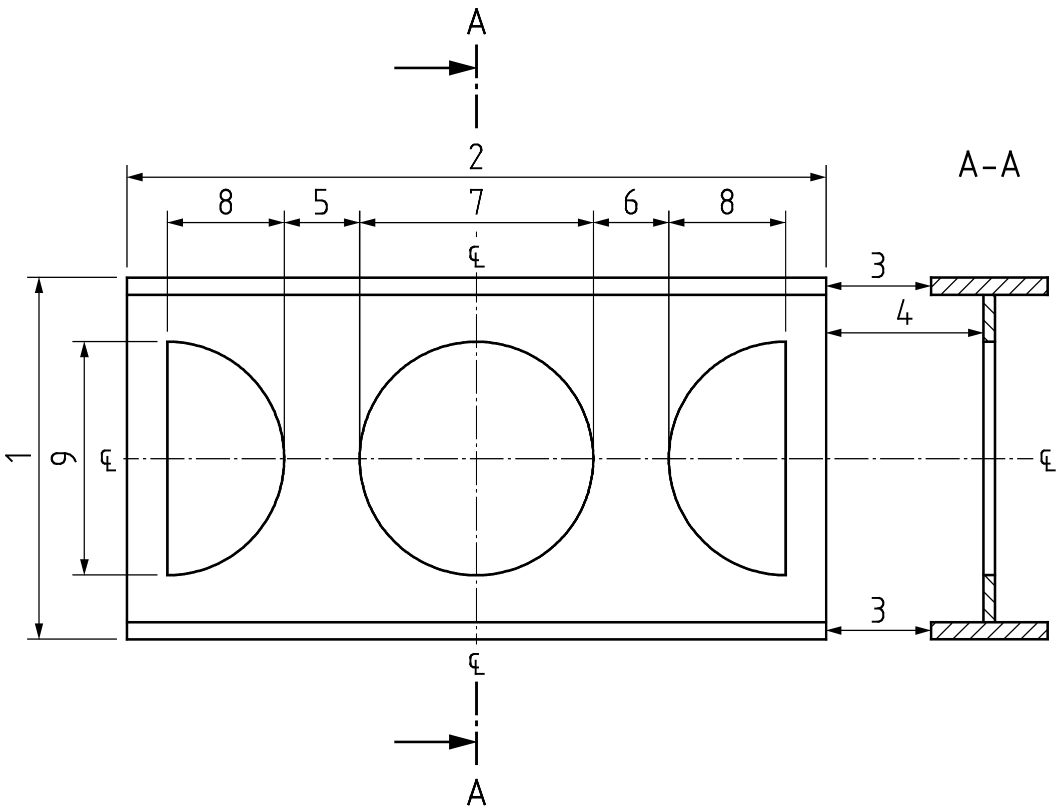
Temperature and section factor ranges for illustration only. Actual range to be determined by the scope of the assessment.

Table 5 — Example of tabulated data based on the mean steel temperature of the bottom flange of I-section beams

Fire Resistance Period – 30 Minutes								
Design Temperature °C	350	400	450	500	550	600	650	700
Section factor m^{-1}	Thickness of Fire Protection Material to Maintain Steel Temperature of Bottom Flange Below Design Temperature							
40								
50								
60								
70								
80								
90								
100								
110								
120								
130								
140								
150								
160								
170								
180								
190								
200								
210								
220								
230								
240								
250								
260								
270								
280								
290								
300								

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

Dimensions in millimetres

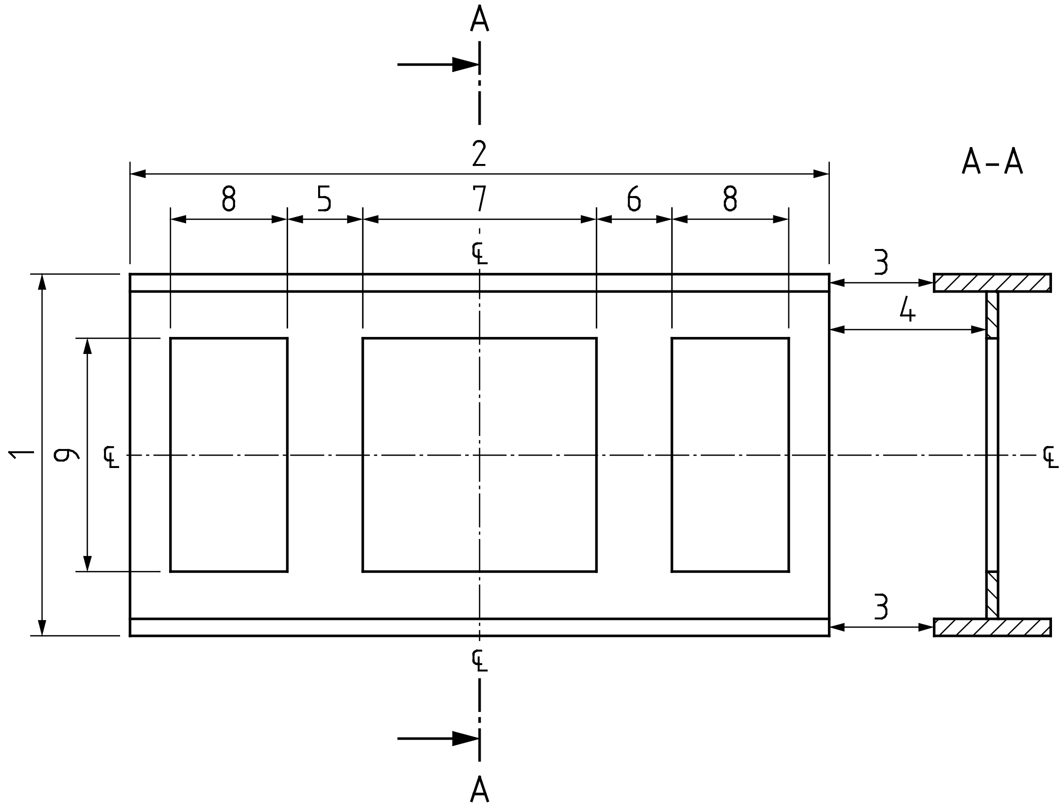


Key

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

Figure 1 — Test Specimens with Circular Holes

Dimensions in millimetres

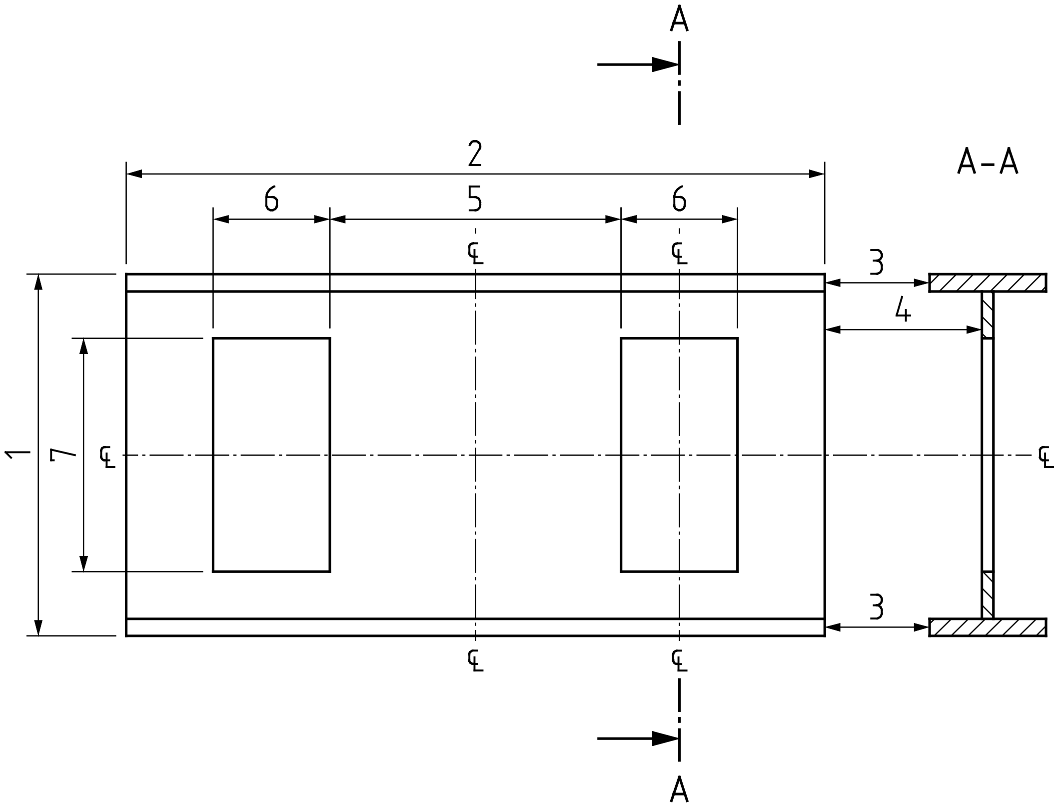


Key

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

Figure 2 — Test Specimens with Rectangular Holes

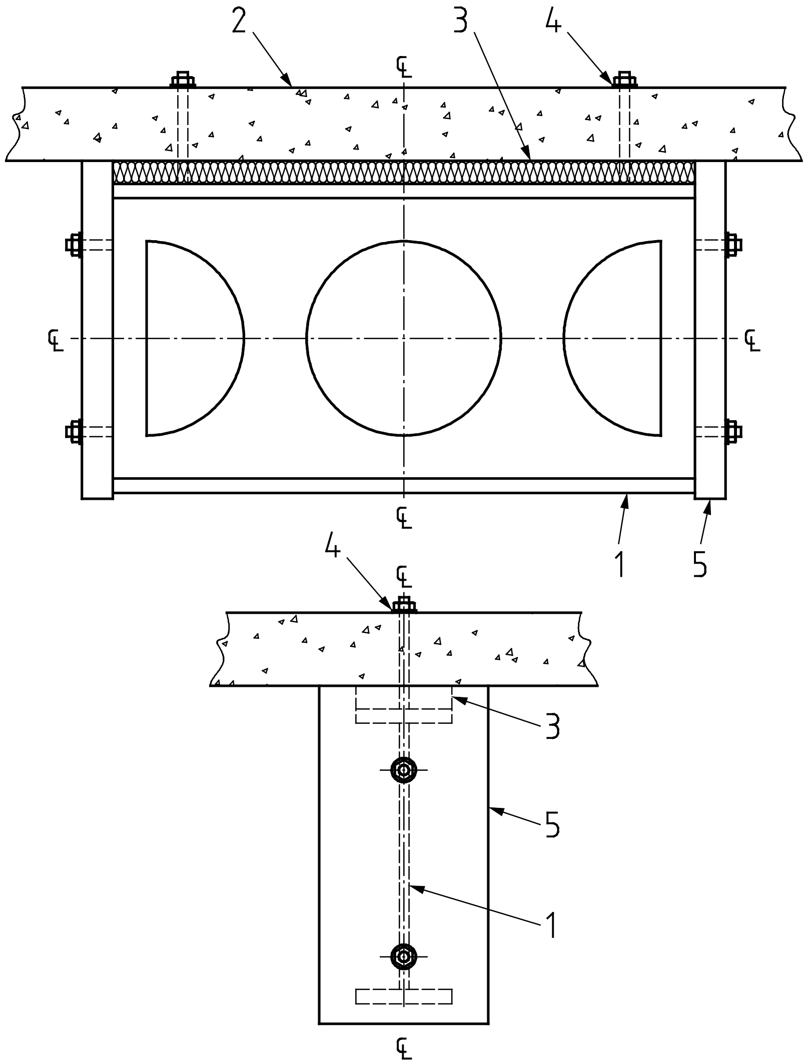
Dimensions in millimetres



Key

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

Figure 3 — Test Specimens with Rectangular Holes



Key

1 steel section

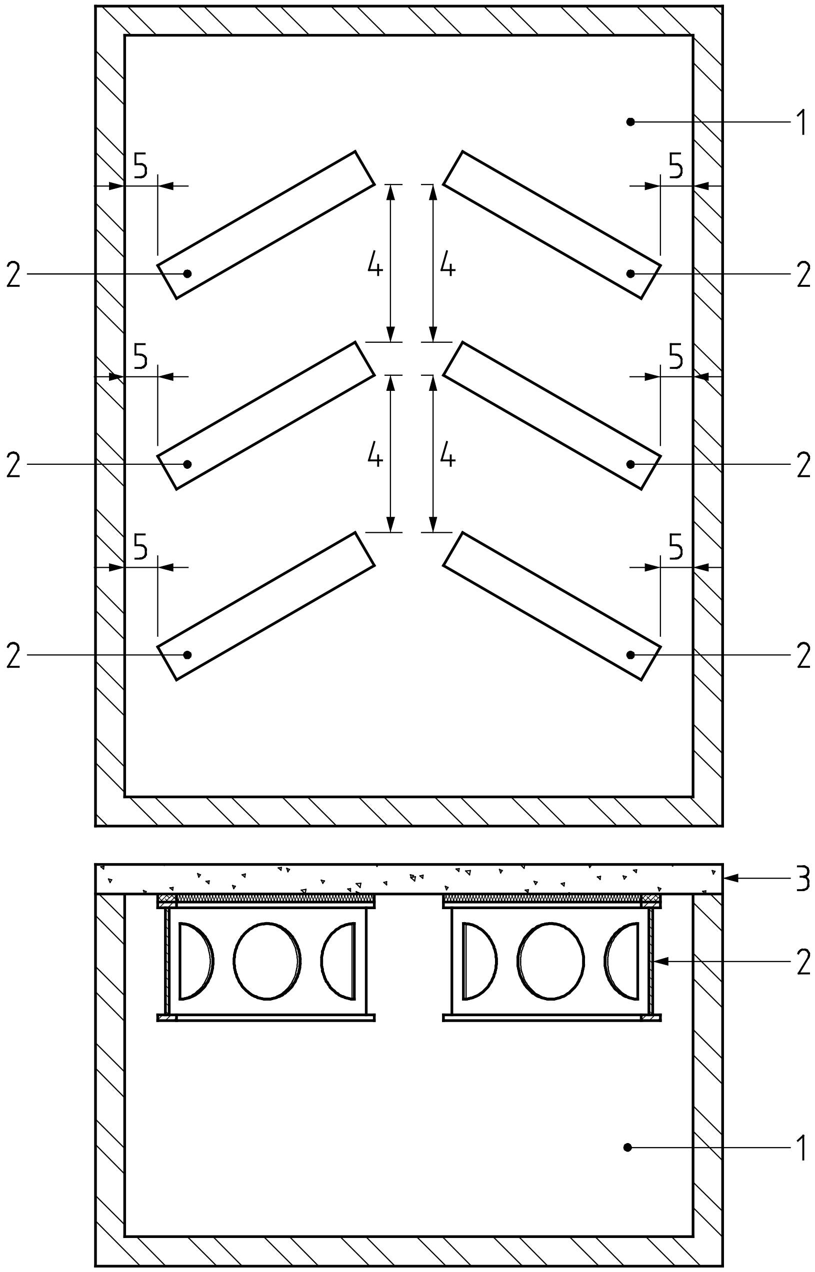
2 furnace cover

3 insulation board

4 stud/plate/locking nut

5 insulation board end cap

Figure 4 — Unloaded Beam - Typical Construction - Circular Holes (Rectangular holes similar)



Key

1 furnace area

2 unloaded cellular beam specimen fixed to 3 as Figure 4

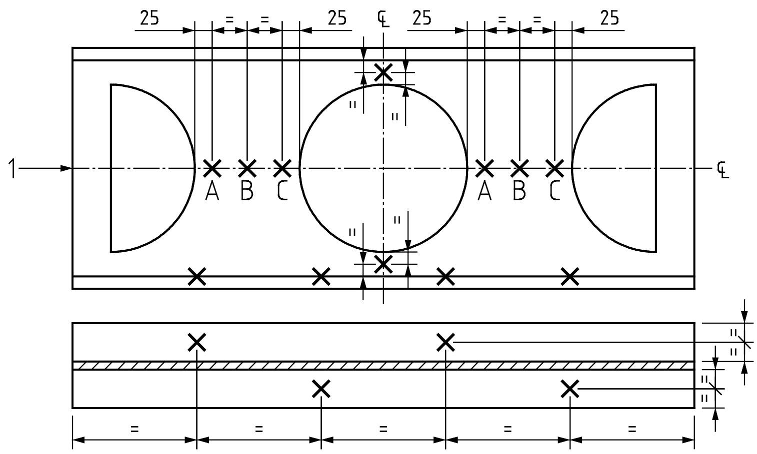
3 furnace slab cover

4 minimum distance of separation 450 mm

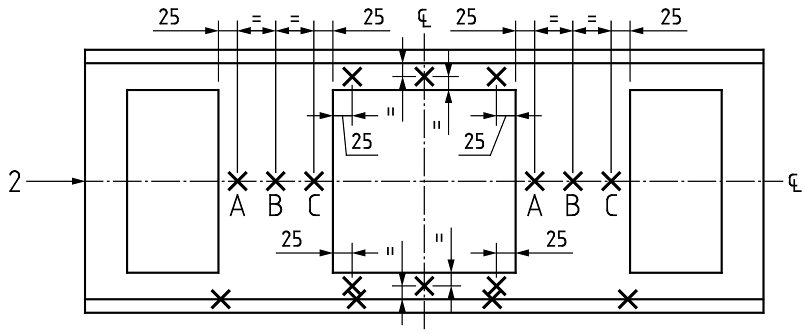
5 minimum distance of 300 mm

Figure 5 — Typical Test Specimen Installation Pattern

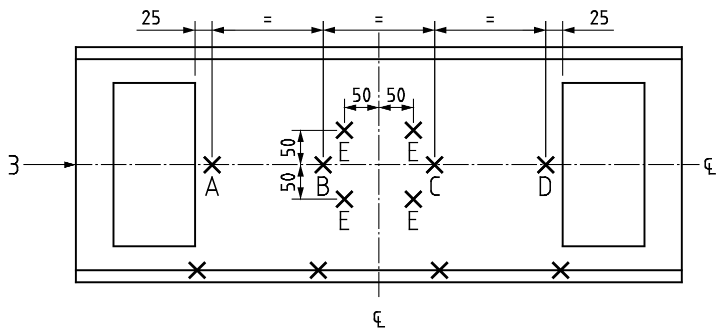
Dimensions in millimetres



a) Plan of all sections



b)



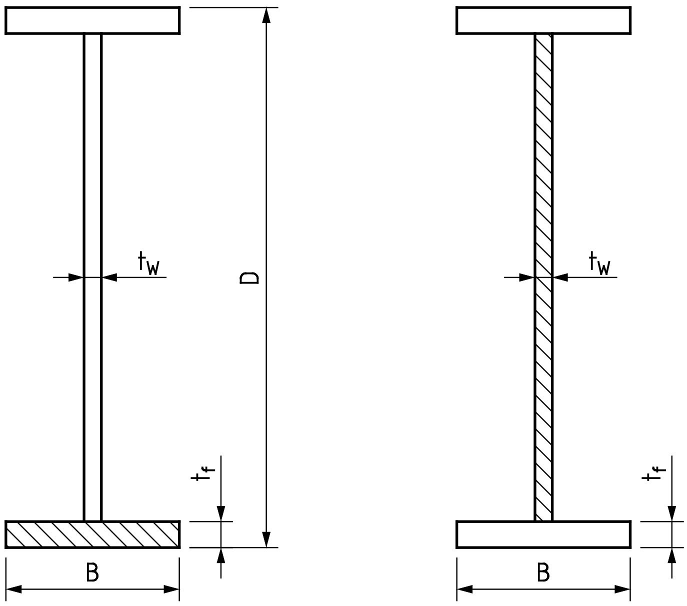
c)

Key

1	beam with circular openings
2	beam with rectangular openings – web posts equal to or less than 225
3	beam with rectangular openings – web posts greater than 225
A, B, C, D	web post thermocouples for web post average temperature
E	web post thermocouples for web reference temperature

Figure 6 — Thermocouple Positions

Dimensions in metres



	Lower Flange	Web
Heated perimeter (A) m	$(2B + 2t_f) - t_w$	$2D – 4t_f$
Area (V) m^2	$B \times t_f$	$(D – 2t_f) \times t_w$
Section factor = A/V(m^{-1})		

Key

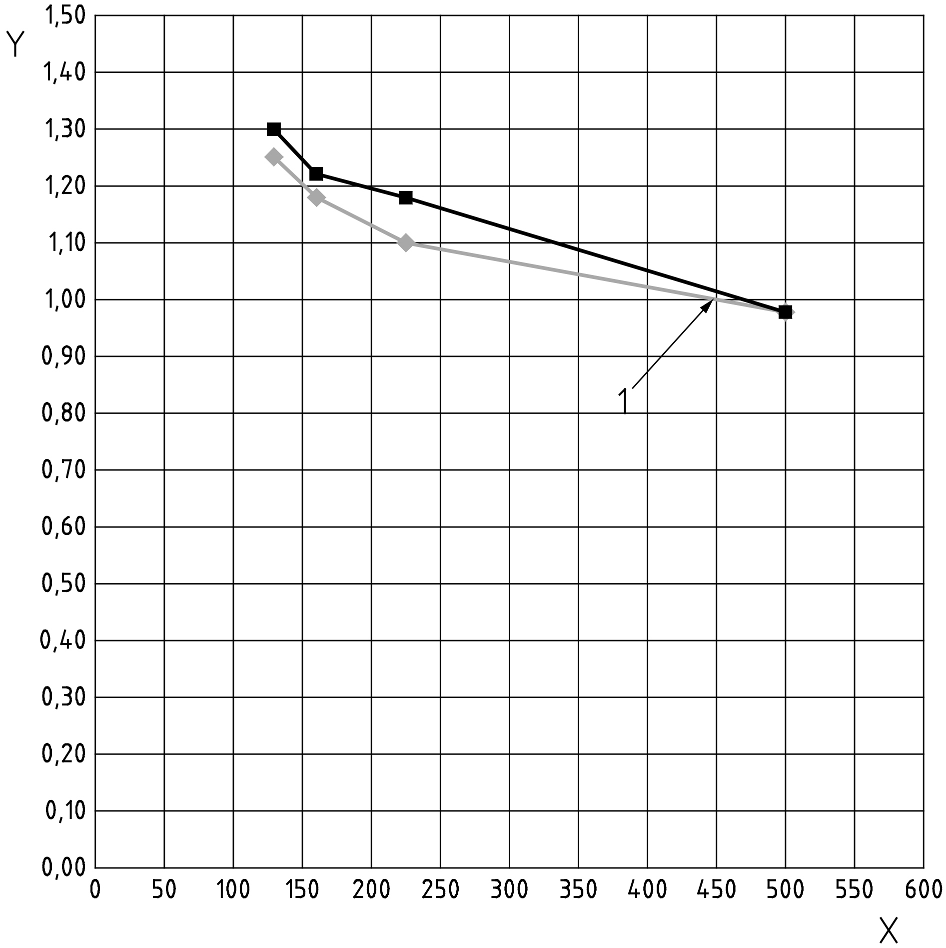
B width of beam flanges

D depth of beam

t_w thickness of web

t_f thickness of flanges

Figure 7 — Elemental Section Factor



Key

X web post width mm

Y ratio of Web Post Temperature to Web Reference Temperature

1 At the point where the line intersects with a ratio of 1,0 all greater web post widths have a ratio of 1,0.

circular holes

rectangular holes

Figure 8 — Example Plot of Web Post Lines

Annex A
(informative)

Determination of Product Thickness on Beams with Web Openings

A.1 Purpose

This informative Annex outlines possible approaches to determining the necessary thickness of a given fire protection product that would be required to provide a specific design of beam, incorporating web openings, with a given fire resistance performance. They all require the adoption of a structural model to determine the value and location of the limiting temperature at structural failure (i.e. the fire limit state) which can then be utilized together with the product characterization data given by this standard.

A.2 Background

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

These beams can be fabricated from either hot rolled sections or welded steel plate. They may even be produced from two different size beams using a cutting technique along the centre of the web along the beam's length. Then two halves of different size beams are welded along the centre of the web over the entire length of the beam. This then creates an asymmetrical section. In the case of plate girders asymmetry can be achieved by using different plate thicknesses for the top and bottom flanges.

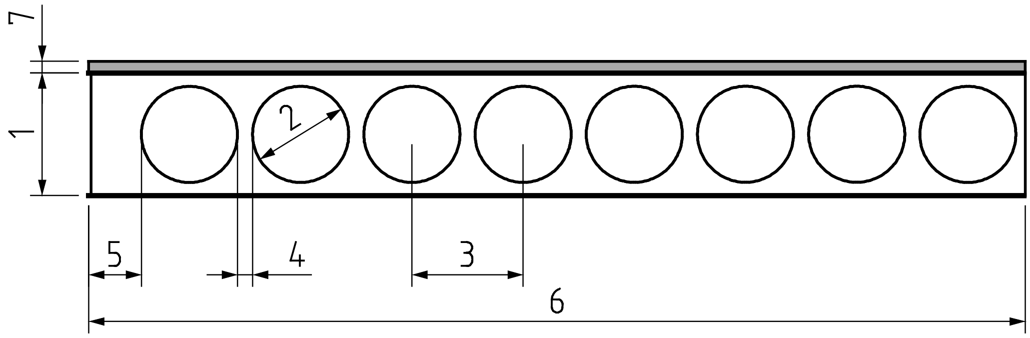
Beams with web openings behave differently to solid beams in that additional failure modes at the fire limit state (FLS) are possible as a result of the proximity of openings and web slenderness. Solid beams generally fail in bending but a beam with web openings can fail in many ways including buckling of the web-post, shear at an opening and Vierendeel bending around the opening. These failure modes generally occur at lower temperatures than for a solid beam at similar utilization. The lower failure temperatures lead to higher thicknesses of fire protection.

The purpose of this standard is to provide product specific thermal data to be used in conjunction with a structural model (which is used to determine limiting steel temperatures) of beams with web openings.

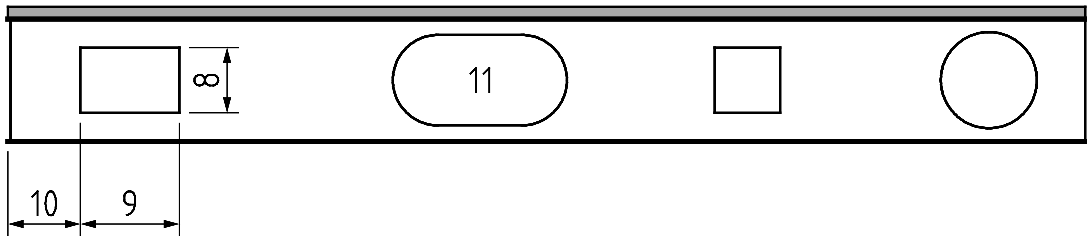
A.3 Overview of structural geometry

Typical beams with web openings are shown in Figure A.1. Figure A.1 also shows some of the important beam dimensions which will affect the performance in fire.

Data generated from the tests in this standard can be used for beams with circular openings, rectangular openings and elongated openings formed by joining 2 circular openings. It 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 A.2.



a) Beam with regular circular openings

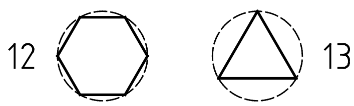


b) Beam with mixed openings

Key

1	Steel beam
2	Circular opening
3	Spacing of openings
4	Web post
5	End post
6	Span
7	Composite floor slab
8	Height of rectangular opening
9	Width of rectangular opening
10	Position of opening
11	Elongated opening with circular ends

Figure A.1



Key

12	Hexagonal opening inside an elongated opening
13	Triangular opening inside a circle

Figure A.2 — Other shapes

A.4 Interaction with EN 13381-4 and EN 13381-8

In most cases, failure of the web will be limiting but failure of the bottom flange may also occur.

Where the web is limiting, 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 EN 13381-4 or EN 13381-8 test data can be used to determine a product thickness to achieve the required fire resistance rating.

Where the bottom flange is limiting, 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 EN 13381-4 or EN 13381-8 test data to determine a product thickness to achieve the required fire resistance rating.

A.5 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.

In this standard, 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.

A.6 Structural analysis of the beam design

In specifying correctly and adequately a level of fire resistance performance for any steel structural member, a structural engineer should specify not only the fire resistance performance level required but the value and location of the associated limiting temperature at the fire limit state. However, this is infrequently the case, even for beams without any openings within the web, and for a beam containing web openings the specification will not usually take into account any effects of product specific temperature variations over the web of the beam.

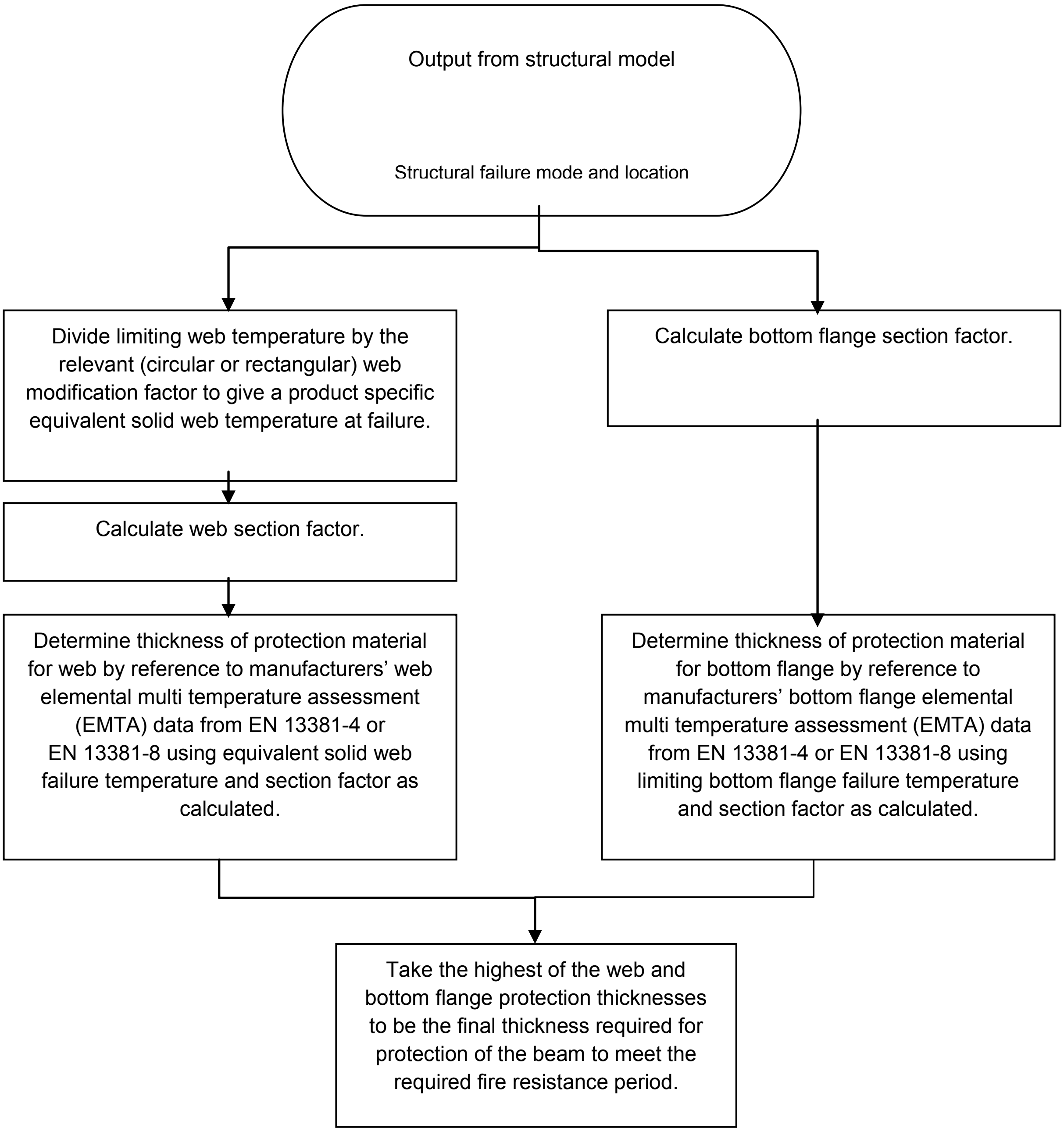
In order to determine an appropriate thickness of fire protection for a given beam design to achieve a prescribed fire resistance performance it is essential to understand:

- the structural failure mode of the beam at the fire limit state,
- the location and temperature at the point of failure (e.g. the web post),
- the width of the web (if this is the point of failure),
- the temperature of the bottom flange at failure.

This information shall be determined from an appropriate structural analysis conducted by a professional structural engineer following the guidance in EN 1994-1-2 for 'Advanced calculation models'. However, as a minimum, the following modes of failure 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.



If the output of the structural model does not differentiate between web and bottom flange limiting steel temperatures then any temperature output shall be assumed to be the limiting web temperature.

In the absence of further information on the failure modes along the beam, the smallest web-post width shall be assumed to get the web modification ratio to determine the product specific equivalent solid web temperature at failure.

Figure A.3 — Flow chart to determine a product thickness of fire protection for a beam with web openings when outputs are provided to a manufacturer by a structural engineer

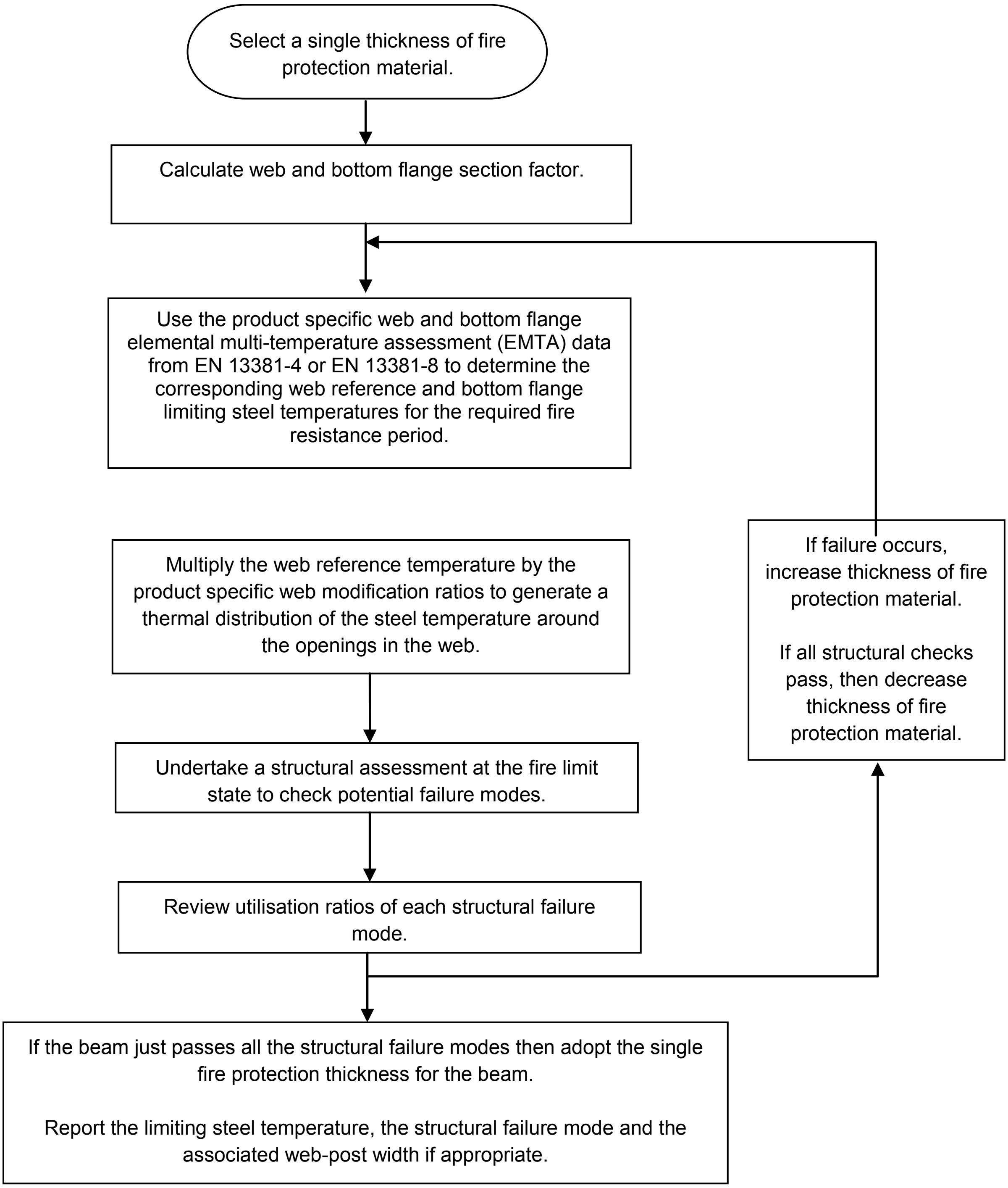


Figure A.4 — Flow chart to determine a product thickness of fire protection for a beam with web openings using an iterative thickness analysis

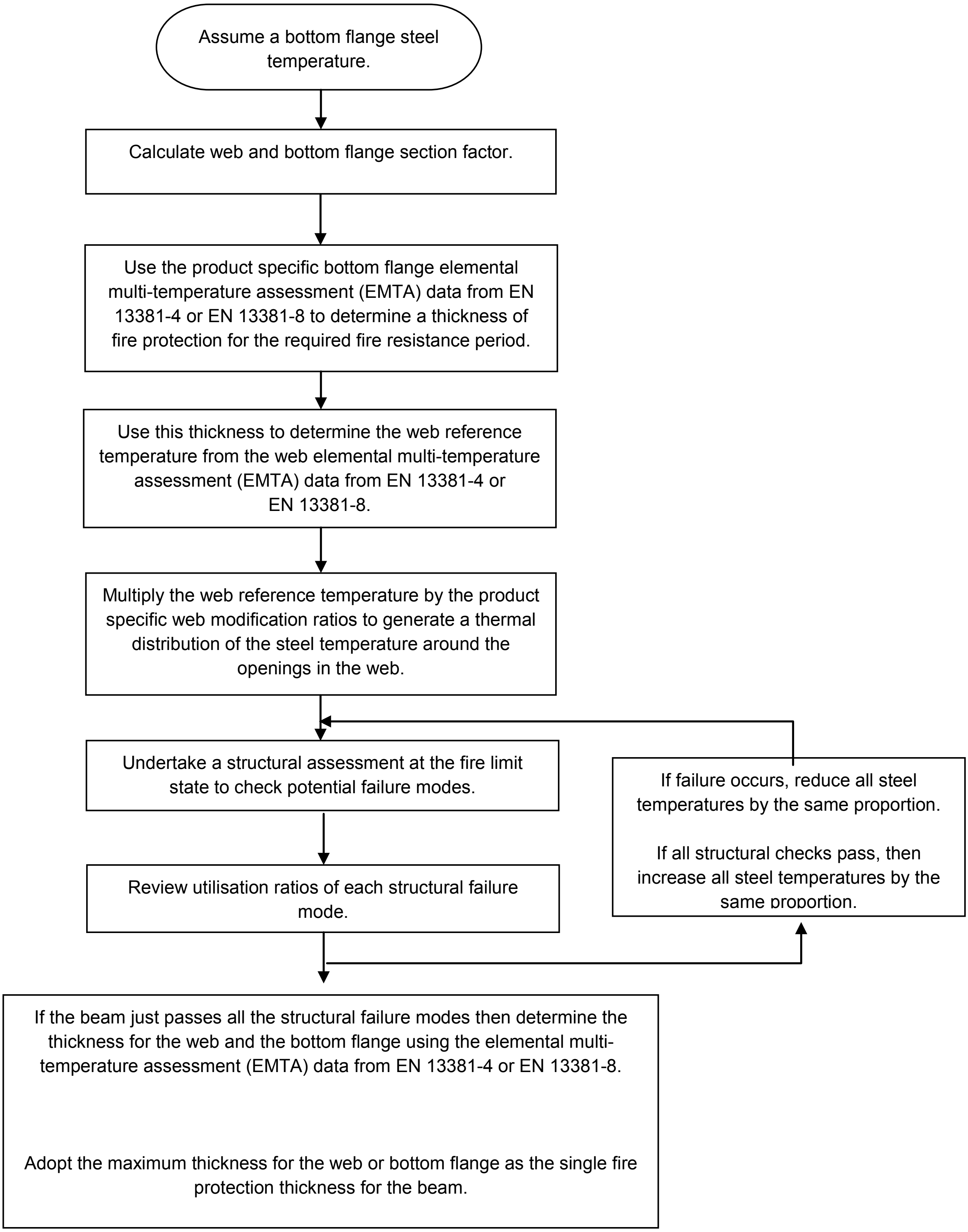


Figure A.5 — Flow chart to determine a product thickness of fire protection for a beam with web openings using an iterative steel temperature analysis

A.7 Determination of fire protection thickness

A.7.1 Product specific analysis on the basis of a specified critical temperature

When limiting temperatures are supplied by a structural engineer to a fire protection product manufacturer for a beam containing web openings, they will not usually take into account any effect of temperature variations over the web of the beam caused by the product specific performance during fire exposure.

For this situation, the approach illustrated in Figure A.3 may be used.

If the specification from the structural engineer (the output from the structural analysis) does not specify and differentiate between the web and bottom flange critical steel temperatures at the fire limit state, then any specified temperature shall be assumed to be the critical web temperature. And in the absence of further information on the failure modes along the beam, the smallest web post width shall be assumed to derive the web post modification ratio to determine the product specific equivalent solid web temperature at failure.

A.7.2 Iterative protection thickness analysis

An alternative and more sophisticated approach may be adopted whereby product specific modification ratios are used to define the thermal variation of temperature over the web of the beam for a specific thickness of fire protection material.

A structural check at the fire limit state is then undertaken and the product thickness adjusted until a minimum thickness is found that just results in a predicted structural failure.

This approach is illustrated in the flow chart in Figure A.4.

A.7.3 Iterative steel temperature analysis

A similar approach to that in A.7.2 is to assume a specific temperature of the bottom flange and then to use the product specific modification ratios to find the thermal variation of temperature over the web of the beam.

A structural check at the fire limit state is then undertaken and the bottom flange temperature adjusted until an associated minimum thickness of fire protection is found that just results in a predicted structural failure.

This approach is illustrated in the flow chart in Figure A.5.

A.8 Structural models

As emphasized above, a structural analysis of a beam containing web openings needs to be conducted by a professional structural engineer to provide limiting temperatures related to the fire limit state and having regard to the potential different failure modes.

At present, no specific standardized guidance is available within published European structural design codes. However, CEN/TC 250 currently has an activity targeted at the design and analysis of beams containing web openings which should eventually provide appropriate guidance that is anticipated to be compatible and consistent with the approach given in this standard.

Currently, there is only one known published engineering design guide addressing beams with web openings which is available from the Steel Construction Institute in the UK as report RT1356 " Fire design of composite beams with rectangular and circular web openings" [4]. This also contains a procedure for determining the thickness of a specific fire protection product utilizing an iterative steel temperature analysis as explained in A.7.3 above.

Annex B
(informative)

The logic for determining the web post average temperature

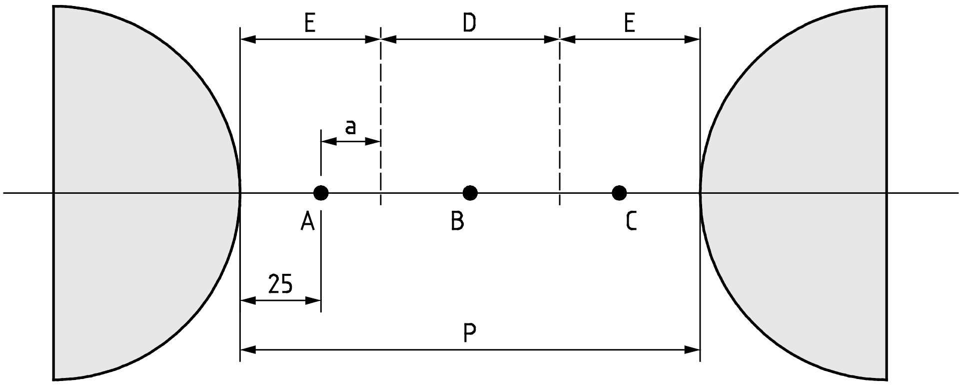


Figure B.1 — Determination of average web post temperature

The post is divided into 3 zones: 2 edge zones of width E and a central zone of width D. The web post average is always given by:

[(temp at A) x E + (temp at C) x E + (temp at B) x D] / post width, P

For different web post widths, the dimension ‘a’ shall be determined.

The influence of the higher edge temperatures is not considered to be at more than twice the thermocouple position from the edge of the opening. Therefore ‘a’ is limited to 25 mm. This limit applies for post widths greater or equal to 150 mm (at 150mm, ‘a’ equals 25 mm).

Posts ≥ 150 mm

Thus for a post width greater or equal to 150 mm the web post average temperature is given by:

[(temp at A) × 50 + (temp at C) × 50 + (temp at B) x (P – 100)] / post width, P

Posts < 150 mm

For post widths less than 150 mm dimension E is given by:

$E = 25 + a$

And D is given by:

$D = 2 \times a$

Thus

$P = 2 (25 + a) + 2a$

Giving,

$a = (P - 50)/4$

This gives the result that for a post of 50 mm, ‘a’ is zero and this method of averaging therefore cannot be used for narrower posts.

The general formula for the average web post temperature for posts between 150 mm and 50 mm is given by:

[(temp at A) x (25 + a) + (temp at C) x (25 + a) + (temp at B) × 2a] / P

For a 100 mm web post this formula is more conservative;

(temp at A) × 37.5 + (temp at C) × 37.5) + (temp at B) × 25] / P

Bibliography

[1] EN 1365-3, *Fire resistance tests for loadbearing elements - Part 3: Beams*

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

[3] EN 60584-1, *Thermocouples — Part 1: EMF specifications and tolerances (IEC 60584-1)*

[4] Report RT1356 “Fire design of composite beams with rectangular and circular web openings”, Steel Construction Institute

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