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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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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

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Contents

Page

Foreword

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

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

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,

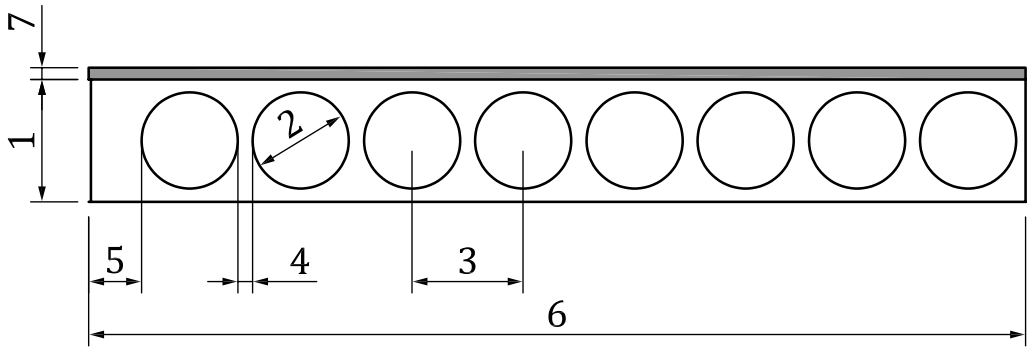
— shear at an opening,

— 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.

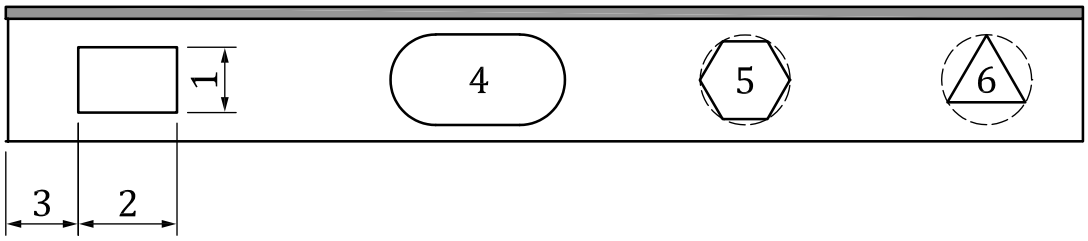


Key

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