

# Eurocode 4 — Design of composite steel and concrete structures —

## Part 1-2: General rules — Structural fire design

ICS 13.220.50; 91.010.30; 91.080.10; 91.080.40

# National foreword

This British Standard is the UK implementation of EN 1994-1-2:2005+A1:2014, incorporating corrigendum July 2008. It supersedes BS EN 1994-1-2:2005, which is withdrawn.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by CEN corrigendum July 2008 is indicated in the text by **AC1** **AC1**.

The structural Eurocodes are divided into packages by grouping Eurocodes for each of the main materials, concrete, steel, composite concrete and steel, timber, masonry and aluminium; this is to enable a common date of withdrawal (DOW) for all the relevant parts that are needed for a particular design. The conflicting national standards will be withdrawn at the end of the coexistence period, after all the EN Eurocodes of a package are available.

Following publication of the EN, there is a period of two years allowed for the national calibration period during which the national annex is issued, followed by a three year coexistence period. During the coexistence period Member States will be encouraged to adapt their national provisions to withdraw conflicting national rules before the end of the coexistence period. The Commission in consultation with Member States is expected to agree the end of the coexistence period for each package of Eurocodes.

At the end of this coexistence period, the national standard(s) will be withdrawn.

In the case of BS EN 1994-1-2:2005, there are no corresponding national standards.

The UK participation in its preparation was entrusted by Technical Committee B/525, Building and civil engineering structures, to Subcommittee B/525/4, Composite structures.

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

Where a normative part of this EN allows for a choice to be made at the national level, the range and possible choice will be given in the normative text, and a note will qualify it as a Nationally Determined Parameter (NDP). NDPs can be a specific value for a factor, a specific level or class, a particular method or a particular application rule if several are proposed in the EN.

## Amendments/corrigenda issued since publication

| Date             | Comments                                                       |
|------------------|----------------------------------------------------------------|
| 28 February 2014 | Implementation of CEN corrigendum July 2008                    |
| 30 April 2014    | Implementation of CEN amendment A1:2014: Clause H.5 amended    |
| 31 August 2014   | Correction to Amendments/corrigenda table in national foreword |
|                  |                                                                |

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To enable EN 1994-1-2 to be used in the UK, the NDPs will be published in a national annex, which will be made available by BSI in due course, after public consultation has taken place.

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

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



English Version

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

Eurocode 4 - Calcul des structures mixtes acier-béton -  
Partie 1-2: Règles générales - Calcul du comportement au  
feu

Eurocode 4 - Bemessung und Konstruktion von  
Verbundtragwerken aus Stahl und Beton - Teil 1-2:  
Allgemeine Regeln Tragwerksbemessung im Brandfall

This European Standard was approved by CEN on 4 November 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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## **Foreword**

This European Standard EN 1994-1-2: 2005, Eurocode 4: Design of composite steel and concrete structures: Part 1-2 : General rules – Structural fire design, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI.

CEN/TC250 is responsible for all Structural Eurocodes.

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 February 2006, and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1994-1-2: 1994.

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

## **Foreword to amendment A1**

This document (EN 1994-1-2:2005/A1:2014) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI.

This Amendment to the European Standard EN 1994-1-2:2005 shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2015, and conflicting national standards shall be withdrawn at the latest by February 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.

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

## **Background of the Eurocode programme**

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980's.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement<sup>1</sup> between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links *de facto* the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products – CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

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<sup>1</sup> Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN1990, Eurocode : Basis of structural design

EN1991, Eurocode 1: Actions on structures

EN1992, Eurocode 2: Design of concrete structures

EN1993, Eurocode 3: Design of steel structures

EN1994, Eurocode 4: Design of composite steel and concrete structures

EN1995, Eurocode 5: Design of timber structures

EN1996, Eurocode 6: Design of masonry structures

EN1997, Eurocode 7: Geotechnical design

EN1998, Eurocode 8: Design of structures for earthquake resistance

EN1999, Eurocode 9: Design of aluminium structures

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

### **Status and field of application of Eurocodes**

The Member States of the EU and EFTA recognise that EUROCODES serve as reference documents for the following purposes :

- as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 – Mechanical resistance and stability – and Essential Requirement N°2 – Safety in case of fire;
- as a basis for specifying contracts for construction works and related engineering services ;
- as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs).

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents<sup>2</sup> referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards<sup>3</sup>. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving full compatibility of these technical specifications with the Eurocodes.

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<sup>2</sup> According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for hENs and ETAGs/ETAs.

<sup>3</sup> According to Art. 12 of the CPD the interpretative documents shall :

- a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary ;
- b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc. ;
- c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.

The Eurocodes, *de facto*, play a similar role in the field of the ER 1 and a part of ER 2.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

### **National Standards implementing Eurocodes**

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National annex.

The National Annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, *i.e.* :

- values and/or classes where alternatives are given in the Eurocode;
- values to be used where a symbol only is given in the Eurocode;
- country specific data (geographical, climatic, etc), e.g. snow map;
- the procedure to be used where alternative procedures are given in the Eurocode;

it may also contain:

- decisions on the application of informative annexes, and
- references to non-contradictory complementary information to assist the user to apply the Eurocode.

### **Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products.**

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works<sup>4</sup>. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes shall clearly mention which Nationally Determined Parameters have been taken into account.

### **Additional information specific for EN 1994-1-2**

EN 1994-1-2 describes the Principles, requirements and rules for the structural design of buildings exposed to fire, including the following aspects:

#### *Safety requirements*

EN 1994-1-2 is intended for clients (e.g. for the formulation of their specific requirements), designers, contractors and public authorities.

---

<sup>4</sup> see Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID N°1.

The general objectives of fire protection are to limit risks with respect to the individual and society, neighbouring property, and where required, environment or directly exposed property, in the case of fire.

Construction Products Directive 89/106/EEC gives the following essential requirement for the limitation of fire risks:

"The construction works must be designed and built in such a way, that in the event of an outbreak of fire

- the load bearing resistance of the construction can be assumed for a specified period of time;
- the generation and spread of fire and smoke within the works are limited;
- the spread of fire to neighbouring construction works is limited;
- the occupants can leave the works or can be rescued by other means;
- the safety of rescue teams is taken into consideration".

According to the Interpretative Document N°2 "Safety in Case of Fire"<sup>5</sup> the essential requirement may be observed by following various possibilities for fire safety strategies prevailing in the Member States like conventional fire scenarios (nominal fires) or "natural" (parametric) fire scenarios, including passive and/or active fire protection measures.

The fire parts of Structural Eurocodes deal with specific aspects of passive fire protection in terms of designing structures and parts thereof for adequate load bearing resistance and for limiting fire spread as relevant.

Required functions and levels of performance can be specified either in terms of nominal (standard) fire resistance rating, generally given in national regulations or, where allowed by national fire regulations, by referring to fire safety engineering for assessing passive and active measures.

Supplementary requirements concerning, for example

- the possible installation and maintenance of sprinkler systems;
- conditions on occupancy of building or fire compartment;
- the use of approved insulation and coating materials, including their maintenance.

are not given in this document, because they are subject to specification by the competent authority.

Numerical values for partial factors and other reliability elements are given as recommended values that provide an acceptable level of reliability. They have been selected assuming that an appropriate level of workmanship and of quality management applies.

### *Design procedures*

A full analytical procedure for structural fire design would take into account the behaviour of the structural system at elevated temperatures, the potential heat exposure and the beneficial effects of active fire protection systems, together with the uncertainties associated with these three features and the importance of the structure (consequences of failure).

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<sup>5</sup> see clauses 2.2, 3.2(4) and 4.2.3.3 of ID N°2

At the present time it is possible to undertake a procedure for determining adequate performance which incorporates some, if not all, of these parameters and to demonstrate that the structure, or its components, will give adequate performance in a real building fire. However where the procedure is based on a nominal (standard) fire, the classification system, which calls for specific periods of fire resistance, takes into account (though not explicitly), the features and uncertainties described above.

Application of this Part 1-2 is illustrated below. The prescriptive approach and the performance-based approach are identified. The prescriptive approach uses nominal fires to generate thermal actions. The performance-based approach, using fire safety engineering, refers to thermal actions based on physical and chemical parameters.

For design according to this part, EN 1991-1-2 is required for the determination of thermal and mechanical actions to the structure.

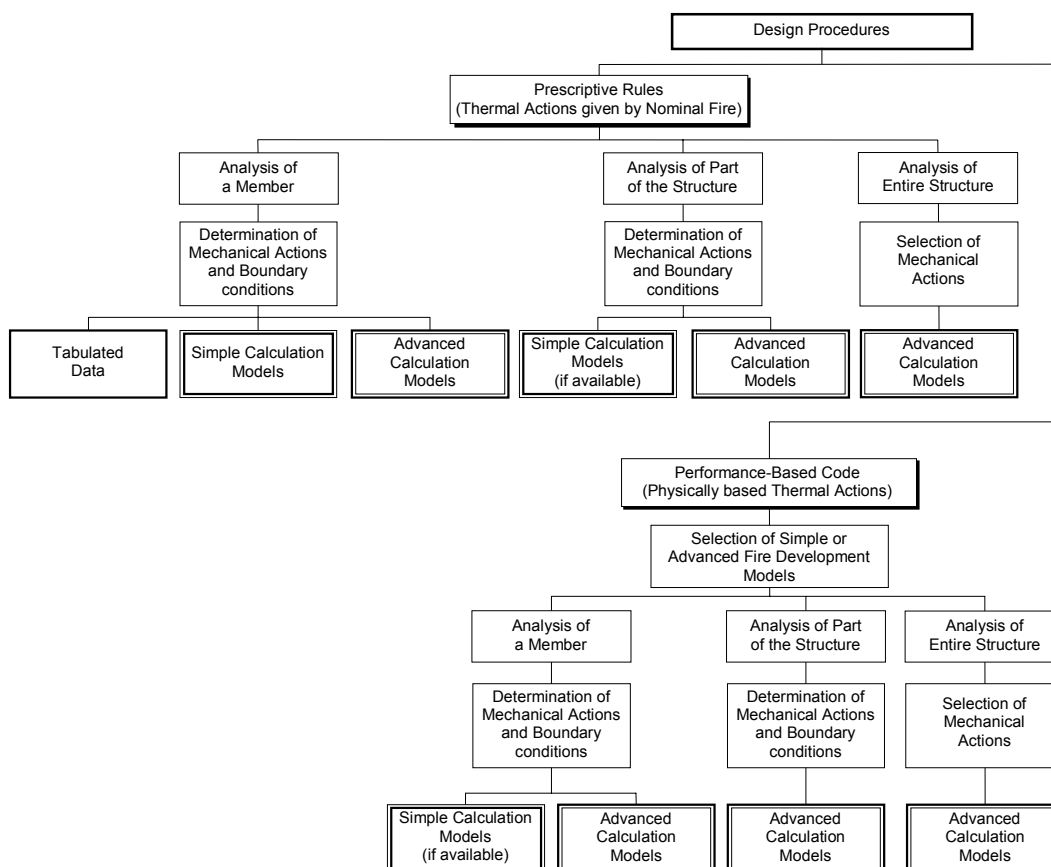


**Figure 0.1: Alternative design procedures**

### Design aids

Apart from simple calculation models, EN 1994-1-2 gives design solutions in terms of tabulated data (based on tests or advanced calculation models) which may be used within the specified limits of validity.

It is expected, that design aids based on the calculation models given in EN 1994-1-2, will be prepared by interested external organizations.

The main text of EN 1994-1-2 together with informative Annexes A to I includes most of the principal concepts and rules necessary for structural fire design of composite steel and concrete structures.

## **National annex for EN 1994-1-2**

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1994-1-2 should have a National annex containing all Nationally Determined Parameters to be used for the design of buildings to be constructed in the relevant country.

National choice is allowed in EN 1994-1-2 through clauses:

- 1.1(16)
- 2.1.3(2)
- AC1 – 2.3 (1)P NOTE 1
  - 2.3 (2)P NOTE 1
  - 2.4.2 (3) NOTE 1
  - 3.3.2 (9) NOTE 1
- 4.1(1)P
  - 4.3.5.1 (10) NOTE 1 AC1

## Section 1 General

### 1.1 Scope

(1) This Part 1-2 of EN 1994 deals with the design of composite steel and concrete structures for the accidental situation of fire exposure and is intended to be used in conjunction with EN 1994-1-1 and EN 1991-1-2. This Part 1-2 only identifies differences from, or supplements to, normal temperature design.

(2) This Part 1-2 of EN 1994 deals only with passive methods of fire protection. Active methods are not covered.

(3) This Part 1-2 of EN 1994 applies to composite steel and concrete structures that are required to fulfil certain functions when exposed to fire, in terms of:

- avoiding premature collapse of the structure (load bearing function);
- limiting fire spread (flame, hot gases, excessive heat) beyond designated areas (separating function).

(4) This Part 1-2 of EN 1994 gives principles and application rules (see EN 1991-1-2) for designing structures for specified requirements in respect of the aforementioned functions and the levels of performance.

(5) This Part 1-2 of EN 1994 applies to structures, or parts of structures, that are within the scope of EN 1994-1-1 and are designed accordingly. However, no rules are given for composite elements which include prestressed concrete parts.

(6) For all composite cross-sections longitudinal shear connection between steel and concrete should be in accordance with EN 1994-1-1 or be verified by tests (see also 4.3.4.1.5 and Annex I).

(7) Typical examples of concrete slabs with profiled steel sheets with or without reinforcing bars are given in Figure 1.1.

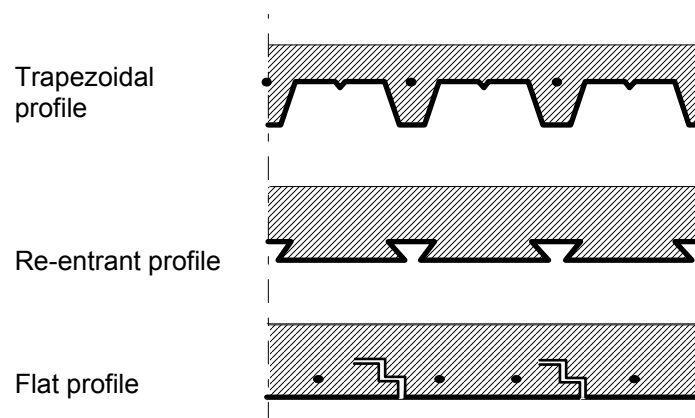
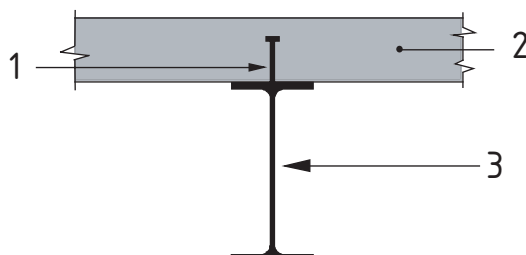


**Figure 1.1 Typical examples of concrete slabs with profiled steel sheets with or without reinforcing bars**

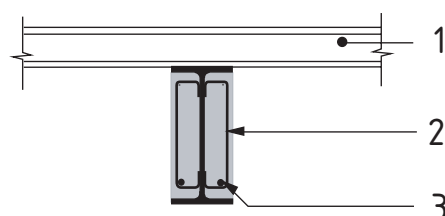
(8) Typical examples of composite beams are given in Figures 1.2 to 1.5. The corresponding constructional detailing is covered in section 5.



**Key**

- 1 – Shear connectors
- 2 – Flat concrete slab or composite slab with profiled steel sheeting
- 3 – Profiles with or without protection

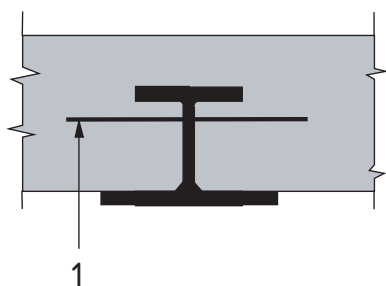
**Figure 1.2: Composite beam comprising steel beam with no concrete encasement**



**Key**

- 1 – Optional
- 2 – Stirrups welded to web of profile
- 3 – Reinforcing bar

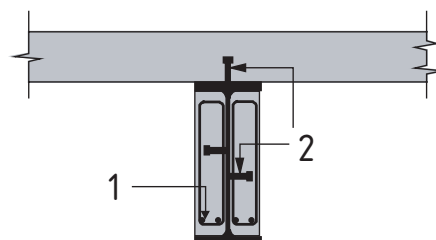
**Figure 1.3: Steel beam with partial concrete encasement**



**Key**

- 1 – Reinforcing bar

**Figure 1.4: Steel beam partially encased in slab**



**Key**

- 1 – Reinforcing bar
- 2 – Shear connectors

**Figure 1.5: Composite beam comprising steel beam with partial concrete encasement**

(9) Typical examples of composite columns are given in Figures 1.6 to 1.8. The corresponding constructional detailing is covered in section 5.

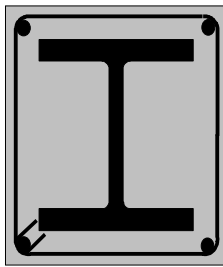
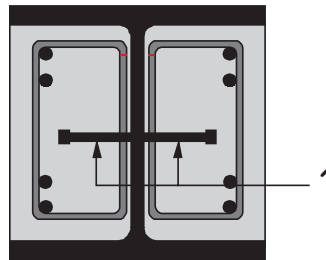


**Figure 1.6:**  
**Concrete encased profiles**



**Key**  
1 – Shear connectors welded to web of profile

**Figure 1.7:**  
**Partially encased profiles**

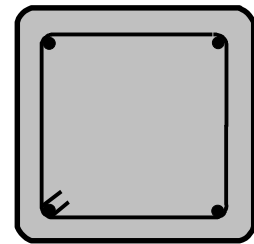


**Figure 1.8:**  
**Concrete filled profiles**

(10) Different shapes, like circular or octagonal cross-sections may also be used for columns. Where appropriate, reinforcing bars may be replaced by steel sections.

(11) The fire resistance of these types of constructions may be increased by applying fire protection materials.

**NOTE:** The design principles and rules given in 4.2, 4.3 and 5 refer to steel surfaces directly exposed to the fire, which are free of any fire protection material, unless explicitly specified otherwise.

(12)P The methods given in this Part 1-2 of EN 1994 are applicable to structural steel grades S235, S275, S355, S420 and S460 of EN 10025, EN 10210-1 and EN 10219-1.

(13) For profiled steel sheeting, reference is made to section 3.5 of EN 1994-1-1.

(14) Reinforcing bars should be in accordance with EN 10080.

(15) Normal weight concrete, as defined in EN 1994-1-1, is applicable to the fire design of composite structures. The use of lightweight concrete is permitted for composite slabs.

(16) This part of EN 1994 does not cover the design of composite structures with concrete strength classes lower than C20/25 and LC20/22 and higher than C50/60 and LC50/55.

**NOTE :** Information on Concrete Strength Classes higher than C50/60 is given in section 6 of EN 1992-1-2. The use of these concrete strength classes may be specified in the National Annex.

(17) For materials not included herein, reference should be made to relevant CEN product standards or European Technical Approval (ETA).

## 1.2 Normative references

(1)P This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

|            |                                                                           |
|------------|---------------------------------------------------------------------------|
| EN 1365 -1 | Fire resistance tests for loadbearing elements – Part 1: Walls            |
| EN 1365 -2 | Fire resistance tests for loadbearing elements – Part 2: Floors and roofs |
| EN 1365 -3 | Fire resistance tests for loadbearing elements – Part 3: Beams            |

|                        |                                                                                                                                                                                    |
|------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| EN 1365 -4             | Fire resistance tests for loadbearing elements – Part 4: Columns                                                                                                                   |
| EN 10025-1             | Hot-rolled products of structural steels - Part 1: General technical delivery conditions                                                                                           |
| EN 10025-2             | Hot-rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels                                                                   |
| EN 10025-3             | Hot-rolled products of structural steels - Part 3: Technical delivery conditions for normalized/normalized rolled weldable fine grain structural steels                            |
| EN 10025-4             | Hot-rolled products of structural steels - Part 4: Technical delivery conditions for thermomechanical rolled weldable fine grain structural steels                                 |
| EN 10025-5             | Hot-rolled products of structural steels - Part 5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance                              |
| EN 10025-6             | Hot-rolled products of structural steels - Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition |
| EN 10080               | Steel for the reinforcement of concrete - Weldable reinforcing steel General                                                                                                       |
| EN 10210-1             | Hot finished structural hollow sections of non-alloy and fine grain structural steels – Part 1 : Technical delivery conditions                                                     |
| EN 10219-1             | Cold formed welded structural hollow sections of non-alloy and fine grain structural steels – Part 1: Technical delivery conditions                                                |
| ENV 13381-1            | Test methods for determining the contribution to the fire resistance of structural members – Part 1: Horizontal protective membranes                                               |
| ENV 13381-2            | Test methods for determining the contribution to the fire resistance of structural members – Part 2: Vertical protective membranes                                                 |
| ENV 13381-3            | Test methods for determining the contribution to the fire resistance of structural members – Part 3: Applied protection to concrete members                                        |
| ENV 13381-4            | Test methods for determining the contribution to the fire resistance of structural members – Part 4: Applied protection to steel members                                           |
| ENV 13381-5            | Test methods for determining the contribution to the fire resistance of structural members – Part 5: Applied protection to concrete/profiled sheet composite members               |
| <b>AC1</b> ENV 13381-6 | Test methods for determining the contribution to the fire resistance of structural members – Part 6: Applied protection to concrete filled hollow steel columns <b>AC1</b>         |
| EN 1990                | Eurocode: Basis of structural design                                                                                                                                               |
| EN 1991 -1-1           | Eurocode 1 : Actions on Structures – Part 1.1: General Actions - Densities, self-weight and imposed loads                                                                          |
| EN 1991 -1-2           | Eurocode 1 : Actions on Structures – Part 1.2: General Actions - Actions on structures exposed to fire                                                                             |

|              |                                                                                                                  |
|--------------|------------------------------------------------------------------------------------------------------------------|
| EN 1991 -1-3 | Eurocode 1 : Actions on Structures – Part 1.3: General Actions - Actions on structures - Snow loads              |
| EN 1991 -1-4 | Eurocode 1 : Actions on Structures – Part 1.4: General Actions - Actions on structures - Wind loads              |
| EN 1992-1-1  | Eurocode 2: Design of concrete structures - Part 1.1: General rules and rules for buildings                      |
| EN 1992-1-2  | Eurocode 2: Design of concrete structures - Part 1.2: Structural fire design                                     |
| 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: Structural fire design                                        |
| EN 1993-1-5  | Eurocode 3: Design of steel structures - Part 1.5: Plated structural elements                                    |
| EN 1994-1-1  | Eurocode 4: Design of composite steel and concrete structures - Part 1.1: General rules and rules for buildings" |

### **1.3 Assumptions**

(1)P Assumptions of EN 1990 and EN 1991-1-2 apply.

### **1.4 Distinction between Principles and Application Rules**

(1) The rules given in EN 1990 clause 1.4 apply.

### **1.5 Definitions**

(1)P The rules given in clauses 1.5 of EN 1990 and EN 1991-1-2 apply

(2)P The following terms are used in Part 1-2 of EN 1994 with the following meanings:

#### **1.5.1 Special terms relating to design in general**

##### **1.5.1.1**

##### **axis distance**

distance between the axis of the reinforcing bar and the nearest edge of concrete

##### **1.5.1.2**

##### **part of structure**

isolated part of an entire structure with appropriate support and boundary conditions

##### **1.5.1.3**

##### **protected members**

members for which measures are taken to reduce the temperature rise in the member due to fire

##### **1.5.1.4**

##### **braced frame**

a frame which has a sway resistance supplied by a bracing system which is sufficiently stiff for it to be acceptably accurate to assume that all horizontal loads are resisted by the bracing system

## 1.5.2 Terms relating to material and products properties

### 1.5.2.1

#### **failure time of protection**

duration of protection against direct fire exposure; that is the time when the fire protective claddings or other protection fall off the composite member, or other elements aligned with that composite member fail due to collapse, or the alignment with other elements is terminated due to excessive deformation of the composite member

### 1.5.2.2

#### **fire protection material**

any material or combination of materials applied to a structural member for the purpose of increasing its fire resistance

## 1.5.3 Terms relating to heat transfer analysis

### 1.5.3.1

#### **section factor**

for a steel member, the ratio between the exposed surface area and the volume of steel; for an enclosed member, the ratio between the internal surface area of the exposed encasement and the volume of steel

## 1.5.4 Terms relating to mechanical behaviour analysis

### 1.5.4.1

#### **critical temperature of structural steel**

for a given load level, the temperature at which failure is expected to occur in a structural steel element for a uniform temperature distribution

### 1.5.4.2

#### **critical temperature of reinforcement**

the temperature of the reinforcement at which failure in the element is expected to occur at a given load level

### 1.5.4.3

#### **effective cross section**

cross section of the member in structural fire design used in the effective cross section method. It is obtained by removing parts of the cross section with assumed zero strength and stiffness

### 1.5.4.4

#### **maximum stress level**

for a given temperature, the stress level at which the stress-strain relationship of steel is truncated to provide a yield plateau

## 1.6 Symbols

(1)P For the purpose of this Part 1-2 of EN 1994, the following symbols apply

#### *Latin upper case letters*

|                |                                                                                  |
|----------------|----------------------------------------------------------------------------------|
| $A$            | cross-sectional area or concrete volume of the member per metre of member length |
| $A_{a,\theta}$ | cross-sectional area of the steel profile at the temperature $\theta$            |
| $A_{c,\theta}$ | cross-sectional area of the concrete at the temperature $\theta$                 |
| $A_f$          | cross-sectional area of a steel flange                                           |

|                       |                                                                                                                                                                           |
|-----------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $A_i, A_j$            | elemental area of the cross section with a temperature $\theta_i$ or $\theta_j$<br>or the exposed surface area of the part $i$ of the steel cross-section per unit length |
| $A/L_r$               | the rib geometry factor                                                                                                                                                   |
| $A_i / V_i$           | section factor [ $\text{m}^{-1}$ ] of the part $i$ of the steel cross-section (non-protected member)                                                                      |
| $A_m$                 | directly heated surface area of member per unit length                                                                                                                    |
| $A_m/V$               | section factor of structural member                                                                                                                                       |
| $A_{p,i}$             | area of the inner surface of the fire protection material per unit length of the part $i$ of the steel member                                                             |
| $A_{p,i} / V_i$       | section factor [ $\text{m}^{-1}$ ] of the part $i$ of the steel cross-section (with contour protection)                                                                   |
| $A_r$                 | cross-sectional area of the stiffeners                                                                                                                                    |
| $A_r/V_r$             | section factor of stiffeners                                                                                                                                              |
| $A_{s,\theta}$        | cross-sectional area of the reinforcing bars at the temperature $\theta$                                                                                                  |
| $E$                   | integrity criterion                                                                                                                                                       |
| $E 30$                | or $E 60, \dots$ a member complying with the integrity criterion for 30, or 60... minutes in standard fire exposure                                                       |
| $E_a$                 | characteristic value for the modulus of elasticity of structural steel at 20°C                                                                                            |
| $E_{a,f}$             | characteristic value for the modulus of elasticity of a profile steel flange                                                                                              |
| $E_{a,\theta}$        | characteristic value for the slope of the linear elastic range of the stress-strain relationship of structural steel at elevated temperatures                             |
| $E_{a,\theta,\sigma}$ | tangent modulus of the stress-strain relationship of the steel profile at elevated temperature $\theta$ and for stress $\sigma_{i,\theta}$                                |
| $E_{c,sec,\theta}$    | characteristic value for the secant modulus of concrete in the fire situation, given by $f_{c,\theta}$ divided by $\varepsilon_{cu,\theta}$                               |
| $E_{c0,\theta}$       | characteristic value for the tangent modulus at the origin of the stress-strain relationship for concrete at elevated temperatures and for short term loading             |
| $E_{c,\theta,\sigma}$ | tangent modulus of the stress-strain relationship of the concrete at elevated temperature $\theta$ and for stress $\sigma_{i,\theta}$                                     |
| $E_d$                 | design effect of actions for normal temperature design                                                                                                                    |
| $E_{fi,d}$            | design effect of actions in the fire situation, supposed to be time independent                                                                                           |
| $E_{fi,d,t}$          | design effect of actions, including indirect fire actions and loads in the fire situation, at time $t$                                                                    |
| $(EI)_{fi,c,z}$       | flexural stiffness in the fire situation (related to the central axis $Z$ of the composite cross-section)                                                                 |

|                            |                                                                                                                                                 |
|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------|
| $(EI)_{fi,eff}$            | effective flexural stiffness in the fire situation                                                                                              |
| $(EI)_{fi,f,z}$            | flexural stiffness of the two flanges of the steel profile in the fire situation (related to the central axis Z of the composite cross-section) |
| $(EI)_{fi,s,z}$            | flexural stiffness of the reinforcing bars in the fire situation (related to the central axis Z of the composite cross-section)                 |
| $(EI)_{fi,eff,z}$          | effective flexural stiffness (for bending around axis z) in the fire situation                                                                  |
| $(EI)_{fi,w,z}$            | flexural stiffness of the web of the steel profile in the fire situation (related to the central axis Z of the composite cross-section)         |
| $E_k$                      | characteristic value of the modulus of elasticity                                                                                               |
| $E_s$                      | modulus of elasticity of the reinforcing bars                                                                                                   |
| $E_{s,\theta}$             | characteristic value for the slope of the linear elastic range of the stress-strain relationship of reinforcing steel at elevated temperatures  |
| $E_{s,\theta,\sigma}$      | tangent modulus of the stress-strain relationship of the reinforcing steel at elevated temperature $\theta$ and for stress $\sigma_{i,\theta}$  |
| $F_a$                      | compressive force in the steel profile                                                                                                          |
| $F^+, F^-$                 | total compressive force in the composite section in case of sagging or hogging bending moments                                                  |
| $F_c$                      | compression force in the slab                                                                                                                   |
| $G_k$                      | characteristic value of a permanent action                                                                                                      |
| $HC$                       | hydrocarbon fire exposure curve                                                                                                                 |
| $I$                        | thermal insulation criterion                                                                                                                    |
| $I_{i,\theta}$             | second moment of area, of the partially reduced part i of the cross-section for bending around the weak or strong axis in the fire situation    |
| $I\ 30$                    | or $I\ 60, \dots$ a member complying with the thermal insulation criterion for 30, or 60... minutes in standard fire exposure                   |
| $L$                        | system length of a column in the relevant storey                                                                                                |
| $L_{ei}$                   | buckling length of a column in an internal storey                                                                                               |
| $L_{et}$                   | buckling length of a column in the top storey                                                                                                   |
| $M$                        | bending moment                                                                                                                                  |
| $M_{fi,Rd^+}; M_{fi,Rd^-}$ | design value of the sagging or hogging moment resistance in the fire situation                                                                  |
| $M_{fi,t,Rd}$              | design moment resistance in the fire situation at time t                                                                                        |
| $N$                        | number of shear connectors in one critical length,                                                                                              |

|                |                                                                                                                                                        |
|----------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|
|                | or axial load                                                                                                                                          |
| $N_{equ}$      | equivalent axial load                                                                                                                                  |
| $N_{fi,cr}$    | elastic critical load ( $\equiv$ Euler buckling load) in the fire situation                                                                            |
| $N_{fi,cr,z}$  | elastic critical load ( $\equiv$ Euler buckling load) around the axis Z in the fire situation                                                          |
| $N_{fi,pl,Rd}$ | design value of the plastic resistance to axial compression of the total cross-section in the fire situation                                           |
| $N_{fi,Rd}$    | design value of the resistance of a member in axial compression ( $\equiv$ design axial buckling load) and in the fire situation                       |
| $N_{fi,Rd,z}$  | design value of the resistance of a member in axial compression, for bending around the axis Z, in the fire situation                                  |
| $N_{fi,Sd}$    | design value of the axial load in the fire situation                                                                                                   |
| $N_{Rd}$       | axial buckling load at normal temperature                                                                                                              |
| $N_s$          | normal force in the hogging reinforcement ( $A_s \cdot f_{sy}$ )                                                                                       |
| $P_{Rd}$       | design shear resistance of a headed stud automatically welded                                                                                          |
| $P_{fi,Rd}$    | design shear resistance in the fire situation of a shear connector                                                                                     |
| $Q_{k,1}$      | characteristic value of the leading variable action 1                                                                                                  |
| $R$            | Load bearing criterion                                                                                                                                 |
| $R\ 30$        | or R 60, R90, R120, R180, R240... a member complying with the load bearing criterion for 30, 60, 90, 120, 180 or 240 minutes in standard fire exposure |
| $R_d$          | design resistance for normal temperature design                                                                                                        |
| $R_{fi,d,t}$   | design resistance in the fire situation, at time t                                                                                                     |
| $R_{fi,y,Rd}$  | design crushing resistance in the fire situation                                                                                                       |
| $T$            | tensile force                                                                                                                                          |
| $V$            | volume of the member per unit length                                                                                                                   |
| $V_{fi,pl,Rd}$ | design value of the shear plastic resistance in the fire situation                                                                                     |
| $V_{fi,Sd}$    | design value of the shear force in the fire situation                                                                                                  |
| $V_i$          | volume of the part i of the steel cross section per unit length [ $m^3/m$ ]                                                                            |
| $X$            | X (horizontal) axis                                                                                                                                    |
| $X_{fi,d}$     | design values of mechanical (strength and deformation) material properties in the fire situation                                                       |

|                |                                                                                                     |
|----------------|-----------------------------------------------------------------------------------------------------|
| $X_k$          | characteristic or nominal value of a strength or deformation property for normal temperature design |
| $X_{k,\theta}$ | value of a material property in the fire situation, generally dependant on the material temperature |
| $Y$            | Y (vertical) axis                                                                                   |
| $Z$            | Z (column) central axis of the composite cross-section                                              |

*Latin lower case letters*

|                |                                                                                                                                          |
|----------------|------------------------------------------------------------------------------------------------------------------------------------------|
| $a_w$          | throat thickness of weld (connection between steel web and stirrups)                                                                     |
| $b$            | width of the steel section                                                                                                               |
| $b_1$          | width of the bottom flange of the steel section                                                                                          |
| $b_2$          | width of the upper flange of the steel section                                                                                           |
| $b_c$          | depth of the composite column made of a totally encased section, or width of concrete partially encased steel beams                      |
| $b_{c,fi}$     | width reduction of the encased concrete between the flanges in the fire situation                                                        |
| $b_{c,fi,min}$ | minimum value of the width reduction of the encased concrete between the flanges in the fire situation                                   |
| $b_{eff}$      | effective width of the concrete slab                                                                                                     |
| $b_{fi}$       | width reduction of upper flange in the fire situation                                                                                    |
| $c$            | specific heat,<br>or buckling curve,<br>or concrete cover from edge of concrete to border of structural steel                            |
| $c_a$          | specific heat of steel                                                                                                                   |
| $c_c$          | specific heat of normal weight concrete                                                                                                  |
| $c_p$          | specific heat of the fire protection material                                                                                            |
| $d$            | diameter of the composite column made of concrete filled hollow section, or diameter of the studs welded to the web of the steel profile |
| $d_p$          | thickness of the fire protection material                                                                                                |
| $e$            | thickness of profile or hollow section                                                                                                   |
| $e_1$          | thickness of the bottom flange of the steel profile                                                                                      |
| $e_2$          | thickness of the upper flange of the steel profile                                                                                       |
| $e_f$          | thickness of the flange of the steel profile                                                                                             |
| $e_w$          | thickness of the web of the steel profile                                                                                                |

|                                |                                                                                                                                                                  |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $ef$                           | external fire exposure curve                                                                                                                                     |
| $f_{ay,\theta}$                | maximum stress level or effective yield strength of structural steel in the fire situation                                                                       |
| $f_{ay,\theta_{cr}}$           | strength of steel at critical temperature $\theta_{cr}$                                                                                                          |
| $f_{ap,\theta}; f_{sp,\theta}$ | proportional limit of structural or reinforcing steel in the fire situation                                                                                      |
| $f_{au,\theta}$                | ultimate tensile strength of structural steel or steel for stud connectors in the fire situation, allowing for strain-hardening                                  |
| $f_{ay}$                       | characteristic or nominal value for the yield strength of structural steel at 20°C                                                                               |
| $f_c$                          | characteristic value of the compressive cylinder strength of concrete at 28 days and at 20°C.                                                                    |
| $f_{c,j}$                      | characteristic strength of concrete part j at 20°C.                                                                                                              |
| $f_{c,\theta}$                 | characteristic value for the compressive cylinder strength of concrete in the fire situation at temperature $\theta$ °C.                                         |
| $f_{c,\theta n}$               | residual compressive strength of concrete heated to a maximum temperature (with n layers)                                                                        |
| $f_{c,\theta y}$               | residual compressive strength of concrete heated to a maximum temperature                                                                                        |
| $f_{fi,d}$                     | design strength property in the fire situation                                                                                                                   |
| $f_k$                          | characteristic value of the material strength                                                                                                                    |
| $f_{ry}, f_{sy}$               | characteristic or nominal value for the yield strength of a reinforcing bar at 20°C                                                                              |
| $f_{sy,\theta}$                | maximum stress level or effective yield strength of reinforcing steel in the fire situation                                                                      |
| $f_{y,i}$                      | nominal yield strength $f_y$ for the elemental area $A_i$ taken as positive on the compression side of the plastic neutral axis and negative on the tension side |
| $h$                            | depth or height of the steel section                                                                                                                             |
| $h_1$                          | height of the concrete part of a composite slab above the decking                                                                                                |
| $h_2$                          | height of the concrete part of a composite slab within the decking                                                                                               |
| $h_3$                          | thickness of the screed situated on top of the concrete                                                                                                          |
| $h_c$                          | depth of the composite column made of a totally encased section, or thickness of the concrete slab                                                               |
| $h_{eff}$                      | effective thickness of a composite slab                                                                                                                          |
| $h_{fi}$                       | height reduction of the encased concrete between the flanges in the fire situation                                                                               |
| $\dot{h}_{net}$                | design value of the net heat flux per unit area                                                                                                                  |

|                          |                                                                                                                                                                          |
|--------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| $\dot{h}_{net,c}$        | design value of the net heat flux per unit area by convection                                                                                                            |
| $\dot{h}_{net,r}$        | design value of the net heat flux per unit area by radiation                                                                                                             |
| $h_u$                    | thickness of the compressive zone                                                                                                                                        |
| $h_{u,n}$                | thickness of the compressive zone (with n layers)                                                                                                                        |
| $h_v$                    | height of the stud welded on the web of the steel profile                                                                                                                |
| $h_w$                    | height of the web of the steel profile                                                                                                                                   |
| $k_{c,\theta}$           | reduction factor for the compressive strength of concrete giving the strength at elevated temperature $f_{c,\theta}$                                                     |
| $k_{E,\theta}$           | reduction factor for the elastic modulus of structural steel giving the slope of the linear elastic range at elevated temperature $E_{a,\theta}$                         |
| $k_{y,\theta}$           | reduction factor for the yield strength of structural steel giving the maximum stress level at elevated temperature $f_{ay,\theta}$                                      |
| $k_{p,\theta}$           | reduction factor for the yield strength of structural steel or reinforcing bars giving the proportional limit at elevated temperature $f_{ap,\theta}$ or $f_{sp,\theta}$ |
| $k_r, k_s$               | reduction factor for the yield strength of a reinforcing bar                                                                                                             |
| $k_{shadow}$             | correction factor for the shadow effect                                                                                                                                  |
| $k_{u,\theta}$           | reduction factor for the yield strength of structural steel giving the strain hardening stress level at elevated temperature $f_{au,\theta}$                             |
| $k_\theta$               | reduction factor for a strength or deformation property dependent on the material temperature in the fire situation                                                      |
| $\ell$                   | length or buckling length                                                                                                                                                |
| $\ell_1, \ell_2, \ell_3$ | specific dimensions of the re-entrant steel sheet profile or the trapezoidal steel profile                                                                               |
| $\ell_w$                 | length (connection between steel profile and the encased concrete)                                                                                                       |
| $\ell_\theta$            | buckling length of the column in the fire situation                                                                                                                      |
| $s_s$                    | length of the rigid support (calculation of the crushing resistance of stiffeners)                                                                                       |
| $t$                      | duration of fire exposure                                                                                                                                                |
| $t_{fi,d}$               | design value of standard fire resistance of a member in the fire situation                                                                                               |
| $t_{fi,requ}$            | required standard fire resistance in the fire situation                                                                                                                  |
| $t_i$                    | the fire resistance with respect to thermal insulation                                                                                                                   |

|             |                                                                                                                         |
|-------------|-------------------------------------------------------------------------------------------------------------------------|
| $u$         | geometrical average of the axis distances $u_1$ and $u_2$ (composite section with partially encased steel profile)      |
| $u_1 ; u_2$ | shortest distance from the centre of the reinforcement bar to the inner steel flange or to the nearest edge of concrete |
| $z_i ; z_j$ | distance from the plastic neutral axis to the centroid of the elemental area $A_i$ or $A_j$                             |

*Greek letters upper case letters*

|                       |                                                                             |
|-----------------------|-----------------------------------------------------------------------------|
| $\Delta l$            | temperature induced elongation of a member                                  |
| $\Delta l/l$          | related thermal elongation                                                  |
| $\Delta t$            | time interval                                                               |
| $\Delta \theta_{a,t}$ | increase of temperature of a steel beam during the time interval $\Delta t$ |
| $\Delta \theta_t$     | increase in the gas temperature [°C] during the time interval $\Delta t$    |
| $\Phi$                | configuration or view factor                                                |

*Greek letters lower case letters*

|                   |                                                                                                     |
|-------------------|-----------------------------------------------------------------------------------------------------|
| $\alpha$          | angle of the web                                                                                    |
| $\alpha_c$        | convective heat transfer coefficient                                                                |
| $\alpha_{slab}$   | coefficient taking into account the assumption of the rectangular stress block when designing slabs |
| $\gamma_G$        | partial factor for permanent action $G_k$                                                           |
| $\gamma_{M,fi}$   | partial factor for a material property in the fire situation                                        |
| $\gamma_{M,fi,a}$ | partial factor for the strength of structural steel in the fire situation                           |
| $\gamma_{M,fi,c}$ | partial factor for the strength of concrete in the fire situation                                   |
| $\gamma_{M,fi,s}$ | partial factor for the strength of reinforcing bars in the fire situation                           |
| $\gamma_{M,fi,v}$ | partial factor for the shear resistance of stud connectors in the fire situation                    |
| $\gamma_Q$        | partial factor for variable action $Q_k$                                                            |
| $\gamma_v$        | partial factor for the shear resistance of stud connectors at normal temperature                    |
| $\delta$          | eccentricity                                                                                        |
| $\varepsilon$     | strain                                                                                              |
| $\varepsilon_a$   | axial strain of the steel profile of the column                                                     |

|                                 |                                                                                             |
|---------------------------------|---------------------------------------------------------------------------------------------|
| $\varepsilon_{a,\theta}$        | strain in the fire situation                                                                |
| $\varepsilon_{ae,\theta}$       | ultimate strain in the fire situation                                                       |
| $\varepsilon_{ay,\theta}$       | yield strain in the fire situation                                                          |
| $\varepsilon_{ap,\theta}$       | strain at the proportional limit in the fire situation                                      |
| $\varepsilon_{au,\theta}$       | limiting strain for yield strength in the fire situation                                    |
| $\varepsilon_c$                 | axial strain of the concrete of the column                                                  |
| $\varepsilon_{c,\theta}$        | concrete strain in the fire situation                                                       |
| $\varepsilon_{ce,\theta}$       | maximum concrete strain in the fire situation                                               |
| $\varepsilon_{ce,\theta_{max}}$ | maximum concrete strain in the fire situation at the maximum temperature                    |
| $\varepsilon_{cu,\theta}$       | concrete strain corresponding to $f_{c,\theta}$                                             |
| $\varepsilon_{cu,\theta_{max}}$ | concrete strain at the maximum concrete temperature                                         |
| $\varepsilon_f$                 | emissivity coefficient of the fire                                                          |
| $\varepsilon_m$                 | emissivity coefficient related to the surface material of the member                        |
| $\varepsilon_s$                 | axial deformation of the reinforcing steel of the column                                    |
| $\phi_b$                        | diameter of a bar                                                                           |
| $\phi_s$                        | diameter of a stirrup                                                                       |
| $\phi_r$                        | diameter of a longitudinal reinforcement at the corner of the stirrups                      |
| $\eta$                          | load level according to EN 1994-1-1                                                         |
| $\eta_{fi}$                     | reduction factor applied to $E_d$ in order to obtain $E_{fi,d}$                             |
| $\eta_{fi,t}$                   | load level for fire design                                                                  |
| $\theta$                        | temperature                                                                                 |
| $\theta_a$                      | temperature of structural steel                                                             |
| $\theta_{a,t}$                  | steel temperature at time $t$ assumed to be uniform in each part of the steel cross-section |
| $\theta_c$                      | temperature of concrete                                                                     |
| $\theta_{cr}$                   | critical temperature of a structural member                                                 |
| $\theta_i$                      | temperature in the elemental area $A_i$                                                     |

|                          |                                                                                                               |
|--------------------------|---------------------------------------------------------------------------------------------------------------|
| $\theta_{lim}$           | limiting temperature                                                                                          |
| $\theta_{max}$           | maximum temperature                                                                                           |
| $\theta_r$               | the temperature of a stiffener                                                                                |
| $\theta_R$               | the temperature of additional reinforcement in the rib                                                        |
| $\theta_s$               | temperature of reinforcing steel                                                                              |
| $\theta_t$               | gas temperature at time t                                                                                     |
| $\theta_v$               | temperature of stud connectors                                                                                |
| $\theta_w$               | temperature in the web                                                                                        |
| $\lambda_a$              | thermal conductivity of steel                                                                                 |
| $\lambda_c$              | thermal conductivity of concrete                                                                              |
| $\lambda_p$              | thermal conductivity of the fire protection material                                                          |
| $\bar{\lambda}$          | relative slenderness                                                                                          |
| $\bar{\lambda}_{\theta}$ | relative slenderness of stiffeners in the fire situation                                                      |
| $\xi$                    | reduction factor for unfavourable permanent action $G_k$                                                      |
| $\rho_a$                 | density of steel                                                                                              |
| $\rho_c$                 | density of concrete                                                                                           |
| $\rho_{c,NC}$            | density of normal weight concrete                                                                             |
| $\rho_{c,LC}$            | density of lightweight concrete                                                                               |
| $\rho_p$                 | density of the fire protection material                                                                       |
| $\sigma$                 | stress                                                                                                        |
| $\sigma_{a,\theta}$      | stress of the steel profile in the fire situation                                                             |
| $\sigma_{c,\theta}$      | stress of concrete under compression in the fire situation                                                    |
| $\sigma_{s,\theta}$      | stress of reinforcing steel in the fire situation                                                             |
| $\varphi_{a,\theta}$     | reduction coefficient for the steel profile depending on the effect of thermal stresses in the fire situation |
| $\varphi_{c,\theta}$     | reduction coefficient for the concrete depending on the effect of thermal stresses in the fire situation      |
| $\varphi_{s,\theta}$     | reduction coefficient for reinforcing bars depending on the effect of thermal stresses in the fire situation  |

|              |                                                                                                              |
|--------------|--------------------------------------------------------------------------------------------------------------|
| $\chi$       | reduction or correction coefficient and factor                                                               |
| $\chi_z$     | reduction or correction coefficient and factor (for bending around axis z)                                   |
| $\psi_{0,1}$ | combination factor for the characteristic or rare value of a variable action                                 |
| $\psi_{1,1}$ | combination factor for the frequent value of a variable action                                               |
| $\psi_{2,1}$ | combination factor for the quasi-permanent value of a variable action                                        |
| $\psi_{fi}$  | combination factor for a variable action in the fire situation, given either by $\psi_{1,1}$ or $\psi_{2,1}$ |

## **Section 2     Basis of design**

### **2.1     Requirements**

#### **2.1.1     Basic requirements**

(1)P Where mechanical resistance in the case of fire is required, composite steel and concrete structures shall be designed and constructed in such a way that they maintain their load bearing function during the relevant fire exposure.

(2)P Where compartmentation is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure. This shall ensure, where relevant, that:

- integrity failure does not occur;
- insulation failure does not occur.

NOTE 1: See for definition EN1991-1-2, chapters 1.5.1.8 and 1.5.1.9

NOTE 2: In case of a composite slab, the thermal radiation criterion is not relevant.

(3)P Deformation criterion shall be applied where the means of protection, or the design criterion for separating members, require consideration of the deformation of the load bearing structure.

(4) Consideration of the deformation of the load bearing structure is not necessary in the following cases, as relevant:

- the efficiency of the means of protection has been evaluated according to 3.3.4 and
- the separating elements have to fulfill requirements according to a nominal fire exposure.

#### **2.1.2     Nominal fire exposure**

(1)P For the standard fire exposure, members shall comply with criteria R, E and I as follows:

- separating only: integrity (criterion E) and, when requested, insulation (criterion I);
- load bearing only: mechanical resistance (criterion R);
- separating and load bearing: criteria R, E and, when requested, I.

(2) Criterion "R" is assumed to be satisfied where the load bearing function is maintained during the required time of fire exposure.

(3) Criterion "I" may be assumed to be satisfied where the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K.

(4) With the external fire exposure curve the same criteria should apply, however the reference to this specific curve should be identified by the letters "ef".

NOTE : See EN1991-1-2, chapters 1.5.3.5 and 3.2.2

(5) With the hydrocarbon fire exposure curve the same criteria should apply, however the reference to this specific curve should be identified by the letters "HC".

NOTE : See EN1991-1-2, chapters 1.5.3.11 and 3.2.3

### 2.1.3 Parametric fire exposure

(1) The load-bearing function is ensured when collapse is prevented during the complete duration of the fire including the decay phase or during a required period of time.

(2) The separating function with respect to insulation is ensured when

- at the time of the maximum gas temperature, the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K,
- during the decay phase of the fire, the average temperature rise over the whole of the non-exposed surface should be limited to  $\Delta\theta_1$ , and the maximum temperature rise at any point of that surface should not exceed  $\Delta\theta_2$ .

NOTE : The values of  $\Delta\theta_1$  and  $\Delta\theta_2$  for use in a Country may be found in its National Annex. The recommended values are  $\Delta\theta_1 = 200$  K and  $\Delta\theta_2 = 240$  K.

## 2.2 Actions

(1)P The thermal and mechanical actions shall be taken from EN 1991-1-2.

(2) In addition to 3.1(6) of EN 1991-1-2, the emissivity coefficient for steel and concrete related to the surface of the member should be  $\varepsilon_m = 0,7$ .

## 2.3 Design values of material properties

(1)P Design values of mechanical (strength and deformation) material properties  $X_{fi,d}$  are defined as follows:

$$X_{fi,d} = k_{\theta} X_k / \gamma_{M,fi} \quad (2.1)$$

where:

$X_k$  is the characteristic or nominal value of a strength or deformation property (*generally  $f_k$  or  $E_k$* ) for normal temperature design according to EN 1994-1-1;

$k_\theta$  is the reduction factor for a strength or deformation property ( $X_{k,\theta}/X_k$ ), dependent on the material temperature, see 3.2;

$\gamma_{M,fi}$  is the partial factor for the relevant material property, for the fire situation.

NOTE 1: For mechanical properties of steel and concrete, the recommended values of the partial factor for the fire situation are  $\gamma_{M,fi,a} = 1,0$ ;  $\gamma_{M,fi,s} = 1,0$ ;  $\gamma_{M,fi,c} = 1,0$ ;  $\gamma_{M,fi,v} = 1,0$ . Where modifications are required, these may be defined in the relevant National Annexes of EN 1992-1-2 and EN 1993-1-2.

NOTE 2: If the recommended values are modified, tabulated data may need to be adapted.

(2)P Design values of thermal material properties  $X_{fi,d}$  are defined as follows:

- if an increase of the property is favourable for safety;

$$X_{fi,d} = X_{k,\theta} / \gamma_{M,fi} \quad (2.2a)$$

- if an increase of the property is unfavourable for safety.

$$X_{fi,d} = \gamma_{M,fi} X_{k,\theta} \quad (2.2b)$$

where:

$X_{k,\theta}$  is the value of a material property in the fire situation, generally dependent on the material temperature, see 3.3;

$\gamma_{M,fi}$  is the partial factor for the relevant material property, for the fire situation.

NOTE 1: For thermal properties of steel and concrete, the recommended value of the partial factor for the fire situation is  $\gamma_{M,fi} = 1,0$ ; where modifications are required, these may be defined in the relevant National Annexes of EN 1992-1-2 and EN 1993-1-2.

NOTE 2: If the recommended values are modified, tabulated data may need to be adapted.

(3) The design value of the compressive concrete strength should be taken as  $1,0 f_c$  divided by  $\gamma_{M,fi,c}$ , before applying the required strength reduction due to temperature and given in 3.2.2.

## 2.4 Verification methods

### 2.4.1 General

(1)P The model of the structural system adopted for design to this Part 1-2 of EN 1994 shall reflect the expected performance of the structure in fire.

(2)P It shall be verified for the relevant duration of fire exposure  $t$ :

$$E_{fi,d,t} \leq R_{fi,d,t} \quad (2.3)$$

where:

$E_{fi,d,t}$  is the design effect of actions for the fire situation, determined in accordance with EN 1991-1-2, including the effects of thermal expansions and deformations;

$R_{fi,d,t}$  is the corresponding design resistance in the fire situation.

(3) The structural analysis for the fire situation should be carried out according to 5.1.4(2) of EN 1990.

NOTE: For verifying standard fire resistance requirement, a member analysis is sufficient.

(4) Where application rules given in this Part 1-2 are valid only for the standard temperature-time curve, this is identified in the relevant clauses.

(5) Tabulated data given in 4.2 are based on the standard temperature-time curve.

(6)P As an alternative to design by calculation, fire design may be based on the results of fire tests, or on fire tests in combination with calculations, see EN 1990 clause 5.2.

## 2.4.2 Member analysis

(1) The effect of actions should be determined for time  $t = 0$  using combination factors  $\psi_{1,l}$  or  $\psi_{2,l}$  according to 4.3.1(2) of EN 1991-1-2.

(2) As a simplification to (1), the effect of actions  $E_{fi,d,t}$  may be obtained from a structural analysis for normal temperature design as:

$$E_{fi,d,t} = E_{fi,d} = \eta_{fi} E_d \quad (2.4)$$

where:

$E_d$  is the design value of the corresponding force or moment for normal temperature design, for a fundamental combination of actions (see EN 1990)

$\eta_{fi}$  is the reduction factor of  $E_d$

(3) The reduction factor  $\eta_{fi}$  for load combination (6.10) in EN 1990 should be taken as:

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,l}}{\gamma_G G_k + \gamma_{Q,l} Q_{k,l}} \quad (2.5)$$

or for load combinations (6.10a) and (6.10b) in EN 1990 as the smaller value given by the two following expressions:

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,l}}{\gamma_G G_k + \gamma_{Q,l} \psi_{0,l} Q_{k,l}} \quad (2.5a)$$

$$\eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,l}}{\xi \gamma_G G_k + \gamma_{Q,l} Q_{k,l}} \quad (2.5b)$$

where:

$Q_{k,l}$  is the characteristic value of the leading variable action 1

$G_k$  is the characteristic value of a permanent action

$\gamma_G$  is the partial factor for permanent actions

$\gamma_{Q,l}$  is the partial factor for variable action 1

$\xi$  is a reduction factor for unfavourable permanent action  $G_k$

$\psi_{0,l}$  combination factor for the characteristic value of a variable action

$\psi_{fi}$  is the combination factor for fire situation, given either by  $\psi_{1,i}$  (frequent value) or  $\psi_{2,i}$  (quasi-permanent value) according to 4.3.1(2) of EN 1991-1-2

NOTE 1: An example of the variation of the reduction factor  $\eta_{fi}$  versus the load ratio  $Q_{k,1}/G_k$  for different values of the combination factor  $\psi_{fi} = \psi_{1,1}$  according to expression (2.5), is shown in Figure 2.1 with the following assumptions:  $\gamma_G = 1,35$  and  $\gamma_Q = 1,5$ . Partial factors are specified in the relevant National Annexes of EN 1990. Equations (2.5a) and (2.5b) give slightly higher values.

NOTE 2: As a simplification the recommended value of  $\eta_{fi} = 0,65$  may be used, except for imposed loads according to load category E as given in EN 1991-1-1 (areas susceptible to accumulation of goods, including access areas), where the recommended value is 0,7.

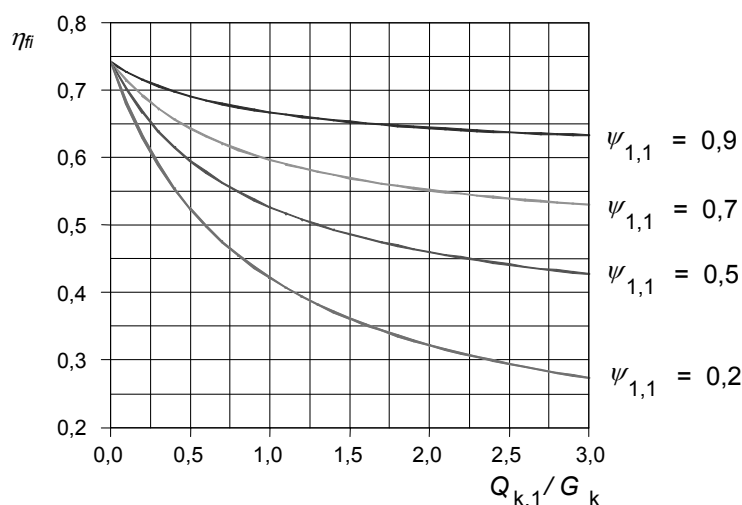


Figure 2.1: Variation of the reduction factor  $\eta_{fi}$  with the load ratio  $Q_{k,1}/G_k$

(4) Only the effects of thermal deformations resulting from thermal gradients across the cross-section need be considered. The effects of axial or in-plane thermal expansions may be neglected.

(5) The boundary conditions at supports and ends of member may be assumed to remain unchanged throughout the fire exposure.

(6) Tabulated data, simplified or advanced calculation models given in 4.2, 4.3 and 4.4 respectively are suitable for verifying members under fire conditions.

### 2.4.3 Analysis of part of the structure

(1) The effect of actions should be determined for time  $t = 0$  using combination factors  $\psi_{1,i}$  or  $\psi_{2,i}$  according to 4.3.1(2) of EN 1991-1-2.

(2) As an alternative to carrying out a structural analysis for the fire situation at time  $t=0$ , the reactions at supports and internal forces and moments at boundaries of part of the structure may be obtained from a structural analysis for normal temperature as given in 2.4.2.

(3) The part of the structure to be analysed should be specified on the basis of the potential thermal expansions and deformations such, that their interaction with other parts of the structure can be approximated by time-independent support and boundary conditions during fire exposure.

(4)P Within the part of the structure to be analysed, the relevant failure mode in fire exposure, the temperature-dependent material properties and member stiffness, effects of thermal expansions and deformations (indirect fire actions) shall be taken into account.

(5) The boundary conditions at supports and forces and moments at boundaries of part of the structure, may be assumed to remain unchanged throughout the fire exposure.

#### 2.4.4 Global structural analysis

(1)P When a global structural analysis for the fire situation is carried out, the relevant failure mode in fire exposure, the temperature-dependent material properties and member stiffness as well as the effects of thermal expansions and deformations (indirect fire actions) shall be taken into account.

### Section 3 Material properties

#### 3.1 General

(1)P In fire conditions the temperature dependent properties shall be taken into account.

(2) The thermal and mechanical properties of steel and concrete should be determined from the following clauses.

(3)P The values of material properties given in 3.2 shall be treated as characteristic values, see 2.3(1)P.

(4) The mechanical properties of concrete, reinforcing and prestressing steel at normal temperature (20°C) should be taken as those given in EN 1992-1-1 for normal temperature design.

(5) The mechanical properties of steel at 20 °C should be taken as those given in EN 1993-1-1 for normal temperature design.

#### 3.2 Mechanical properties

##### 3.2.1 Strength and deformation properties of structural steel

(1) For heating rates between 2 and 50 K/min, the strength and deformation properties of structural steel at elevated temperatures should be obtained from the stress-strain relationship given in Figure 3.1.

NOTE: For the rules of this standard, it is assumed that the heating rates fall within the specified limits.

(2) The stress-strain relationships given in Figure 3.1 and Table 3.1 are defined by three parameters:

- the slope of the linear elastic range  $E_{a,\theta}$  ;
- the proportional limit  $f_{ap,\theta}$  ;
- the maximum stress level or effective yield strength  $f_{ay,\theta}$  .