**DD ENV 1999-1-2:2000**

# Eurocode 9: Design of aluminium structures —

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

ICS 13.220.50; 91.010.30; 91.080.10

# National foreword

This Draft for Development has been prepared by Subcommittee B/525/9 and is the English language version of ENV 1999-1-2:1998 Eurocode 9: Design of aluminium structures Part 1-2: General rules - structural fire design, as published by the European Committee for Standardization.

ENV 1999-1-2:1998 results from a programme of work sponsored by the European Commission to make available a common set of rules for the structural and geotechnical design of building and civil engineering works.

**This publication is not to be regarded as a British Standard.**

An ENV is made available for provisional application, but does not have the status of a European Standard. The aim is to use the experience gained to modify the ENV so that it can be adopted as a European Standard.

Fire safety in the UK is covered by national regulations in the form of Building Regulations, and in particular Approved Document B (1992 edition) of those regulations. There are no current British Standards that give a method of calculating fire resistance of structural members of Aluminium or its alloys.

The values for certain parameters in the ENV Eurocodes may be set by individual CEN members so as to meet the requirements of national regulations. These parameters are designated by □ in the ENV.

The BSI technical committee responsible do not propose any changes to the boxed values for this code.

The ENV allows (clause 2.4.1) structural analysis by several methods. For verifying standard fire resistance requirements, a member analysis is usually considered sufficient.

Users of this documents are invited to comment on its technical content, ease of use and any ambiguities and anomalies. These comments will be taken into account when preparing the UK national response to CEN on the question of whether the ENV can be converted to an EN.

Comments should be sent in writing to the secretary of Subcommittee B/525/9, BSI, 389 Chiswick High Road, London W4 4Al, quoting the document reference, the relevant clause and, where possible, a proposed revision, within 2 years of the issue of this document.

**Summary of pages**

This document comprises a front cover, an inside front cover, pages i and ii, the ENV title page, pages 2 to 56, an inside back cover and a back cover.

The BSI copyright notice displayed in this document indicates when the document was last issued.

This Draft for Development, having been prepared under the direction of the Sector Committee for Building and Civil Engineering, was published under the authority of the Standards Committee and comes into effect on 15 December 2000



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## List of References


| | |
|---|---|
| DD 240: 1997 : | Fire Safety in Buildings |
| DD ENV 1991: Eurocode 1: | Basis for design and actions on structures |
| DD ENV 1991-1: 1996: | Basis of design (together with United Kingdom National Application document) |
| DD ENV 1991-2-2: 1996: | Actions on structures exposed to fire (together with United Kingdom National Application Document) |
| DD ENV 1999-1-1: 1998: | Eurocode 9: Design of aluminium structures part 1-1 General rules and rules for buildings. |

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EUROPEAN PRESTANDARD

PRÉNORME EUROPÉENNE

EUROPÄISCHE VORNORM

# ENV 1999-1-2

May 1998

ICS 13.220.50; 91.010.30; 91.080.10

Descriptors: civil engineering, buildings, steel construction, aluminium, design, building codes, computation, fire resistance

English version

# Eurocode 9: Design of aluminium structures - Part 1-2: General rules - Structural fire design

Eurocode 9: Conception et dimensionnement des structures en aluminium - Partie 1-2: Règles générales - Calcul du comportement au feu

Eurocode 9: Bemessung und Konstruktion von Aluminiumbauten - Teil 1-2: Allgemeine Regeln - Tragwerksbemessung für den Brandfall

This European Prestandard (ENV) was approved by CEN on 26 October 1997 as a prospective standard for provisional application.

The period of validity of this ENV is limited initially to three years. After two years the members of CEN will be requested to submit their comments, particularly on the question whether the ENV can be converted into a European Standard.

CEN members are required to announce the existence of this ENV in the same way as for an EN and to make the ENV available promptly at national level in an appropriate form. It is permissible to keep conflicting national standards in force (in parallel to the ENV) until the final decision about the possible conversion of the ENV into an EN is reached.

CEN members are the national standards bodies of Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

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

**Central Secretariat: rue de Stassart, 36 B-1050 Brussels**



Ref. No. ENV 1999-1-2:1998 E

# Contents

# Foreword

## Objectives of the Eurocodes

The "Structural Eurocodes" comprise a group of standards for the structural and geotechnical design of buildings and civil engineering works.

They are intended to serve as reference documents for the following purposes:

a) As a means to prove compliance of building and civil engineering works with the essential requirements of the Construction Products Directive (CPD).

b) As a framework for drawing up harmonised technical specifications for construction products.

They cover execution and control only to the extent that is necessary to indicate the quality of the construction products, and the standard of the workmanship, needed to comply with the assumptions of the design rules.

Until the necessary set of harmonised technical specifications for products and for methods of testing their performance is available, some of the Structural Eurocodes cover some of these aspects in informative annexes.

## Background to the Eurocode Programme

The Commission of the European Communities (CEC) initiated the work of establishing a set of harmonised technical rules for the design of building and civil engineering works which initially serve as an alternative to the different rules in force in the various Member States and would ultimately replace them. These technical rules became known as the "Structural Eurocodes".

In 1990, after consulting their respective Member States, the CEC transferred the work of further development, issue and updates of the Structural Eurocodes to CEN, and the EFTA Secretariat agreed to support the CEN work.

CEN Technical Committee CEN/TC 250 is responsible for all Structural Eurocodes.

## Eurocode programme

Work is in hand on the following Structural Eurocodes, each generally consisting of a number of parts:

| | | |
|---|---|---|
| EN 1991 | Eurocode 1 | Basis of design and actions on structures |
| EN 1992 | Eurocode 2 | Design of concrete structures |
| EN 1993 | Eurocode 3 | Design of steel structures |
| EN 1994 | Eurocode 4 | Design of composite steel and concrete structures |
| EN 1995 | Eurocode 5 | Design of timber structures |
| EN 1996 | Eurocode 6 | Design of masonry structures |
| EN 1997 | Eurocode 7 | Geotechnical design |
| EN 1998 | Eurocode 8 | Design of structures for earthquake resistance |
| EN 1999 | Eurocode 9 | Design of aluminium structures |

Separate sub-committees have been formed by CEN/TC 250 for the various Eurocodes listed above.

This part of the Structural Eurocode for Design of Aluminium Alloy Structures is being issued by CEN as a European prestandard (ENV) with an initial life of three years.

This European prestandard is intended for experimental practical application in the design of the building and civil engineering works covered by the scope of work as given in 1.1 and for the submission of comments.

After approximately two years CEN members will be invited to submit formal comments to be taken into account in determining future actions.

Meanwhile feedback and comments on this European prestandard should be sent to Secretariat of sub-committee CEN/TC 250/SC 9 at the following address:

Secretariat of CEN/TC 250/SC 9
c/o Norwegian Council for Building Standardization
Postboks 129 Blindern
N-0314 OSLO

or to your national standards organisation.

## National Applications Documents

In view of the responsibilities of authorities in member countries for the safety, health and other matters covered by the essential requirements of the CPD, certain safety elements in this ENV have been assigned indicative values which are identified by □. The authorities in each member country are expected to assign definitive values to these safety elements.

Many of the harmonised supporting standards, including the Eurocodes giving values of actions to be taken into account and measures required for fire protection, will not be available by the time this European prestandard is issued. It is therefore anticipated that a National Application Document (NAD) giving definitive values for safety elements, referencing compatible supporting standards and providing national guidance on the application of this European prestandard, will be issued by each member country or its Standards Organisation.

It is intended that this European prestandard is used in conjunction with the NAD valid in the country where the building or civil engineering works are located.

## Matters specific to this prestandard

### General

The scope of Eurocode 9 is defined in Part 1-1, section 1.1.1 and the scope of this Part of Eurocode 9 is defined in 1.1.

In using this European prestandard in practise, particular regard should be paid to the underlying assumptions and conditions given in Part 1-1, sec. 1.4.

In developing this European prestandard, background documents have been prepared, which give commentaries on, and justifications for, some of the provisions in the European prestandard.

### Annexes

This European prestandard is complemented by three Annexes, all informative.

## Concept of reference standards

When using this European prestandard reference needs to be made to various CEN and ISO standards. These are used to define the product characteristics and processes which have been assumed to apply in formulating the design rules.

This European prestandard mentions certain "Reference Standards". Where any CEN of ISO standards is not yet available, the National Application Document should be consulted for the standard to be used instead. It is assumed that only those grades and qualities given in section 3 of prENV1999-1-1 will be used for buildings and civil engineering works designed to this European prestandard.

## Safety requirements

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

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

Required functions and levels of performance are generally specified by national authorities - mostly in terms of standard fire resistance rating. Where fire safety engineering for assessing passive and active measures is accepted, requirements by authorities may be less prescriptive and allow alternative strategies.

This Part 1-2, together with ENV 1991-2-2, gives the supplements to ENV 1999-1-1 that are necessary so that structures designed according to this set of Structural Eurocodes may also comply with the structural fire resistance requirements.

Supplementary requirements concerning, for example:

- the possible installation and maintenance of sprinkler systems;
- conditions and occupancy of the 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 national authorities.

Normally aluminium alloy structures with requirement for fire resistance, have to be protected. This Part 1-2 has, however, also calculation rules for unprotected aluminium alloy structures exposed to fire. Unprotected aluminium alloy structures may be used for:

- external structures (the walls and the roof of the building protect the structure)
- structures with requirement of 10 or 15 mins. fire resistance (requirements in some countries)
- structures exposed by a thermal load less than the standardized fire load

## 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).

At the present time it is possible to undertake a procedure for determining adequate performance that 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, the principal current procedure in European countries is one based on results from standard fire resistance tests. The definition system in national regulations that call for specific periodes of fire resistance, take into account (though not explicity) the features and uncertainties described above.

Due to the limitations of the test method, further tests or analyses may be used. Nevertheless, the results of standard fire tests form the bulk of the input to calculation methods for structural fire design. This European prestandard therefore deals in the main with design for the standard fire resistance.

## Design aids

Simple calculation models for aluminium alloy structures are given in this document and accordingly tabulated data are not included. It is expected that tables and other design aids based on the calculation methods given in this European prestandard will be prepared by interested external organisations.

# 1 General

## 1.1 Scope

(1)P This European prestandard deals with the design of aluminium alloy structures for the accidental situation of fire exposure and is intended to be used in conjunction with prENV 1999-1-1:1997 and ENV 1991-2-2:1995. This European prestandard only identifies differences from, or supplements to, normal temperature design.

(2)P This document deals only with passive methods of fire protection. Active methods are not covered.

(3)P This European prestandard applies to structures which, for reasons of general fire safety, are required to avoid premature collapse of the structure in exposure to fire (load-bearing function).

(4)P This document only applies to structures or parts of structures which are within the scope of prENV 1999-1-1 and are designed accordingly.

(5)P The methods given in this document are applicable to any aluminium alloys specified in 3.1 (1).

(6)P The aluminium alloy properties given in this document apply to the following aluminium alloys:

| | | |
|---|---|---|
| EN AW-5052 | EN AW-5454 | EN AW-6063 |
| EN AW-5083 | EN AW-6061 | EN AW-6082 |

## 1.2 Distinction between Principles and Application Rules

(1) Depending on the character of the individual clauses, distinction is made in this Eurocode between Principles and Application Rules.

(2) The Principles comprise:

- general statements and definitions for which there is no alternative, as well as
- requirements and analytical models for which no alternative is permitted unless specifically stated.

(3) The Principles are identified by the letter P following the paragraph number.

(4) The Application Rules are generally recognised rules which follow the Principles and satisfy their requirements.

(5) It is permissible to use alternative design rules different from the Application Rules given in the Eurocode, provided that it is shown that the alternative rule accords with the relevant Principles and is at least equivalent with regard to the resistance, serviceability and durability achieved by the structure.

(6) In this Eurocode the Application Rules are identified by a number in brackets, as in this paragraph.

## 1.3 Normative references

(1)P This European prestandard 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 below. For undated references the latest edition of the publication referred to applies.

(2)P Normative reference is made to the following CEN standards:

| | |
|---|---|
| prEN 1363 | Fire resistance tests<br>Part 1 General requirements<br>Part 2 Alternative and additional procedures |
| ENV 1991-1: 1994 | Eurocode 1 - Basis of design and actions on structures - Part 1: Basis of design |
| ENV 1991-2-2: 1994 | Eurocode 1 - Basis of design and actions on structures -<br>Part 2-2: Actions on structures imposed to fire |
| ENV 1999-1-1: 1997 | Eurocode 9: Design of aluminium structures -<br>Part 1.1: General rules and rules for buildings |
| ENV 1999-2:1997 | Eurocode 9: Design of aluminium structures -<br>Part 2: Structures susceptible to fatigue |

NOTE: A- prENV "Fire test on elements of building construction" is under preparation. The following parts are of importance for this European prestandard:
Part 0 "Test method for determining the contribution to the fire resistance of structural members; general requirements of properties of fire protection materials"
Part 1 "Test method for determining the contribution to the fire resistance of structural members by protective membranes"

(3)P Normative reference is made to the following ISO standard:

ISO 1000:1981 "SI units"

## 1.4 Definitions

(1)P For the purpose of this European prestandard, the following definitions apply:

**configuration factor:** Solid angle within which the radiation environment can be seen from a particular point on the member surface, divided by $2\pi$.

NOTE: Information on configuration factors is given in Annex C

**convective heat transfer coefficient:** Convective heat flux to the member related to the difference between the bulk temperature of gas bordering the relevant surface of the member and the temperature of that surface.

**critical aluminium alloy temperature:** For a given load level, the temperature at which failure is expected to occur in an aluminium alloy element for an uniform temperature distribution.

**design fire:** A specified fire development assumed for design purposes.

**effective 0,2% proof strength:** For a given temperature, the stress level at which the stress-strain relationship of aluminium alloy is truncated to provide a (design) yield plateau.

**external member:** Member located outside the building, which may be exposed to fire through openings in the building enclosure.

**fire compartment:** A space within a building, extending over one or several floors, which is enclosed by separating members such that fire spread beyond the compartment is prevented during the relevant fire exposure.

**fire protection material:** A material which has been shown, by fire resistance tests in conformity with prENVs or ENVs

NOTE: See 1.3

to be capable of remaining in position and of providing adequate thermal insulation for the fire resistance period under consideration.

**fire resistance:** The ability of a member, a structure, or a part of a structure, to fulfil its required functions (load bearing function, and/or separating function) for a specified fire exposure.

**global structural analysis (in fire):** An analysis of the entire structure, when either all parts of the structure, or only certain parts of it, are exposed to fire. Indirect fire actions are considered throughout the structure.

**indirect fire actions:** Thermal expansions or thermal deformations causing forces and moments.

**load bearing function:** The ability of a structure or member to sustain actions during the relevant fire, according to stated criteria.

**member analysis (in fire):** The thermal and mechanical analysis of a structural member exposed to fire in which the member is considered as isolated, with appropriate support and boundary conditions. Indirect fire actions are not considered, except those resulting from thermal gradients.

**normal temperature design:** Ultimate limit state design at ambient temperature in accordance with Eurocode 9: Part 1-1 for the fundamental load combination.

**protected members:** Members for which measures are taken to reduce the temperature rise in the member due to fire.

**section factor:** For an aluminium alloy member with no protection or with contour protection, the ratio between the exposed surface area and the volume of aluminium; for an enclosed member, the ratio between the internal surface area of the exposed encasement and the volume of aluminium.

**standard fire exposure:** Exposure to furnace gases with a temperature which varies with time according to the standard temperature-time curve.

**standard fire resistance:** Fire resistance for the standard fire exposure for a stated period of time.

NOTE: Normally, standard fire resistance requirements are expressed in periods of time such as 30, 60 or more minutes.

**standard temperature time curve:** A nominal temperature-time curve in accordance with ENV 1991-2-2:1995.

NOTE: An expression for the standard temperature-time curve is given in ENV 1991-2-2:1995.

**structural members:** The load-bearing members of a structure, including bracings.

**sub-assembly analysis (in fire):** The structural analysis of parts of the structure exposed to fire, in which the respective part of the structure is considered as isolated, with appropriate support and boundary conditions. Indirect fire actions within the sub-assembly are considered, but not time-dependent interaction with other parts of the structure.

**temperature analysis:** The procedure of determining the temperature development in members on the basis of the thermal actions and the thermal material properties of the members and of the protective surfaces, where relevant.

**temperature-time curves:** Gas temperatures in the environment of member surfaces as a function of time.

They may be:

**nominal:** Conventional curves, adopted for classification or verification of fire resistance, e.g. the standard time-temperature curve.

**parametric:** Determined on the basis of fire models and the specific physical parameters defining the conditions in the fire compartment.

**thermal actions:** Actions on the structure described by the net heat flux to the members.

## 1.5 Symbols

(1)P Supplementary to ENV 1999-1-1, the following symbols are used:

| | |
|---|---|
| $A_M$ | is the surface area of a member per unit length ($m^2/m$) |
| $A_p$ | is the area of the inner surface of the fire protection material per unit length of the member ($m^2/m$) |
| $E_{al}$ | is the modulus of elasticity of aluminium alloy for normal temperature design (MPa) |
| $E_{al,\theta}$ | is the slope of the linear elastic part of the stress versus strain relation- ship for aluminium alloy at elevated temperature $\theta_{al}$. (MPa) |
| $E_{fi,d}$ | is the design effect of actions in the fire situation |
| $R_{d,\theta}$ | is the design resistance at uniform elevated material temperature |
| $R_{fi,d}$ | is the design resistance in the fire situation |
| $R_{fi,d,t}$ | is the design value of a resistance in the fire situation, at time t |
| $T$ | is the temperature (K) (cf $\theta$ temperature (°C)) |
| $V$ | is the volume of a member per unit length ($m^3/m$) |
| $X_{fi,d}$ | is the design material property in the fire situation |
| $X_k$ | is the characteristic value of a material property |
| $X_{k,\theta}$ | is the characteristic value of a material property at elevated temperature θ |
| $c$ | is the specific heat (J/kgK) |
| $d_p$ | is the thickness of fire protection material (m) |
| $f_{0.2}$ | is the proportional limit for aluminium alloy (MPa) |
| $f_{p,\theta}$ | is the proportional limit for aluminium alloy at elevated temperature $\theta_{al}$ (MPa) |
| $f_{y,\theta}$ | is the effective yield strength of aluminium alloy at elevated temperature $\theta_{al}$ (MPa) |
| $h_{net,d}$ | is the design value of the net heat flux per unit area ($W/m^2$) |
| $k_\theta$ | is the relative value of a strength or deformation property of aluminium at elevated temperature $\theta_{al}$ |
| $k_{0.2,\theta}$ | is the 0,2% proof stress ratio at elevated temperature $\theta_{al}$ |
| $l$ | is the length at 20 °C (m) |
| $\Delta l$ | is the temperature induced expansion (m) |
| $t$ | is the time in fire exposure (minutes) |
| $\Delta t$ | is the time interval (seconds) |
| $\eta_{fi}$ | is the reduction factor for design load level in the fire situation |
| $\theta$ | is the temperature (°C) (cf $t$ temperature (K)) |
| $\kappa$ | is the adaption factor |

$\lambda$ is the thermal conductivy (W/mK)
$\mu_0$ is the degree of utilisation at time $t = 0$
$\rho_{al}$ is the unit mass of aluminium (kg/m$^3$)

(2)P Supplementary to prENV 1999-1-1, the following subscripts are used:

*al* aluminium alloy
*c* connections
*fi* value relevant for the fire situation
*m* member
*p* fire protection material
*t* dependent on time
$\theta$ dependent on temperature

(3) Additional symbols are used in Annexes A to C. These are defined where they first occur.

## 1.6 Units

(I)P S.I. units shall be used in conformity with ISO 1000:1981.

# 2 Basic principles and rules

## 2.1 Performance requirements

(1)P Where mechanical resistance in the case of fire is required, aluminium alloy structures shall be designed and constructed in such a way that they may maintain their load bearing function during the relevant fire exposure-criterion "*R*".

(2)P Where compartmentation is required, the respective members shall be designed and constructed in such a way, that they maintain their separating function during the relevant fire exposure, i.e.:

- no integrity failure due to cracks, holes or other openings, which are large enough to cause fire penetration by hot gases or flames - criterion "*E*";
- no insulation failure due to temperatures of the non-exposed surface exceeding ignition temperatures - criterion "*I*".

(3) Criterion "*I*" may be assumed to be met where the average temperature rise during the standard fire exposure at the non-exposed surface does not exceed 140 °C and the maximum rise at any point on the non-exposed surface does not exceed 180 °C.

(4)P Members shall comply with criteria *R*, *E*, *I* as follows.

- separating only: *E* and *I*;
- load bearing only: *R*;
- separating and load bearing: *R*, *E* and *I*.

(5) When using general calculation methods (see 4.4), deformations need to be calculated where separating members or protective measures are affected by the deformation of the load bearing structures. Reference should be made to the relevant product specifications.

**Note:** This code deal only with the *R* - criterion. The material properties given in this code can be used when calculating temperatures for the *I* - criterion.

## 2.2 Actions

(1)P The thermal and mechanical actions shall be obtained from European prestandard (ENV 1991-2-2:1995).

(2) Where rules given in this European prestandard are valid only for the standard fire exposure, this is identified in the the relevant clauses.

## 2.3 Design values of material properties

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

- Thermal properties for thermal analysis:
  - if an increase of the property is favourable for safety:

$$X_{fi,d} = X_{k,\theta} / \gamma_{M,fi} \tag{2.1a}$$

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

$$X_{fi,d} = \gamma_{M,fi} \cdot X_{k,\theta} \tag{2.1b}$$

- Strength and deformation properties for structural analysis:

$$X_{fi,d} = k_\theta \cdot X_k / \gamma_{M,fi} \tag{2.1c}$$

where:

$X_{k,\theta}$ is the characteristic value of a material property in fire design, generally dependent on the material temperature, see Chapter 3

$X_k$ is the characteristic value of a strength or deformation property (generally $f_k$ or $E_k$) for normal temperature design to prENV 1999-1-1

$k_\theta$ is the reduction factor for a strength or deformation property ($X_{k,\theta}/X_k$), dependent on the material temperature, see 3.2.1.

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

(2)P For mechanical properties of aluminium alloy, the partial safety factor for the fire situation shall be taken as:

$\gamma_{M,fi} =$ $\boxed{1,0}$

(3)P For thermal properties of aluminium alloy, the partial safety factor for the fire situation shall be taken as:

$\gamma_{M,fi} =$ $\boxed{1,0}$

## 2.4 Assessment methods

### 2.4.1 General

(1)P The model of the structural system adopted for design to this European prestandard shall reflect the expected performance of the structure in fire exposure.

(2)P The structural analysis shall be performed using one of the following:

- global structural analysis, see 2.4.2
- analysis of sub-assemblies, see 2.4.3, or
- member analysis, see 2.4.4.

### 2.4.2 Global structural analysis

(1)P Global structural analysis for the fire situation shall be carried out, taking into account the relevant failure mode in fire exposure, the temperature-dependent material properties and member stiffness.

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

$$E_{fi,d,t} \leq R_{fi,d,t} \tag{2.2}$$

where:

$E_{fi,d,t}$ is the design effect of actions for the fire situation, determined in accordance with ENV 1991-2-2:1995 including the effects of thermal expansions and deformations

$R_{fi,d,t}$ is the corresponding design resistance at elevated temperatures.

### 2.4.3 Analysis of sub-assemblies

(I)P As an alternative to global structural analysis of the entire structure for various fire situations, structural analysis of sub-assemblies comprising appropriate portions of the structure may be carried out in accordance with 2.4.2.

(2) The internal forces and moments at supports and boundaries of sub-assemblies applicable at time $t = 0$ may be assumed to remain unchanged throughout the fire exposure.

(3) As an alternative to carrying out a global structural analysis for the fire situation at $t = 0$, the internal forces and moments at supports and boundaries of sub-assemblies may be obtained from a global structural analysis for normal temperature design by using.

$$E_{fi,d} = \eta_{fi} \cdot E_d \tag{2.3}$$

where:

$E_d$ is the design value of the corresponding internal forces or moment for normal temperature design, resulting from the fundamental combination given sec. 2.2.2.5 in prENV 1999-1-1

$\eta_{fi}$ is the reduction factor for the design load level for the fire situation.

(4) The reduction factor for the design load level for the fire situation $\eta_{fi}$ is given by:

$$\eta_{fi} = \frac{\gamma_{GA} \cdot G_k + \psi_{1,1} \cdot Q_{k,1}}{\gamma_G \cdot G_k + \gamma_{Q,1} \cdot Q_{k,1}} \tag{2.4}$$

where:

$Q_{k,1}$ is the principal variable load

$\gamma_{GA}$ is the partial factor for permanent actions in accidental design situation

$\psi_{1,1}$ is the combination factor for frequent values, see table 9.3 in ENV 1991-1: 1994

**Note:** Fig. 2.1 shows the variation of the reduction factor $\eta_{fi}$ with the load ratio $Q_{k,1}/G_k$ for different values of the factor $\psi_{1,1}$ for $\gamma_{GA} = 1,0$ with $\gamma_G = 1,35$ and $\gamma_Q = 1,5$.

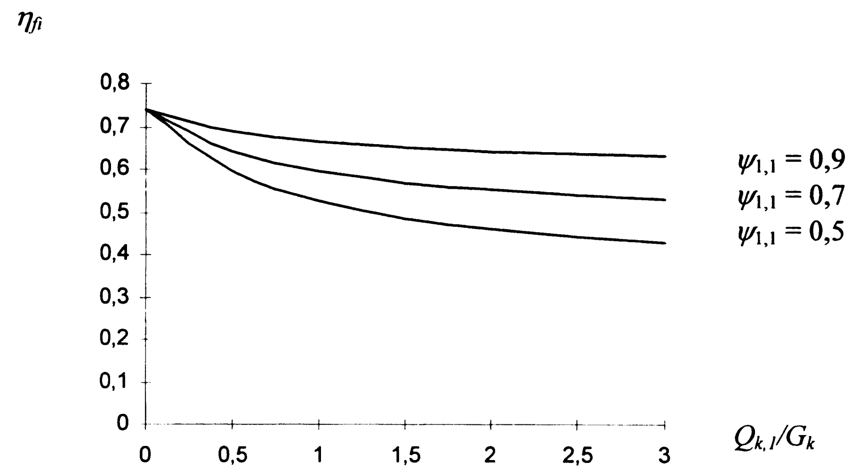



**Fig. 2.1 Variation of the reduction factor $\eta_{fi}$ with the load ratio $Q_{k,1}/G_k$.**

### 2.4.4 Member analysis

(1)P As an alternative to global structural analysis, individual members may be analysed for the fire situation. The restraint conditions at supports and ends of members applicable at time $t = 0$ may generally be assumed to remain unchanged throughout the fire exposure. Where different conditions apply, this is identified in the relevant provisions.

(2) The internal forces and moments at supports and ends of members applicable at time $t = 0$ may be assumed to remain unchanged throughout the fire exposure.

(3) As an alternative to carrying out a global structural analysis for the fire situation at time $t = 0$, the internal forces and moments at supports and ends of members may be obtained from a global structural analysis for normal temperature design by using expression (2.3).

(4) Only the effects of thermal deformations resulting from thermal gradients need be considered. The effects of thermal expansions of the members may be neglected.

### 2.4.5 Design assisted by testing

(I)P As an alternative to the use of calculation methods, design may be based on the results of tests.

# 3 Material properties

## 3.1 General

(1) The thermal and mechanical properties of aluminium alloys shall either be determined from the following or else in conformity with existing EN, prEN or ISO product standards.

(2) The thermal properties of fire protection materials shall be determined in conformity with existing EN, prEN or ISO product standards.

(3) The values of material properties given in prENV 1999-1-1 Section 3 shall be treated as characteristic values.

## 3.2 Mechanical properties of aluminium alloys

### 3.2.1 Strength properties

(1) The 0.2% proof strength of some aluminium alloys up to two hours thermal exposure to elevated temperature $f_{y,\theta}$ should be obtained from the stress ratio $k_{0.2,\theta}$ given in Table 3.1 and the 0.2% proof strength of the material at room temperature $f_{0.2}$ taken from Part 1-1 Section 3, where:

Effective 0.2% proof stress at temperature $\theta$: $f_{y,\theta} = k_{0.2,\theta}\ f_{0.2}$

(2) For intermediate values of aluminium temperature, linear interpolation may be used.

**Table 3.1. 0.2% proof stress ratios $k_{0.2,\theta}$ for aluminium alloys at elevated temperature for up to 2 hours thermal exposure period**

| Alloy | Temper | Aluminium alloy temperature °C | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 20 | 100 | 150 | 200 | 250 | 300 | 350 | 550 |
| EN AW-5052 | O | 1,00 | 1,00 | 0,96 | 0,82 | 0,68 | 0,48 | 0,23 | 0 |
| EN AW-5052 | H34 | 1,00 | 1,00 | 0,92 | 0,52 | 0,33 | 0,22 | 0,13 | 0 |
| EN AW-5083 | O | 1,00 | 1,00 | 0,98 | 0,90 | 0,75 | 0,42 | 0,22 | 0 |
| EN AW-5083 | H113 | 1,00 | 1,00 | 0,89 | 0,78 | 0,63 | 0,47 | 0,29 | 0 |
| EN AW-5454 | O | 1,00 | 1,00 | 0,96 | 0,88 | 0,50 | 0,32 | 0,21 | 0 |
| EN AW-5454 | H32 | 1,00 | 1,00 | 0,92 | 0,78 | 0,36 | 0,23 | 0,14 | 0 |
| EN AW-6061 | T6 | 1,00 | 1,00 | 0,92 | 0,79 | 0,62 | 0,32 | 0,10 | 0 |
| EN AW-6063 | T6 | 1,00 | 1,00 | 0,90 | 0,74 | 0,38 | 0,20 | 0,10 | 0 |
| EN AW-6082 | T6 | 1,00 | 1,00 | 0,79 | 0,65 | 0,38 | 0,20 | 0,11 | 0 |

(3) The 0.2% proof strength of some aluminium alloys, not covered in Table 3.1a of prENV 1999-1-1 Section 3, up to two hours thermal exposure to elevated temperature should be obtained from the stress ratio $k_{0.2,\theta}$ given in Annex A and the 0.2% proof strength of the material at room temperature $f_{0.2}$ taken from the Normative References given in prENV 1999-1-1 Section 3, where:

Effective 0.2% proof stress at temperature $\theta$: $f_{y,\theta} = k_{0.2,\theta}\ f_{0.2}$

### 3.2.2 Modulus of Elasticity

(1)The modulus of elasticity of all aluminium alloys after two hours thermal exposure to elevated temperature $E_{al,\theta}$ should be obtained from Table 3.2.

**Table 3.2. Modulus of Elasticity of Aluminium Alloys at elevated temperature for a two hour thermal exposure period, $E_{al,\theta}$ .**

| Aluminium alloy temperature, $\theta$(°C) | Modulus of Elasticity, $E_{al,\theta}$ (N/mm²) |
|---|---|
| 20 | 70 000 |
| 50 | 69 300 |
| 100 | 67 900 |
| 150 | 65 100 |
| 200 | 60 200 |
| 250 | 54 600 |
| 300 | 47 600 |
| 350 | 37 800 |
| 400 | 28 000 |
| 550 | 0 |

### 3.2.3 Unit Mass

(1)The unit mass of aluminium alloys $\rho_{al}$ should be considered independent of aluminium temperature. The following value should be taken.

$\rho_{al} = 2700$ kg/m$^3$

## 3.3 Thermal properties of aluminium alloys.

### 3.3.1 Thermal elongation

(1)P The thermal elongation of aluminium alloys, $\Delta l/l$ , should be determined from the following:

for 0 °C < $\theta_{al}$ < 500 °C

$$\Delta l/l = 0{,}1 \cdot 10^{-7}\, \theta_{al}^2 + 22{,}5 \cdot 10^{-6}\, \theta_{al} - 4{,}5 \cdot 10^{-4}$$

where:

$l$ : is the length at 20 °C
$\Delta l$ : is the temperature induced expansion
$\theta_{al}$ : is the aluminium alloy temperature (°C)

(2) The variation in the thermal elongation is illustrated in figure 3.1

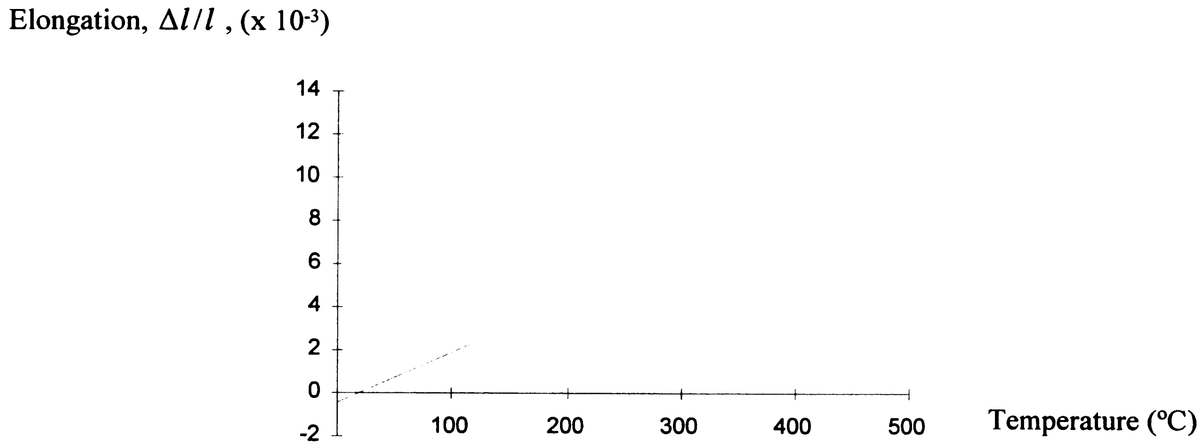



**Figure 3.1 Thermal elongation of aluminium alloys as a function of the temperature.**

(3)P In simple calculation methods the relationship between thermal elongation and aluminium alloy temperature may be consider to be linear. In this case the elongation may be determined from:

$$\frac{\Delta l}{l} = 2{,}5 \cdot 10^{-5}(\theta_{al} - 20)$$

### 3.3.2 Specific heat

(1)P The specific heat of aluminium, $c_{al}$, should be determined from the following:

for 0 °C < $\theta_{al}$ < 500 °C

$$c_{al} = 0{,}41 \cdot \theta_{al} + 903 \text{ (J/kg °C)}$$

where:

$\theta_{al}$ is the aluminium alloy temperature

(2) The variation in specific heat is illustrated in figure 3.2

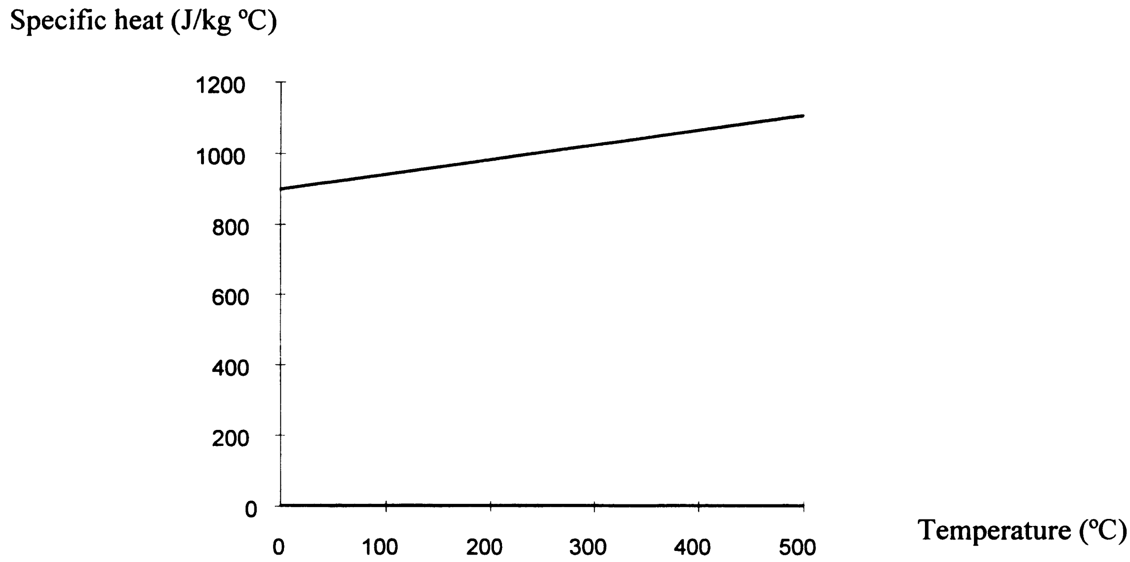



**Figure 3.2 Specific heat of aluminium alloys as a function of the temperature.**

### 3.3.3 Thermal conductivity

(1)P The thermal conductivity of aluminium alloy, $\lambda_{al}$, for 0 °C < $\theta_{al}$ < 400 °C should be determined from the following:

for alloys in 1000, 3000 and 6000 series:

$$\lambda_{al} = 0{,}07 \cdot \theta_{al} + 190 \quad \text{(W/m°C)}$$

for alloys in 2000, 4000, 5000 and 7000 series:

$$\lambda_{al} = 0{,}1 \cdot \theta_{al} + 140 \quad \text{(W/m°C)}$$

where:

$\theta_{al}$ : is the aluminium alloy temperature

(2) The variation of the thermal conductivity is illustrated in figure 3.3

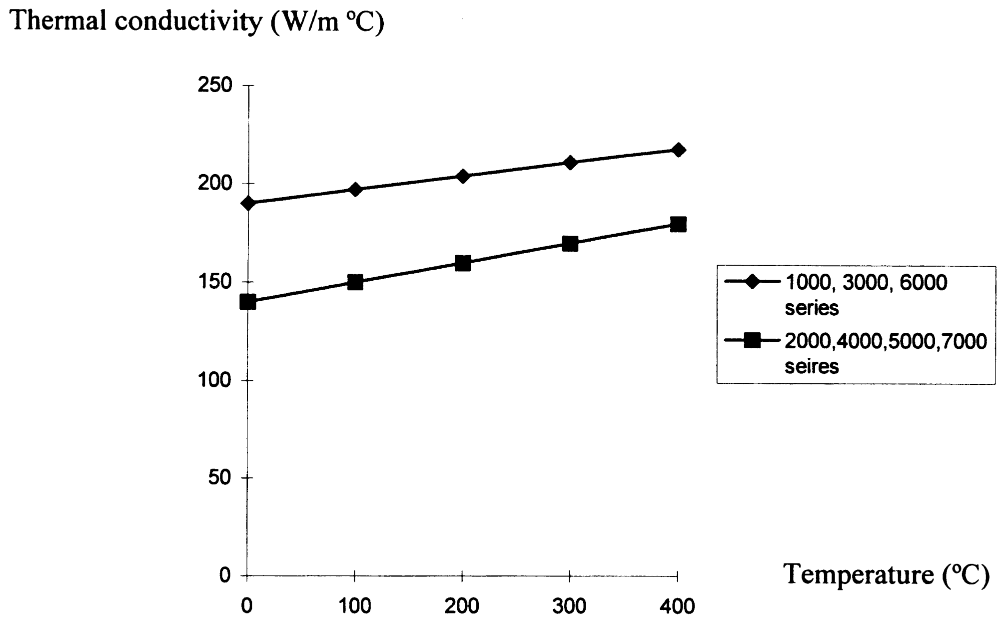



**Figure 3.3 Thermal conductivity as a function of the temperature.**

## 3.4 Fire protection materials

(1) The properties and performance of fire protection materials shall be assessed using the test procedures given in prENs or ENs (when available).

NOTE: It is assumed that these standards will include a requirement that the fire protection materials shall remain coherent and cohesive to their supports throughout the relevant fire exposure. If not, this item will be reviewed.

# 4 Structural fire design

## 4.1 General

(1)P Aluminium alloy structures can be insulated by fire protection material, protected by heat screens or other method which limits the temperature rise of the aluminium alloy element.

(2)P The assessment of structural behaviour in a fire design situation shall be based on one of the following methods, or on a combination of them:

- simple calculation method applied to individual members
- general calculation methods

(3)P Simple calculation methods are simplified methods which give conservative results.

(4)P General calculation methods are methods in which engineering principles are applied in a realistic manner to specific applications.

(5)P Where no simple calculation rule is given, it is necessary to use either a method based on test results or a general calculation method.

## 4.2 Simple calculation models

### 4.2.1 General

(1)P The load-bearing function of an aluminium alloy structure or structural member may be assumed to be maintained after a time *t* in a given fire if:

$E_{fi,d} \leq R_{fi,d,t}$

where:

$E_{fi,d}$ is the design effect of actions for the fire design situation, determined in accordance with ENV 1991-2-2, (the internal forces and moments $M_{fi,Ed}$, $N_{fi,Ed}$, $V_{fi,Ed}$ individually or in combination);

$R_{fi,d,t}$ is the design resistance of the aluminium alloy structure or structural member, for the fire design situation, at time *t*, ($M_{fi,t,Rd}$, $M_{b,fi,t,Rd}$, $N_{fi,t,Rd}$, $V_{fi,t,Rd}$ individually or in combination).

(2)P $R_{fi,d,t}$ shall be determined for the temperature distribution in the structural members at time *t* by modifying the design resistance for normal temperature design, determined from prENV 1999-1-1, to take account of the mechanical properties of aluminium alloys at elevated temperature, see 3.2.1 and 3.2.2

### 4.2.2 Resistance

**Note**: In this section the symbol for design resistance becomes $M_{Rd}$, $N_{Rd}$, $V_{Rd}$ depending on whether the effect of actions concerned is bending moment, axial force or shear force respectively.

#### 4.2.2.1 Classification of cross-sections

(1)P In a fire design situation, the classification of cross-sections can be classified as for normal temperature design according to 5.4 in prENV 1999-1-1, without any changes.

#### 4.2.2.2 Tension members

(1)P The design resistance $N_{fi,t,Rd}$ of a tension member with a non uniform temperature distribution over the cross section at time $t$ may be determined from:

$$N_{fi,t,Rd} = \sum A_i k_{0,2,\theta,i} f_{0,2} / \gamma_{M,fi} \tag{4.2}$$

where:

$A_i$ is an elemental area of the net cross-section with a temperature $\theta_i$, including a deduction when required to allow for the effect of HAZ softening. The deduction is based on the reduced thickness of $k_{HAZ} \cdot t$;

$k_{0,2,\theta,i}$ is the reduction factor for the effective 0.2% proof stress at temperature $\theta_i$. $\theta_i$ is the temperature in the elemental area $A_i$.

(2)P The design resistance $N_{fi,\theta,Rd}$ of a tension member with a uniform temperature $\theta_{al}$ should be determined from:

$$N_{fi,\theta,Rd} = k_{0,2,\theta}\, N_{Rd}\, (\gamma_{M1}/\gamma_{M,fi})$$

where:

$k_{0,2,\theta}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature $\theta_{al}$ see 3.2.1;

and $N_{Rd}$ is the design resistance of the net section for normal temperature design according to ENV 1999-1-1.

(3) It may be assumed that the clauses in 4.2.2.1 are satisfied for a tension member if at time $t$ the aluminium alloy temperature $\theta_{al}$ at all cross-sections is not more than 170 °C.

#### 4.2.2.3 Beams

(1) The design moment resistance $M_{fi,t,Rd}$ of a cross-section in class 1 or 2 with a non uniform temperature distribution at time $t$ may be determined from:

$$M_{fi,t,Rd} = \sum A_i\, z_i\, k_{0.2,\theta,i} f_{0.2} / \gamma_{M,fi} \tag{4.4}$$

where:

$A_i$ is an elemental area of the net cross-section with a temperature $\theta_i$, including a deduction when required to allow for the effect of HAZ softening. The deduction is based on the reduced thickness of $k_{HAZ} \cdot t$, according to ENV 1999-1-1;

$z_i$ is the distance from the plastic neutral axis to the centroid of the elemental area $A_i$;

$k_{0,2,\theta,i} f_{0,2}$ is the strength of the elemental area $A_i$ at temperature $\theta_{al}$.

(2)P The plastic neutral axis of cross-section with a non uniform temperature distribution is that axis perpendicular to the plane of bending which satisfies the following criterion:

$$\sum A_i\, k_{0,2,\theta,i} f_{0,2,i} = 0 \tag{4.5}$$

(3)P The design moment resistance $M_{fi,t,Rd}$ of a cross-section in class 3 with a non-uniform temperature distribution at time $t$ may be determined from:

$$M_{fi,t,Rd} = M_{fi,\theta,Rd} \tag{4.6}$$

where:

$M_{fi,\theta,Rd}$ is the design moment resistance of the cross section for a uniform temperature $\theta_{al}$ equal to the maximum temperature $\theta_{al,max}$ reached at time t.

(4)P The design $M_{fi,t,Rd}$ of a cross-section in class 4 with a non-uniform temperature distribution at time $t$ may be determined from:

$$M_{fi,t,Rd} = k_{0,2,\theta max}\, M_{Rd}\, (\gamma_{M1}/\gamma_{M,fi}) \tag{4.7}$$

where:

$k_{0,2,\theta max}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature $\theta_{al}$ equal to the maximum temperature $\theta_{al,max}$ of the cross section reached at time $t$;

and $M_{Rd}$ is the moment resistance of the cross-section for normal temperature design for class 4 according to ENV 1999-1-1.

(5)P The design $M_{fi,t,Rd}$ of a cross-section in class 1, 2, 3 or 4 with a uniform temperature distribution at time $t$ may be determined from:

$$M_{fi,t,Rd} = k_{0,2,\theta}\, M_{Rd}\, (\gamma_{M1}/\gamma_{M,fi}) \tag{4.8}$$

where:

$k_{0,2,\theta}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature $\theta_{al}$ see 3.2.1.

and $M_{Rd}$ is the moment resistance of the cross-section for normal temperature design.

(6) For beams subjected to lateral-torsional buckling, the design buckling resistance moment $M_{b,fi,t,Rd}$ of a laterally unrestrained beam at time $t$ may be determined using:

$$M_{b,fi,t,Rd} = k_{0,2,\theta,max}\, M_{b,Rd}\, (\gamma_{M1}/\gamma_{M,fi}) \tag{4.9}$$

where:

$k_{0,2,\theta,max}$ is the 0,2% proof stress ratio of aluminium alloy at temperature $\theta_{al}$ equal to the maximum aluminium alloy temperature $\theta_{al,max}$.

$M_{b,Rd}$ is the design buckling resistance moment for normal temperature design, according to ENV 1999-1-1.

(7) The design shear resistance $V_{fi,t,Rd}$ of a beam at time *t* may be determined from:

$$V_{fi,t,Rd} = k_{0,2,\theta}\, V_{Rd}\, (\gamma_{M1}/\gamma_{M,fi}) \quad (4.10)$$

where:

$k_{0,2,\theta}$ is the 0,2% proof stress ratio for the aluminium alloys strength at temperature $\theta_{al}$, . $\theta_{al}$ is the max temperature of that part of the cross section which carrie the shear force.

$V_{Rd}$ is the shear resistance of the net cross-section for normal temperature design, according to ENV 1999-1-1.

(8) It may be assumed that the clauses in 4.2.2.3 are satisfied for a beam if at time *t* the aluminium alloy temperature $\theta_{al}$ at all cross-sections is not more than 170 °C.

### 4.2.2.4 Columns

(1)P The design buckling resistance $N_{b,fi,t,Rd}$ of a compression member at time *t* may be determined from:

$$N_{b,fi,t,Rd} = k_{0,2,\theta,max}\, N_{b,Rd}\, (\gamma_{M1}/1{,}2\gamma_{M,fi}) \quad (4.10)$$

where:

$N_{b,Rd}$ is the buckling resistance for normal temperature design according to prENV 1999-1-1 .

$k_{0.2,\theta max}$ is the 0,2% proof stress ratio of aluminium alloy at temperature $\theta_{al}$ equal to the maximum aluminium alloy temperature $\theta_{al,max}$.

**Note**: The constant 1,2 in this expression is a reduction factor of the design resistance due to the temperature dependent creep of aluminium alloys.

(2) For the determination of the slenderness ratio the provisions of prENV 1999-1-1 apply.

(3) Column lengths in non-sway frames continuosly or semi-continously connected to column lengths in other compartments, may be considered to be completely fixed in direction at such connections, provided that the resistance to fire of the building components which seperate the fire compartments concerned is at least equal to the fire resistance of the column.

(4)P The design buckling resistance $R_{fi,t,d}$ of a member subjected to combined bending and axial compression at time *t* may be determined from:

$$R_{fi,t,d} = k_{0.2,\theta max}\, R_d \quad (4.11)$$

where:

$R_d$ represent a combination of axial compression and bending moments $N_{fi,Ed}$, $M_{y,fi,Ed}$, and $M_{z,fi,Ed}$ such that for normal temperature design the provisions in prENV 1999-1-1 for all types of members are satisfied when:

$$N_{Sd} = 1{,}2\, N_{fi,Ed}$$
$$M_{y,Sd} = M_{y,fi,Ed}$$
$$M_{z,Sd} = M_{z,fi,Ed}$$

(5) It may be assumed that the clauses of 4.2.2.4 are satisfied for a column if at time *t* the aluminium alloy temperature $\theta_{al}$ at all cross-sections is not more than 170 °C.

#### 4.2.2.5 Connections

(1)P The resistance of connections between members need not be checked provided that the thermal resistance $(d_p/\lambda_p)_c$ of the fire protection of the connection is not less than the minimum value of the thermal resistance $(d_p/\lambda_p)_M$ of the fire protection of any of the aluminium alloy members joined by that connection:

where:

$d_p$ is the thickness of the fire protection material

$\lambda_p$ is the effective thermal conductivity of the fire protection material.

(2) For welded connections the reduced strength in the heat affected zones must be taken into account.

### 4.2.3 Aluminium alloy temperature development

#### 4.2.3.1 Unprotected internal aluminium alloy members.

(1) For an equivalent uniform temperature distribution in the cross-section, the increase of temperature $\Delta\theta_{al(t)}$ in an unprotected member during a time interval $\Delta t$ should be determined from:

$$\Delta\theta_{al(t)} = \frac{1}{c_{al} \cdot \rho_{al}} \cdot \frac{A_m}{V} \cdot \dot{h}_{net,d} \cdot \Delta t$$

where:

$c_{al}$ is the specific heat of aluminium alloys, see 3.3.2 (J/kg °C)
$\rho_{al}$ is the unit mass of aluminium (kg/m³)
$A_m/V$ is the section factor for unprotected aluminium alloy members ($m^{-1}$)
$A_m$ is the exposed surface area of the member per unit length (m²/m)
$V$ is the volume of the member per unit length (m³/m)
$\dot{h}_{net,d}$ is the design value of the net heat flux per unit area, see (2)
$\Delta t$ is the time interval (seconds)

(2) The values of $h_{net,d}$ should be obtained from ENV 1991-2-2:1995 using:

$\varepsilon_m$ = | 0,3 | for clean uncovered surfaces and

$\varepsilon_m$ = | 0,7 | for painted and covered (e.g. sooted) surfaces,

where $\varepsilon_m$ and $\varepsilon_{res}$ are defined in ENV 1991-2-2:1995.

(3) The value of $\Delta t$ should not be taken as more than 5 seconds.

(4) The value of the shape factor $A_m/V$ should not be taken as less than 10 $m^{-1}$.

(5) When calculating the exposed surface area of the member, $A_m$, grooves with gap in the surface less than 20 mm should not be included in the exposed surface area. See fig. 4.1.

(6) Some design values of the section factor $A_m/V$ for unprotected aluminium alloy members are given in table 4.1.

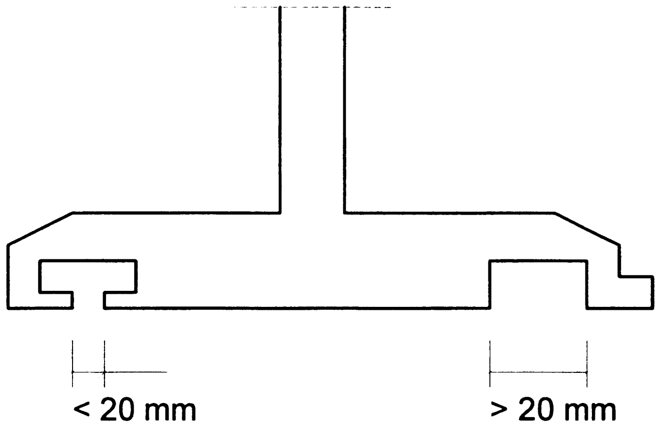
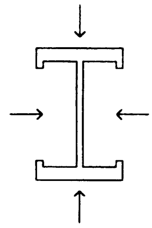
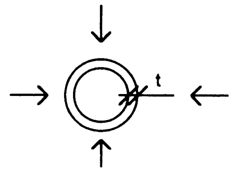
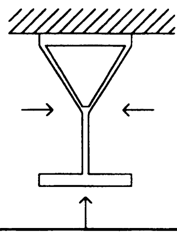
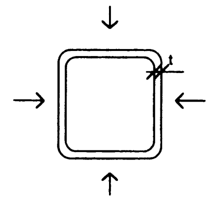
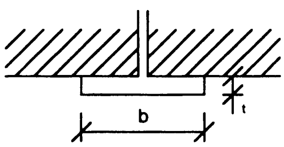
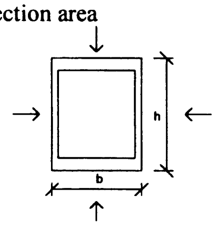
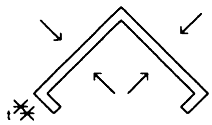
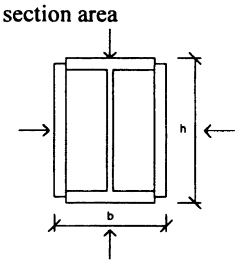
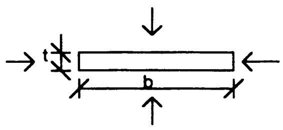
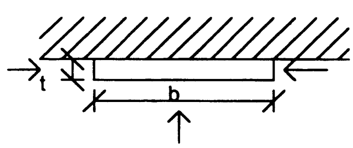



**Fig. 4.1 Grooves with gap in the surface < 20 mm, area of groove not to be included in the area of the exposed surface. Grooves with gap in the surface > 20 mm, area of the groove to be included in the area of the exposed surface.**

**Table 4.1 Section factor $A_m/V$ for unprotected structural aluminium alloy members when using the lumped mass method.**

| | |
|---|---|
| Open section exposed to fire on all sides:<br>$\frac{A_m}{V} = \frac{\text{perimeter}}{\text{cross-section area}}$<br> | Tube exposed to fire on all sides:<br>$\frac{A_m}{V} = \frac{1}{t}$<br><br> |
| Open section exposed to fire on three sides:<br>$\frac{A_m}{V} = \frac{\text{surface exposed to fire}}{\text{cross-section area}}$<br> | Hollow section (or welded box section of uniform thickness) exposed to fire on all sides:<br>If $t << b$: $A_m/V = 1/t$<br><br> |
| I section flange exposed to fire on three sides:<br>$A_m/V = (b + 2t_f)/(b\ t_f)$<br>If $t << b$: $A_m/V = 1/t_f$<br><br> | Box section exposed to fire on all sides:<br>$\frac{A_m}{V} = \frac{2(b + h)}{\text{cross-section area}}$<br><br> |
| Angle (or any open section of uniform thickness) exposed to fire on all sides:<br>$A_m/V = 2/t$<br><br> | I section with box reinforcement, exposed to fire on all sides:<br>$\frac{A_m}{V} = \frac{2(b + h)}{\text{cross-section area}}$<br><br> |
| Flat bar exposed to fire on all sides:<br>$A_m/V = 2(b + t)/(b\ t)$<br>If $t << b$: $A_m/V = 2/t$<br><br> | Flat bar exposed to fire on three sides:<br>$A_m/V = (b + 2\ t)/(b\ t)$<br>If $t << b$: $A_m/V = 1/t$<br><br> |

#### 4.2.3.2 Internal aluminium alloy structures insulated by fire protection material.

(1) For a uniform temperature distribution in a cross-section, the temperature increase $\Delta\theta_{al(t)}$ in an insulated member during a time interval $\Delta t$ should be obtained from:

$$\Delta\theta_{al(t)} = \frac{\lambda_p/d_p}{c_{al}\cdot\rho_{al}}\cdot\frac{A_p}{V}\left[\frac{1}{1+\phi/3}\right](\theta_t - \theta_{al})\Delta t - \left(e^{\phi/10} - 1\right)\Delta\theta_{(t)}$$

but $\Delta\theta_{al(t)} \geq 0$

in which:

$$\phi = \frac{c_p\rho_p}{c_{al}\rho_{al}} d_p \frac{A_p}{V}$$

where:

$A_p/V$ is the section factor for aluminium alloy members insulated by fire protection material ($m^{-1}$)

$A_p$ is the area of the inner surface of the fire protection material, per unit length of the member ($m^2/m$)

is the volume of the member per unit length ($m^3/m$)

$c_{al}$ is the specific heat of aluminium alloys, see 3.3.2 (J/kg °C)

$c_p$ is the specific heat of the fire protection material, see 3.4 (J/kg °C)

$d_p$ is the thickness of the fire protection material (m)

$\Delta t$ is the time interval (seconds)

$\theta_{(t)}$ is the ambient gas temperature at time $t$ (°C)

$\theta_{al(t)}$ is the aluminium temperature at time $t$ (°C)

$\Delta\theta_{(t)}$ is the increase of the ambient temperature during the time interval $\Delta t$ (°C)

$\lambda_p$ is the thermal conductivity of the fire protection material, see 3.4 (W/m °C)

$\rho_{al}$ is the unit mass of aluminium alloys ($kg/m^3$)

$\rho_p$ is the unit mass of the fire protection material, see 3.4 ($kg/m^3$)

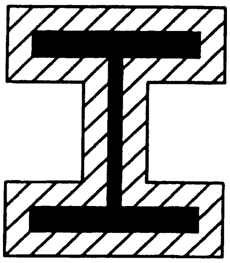
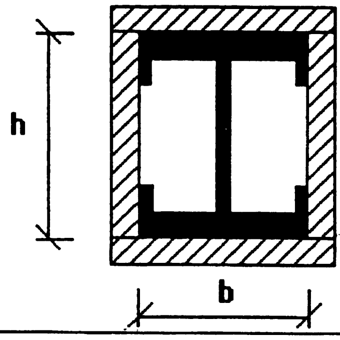
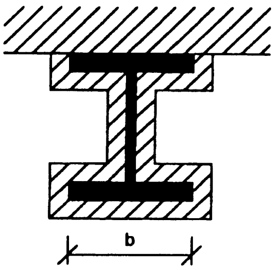
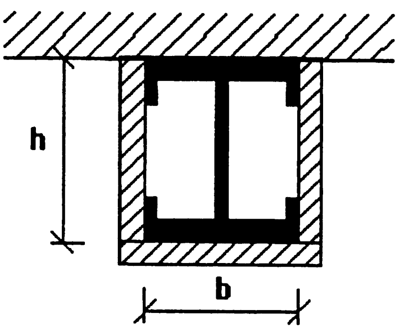
(2) The value of $\Delta t$ should not be taken as more than 30 seconds.

(3) Some design values of the section factor $A_p/V$ for insulated aluminium alloy members are given in table 4.2.

(4) For moist fire protection materials the calculation of the aluminium alloy temperature increase $\Delta\theta_{al(t)}$ may be modified to allow for a time delay in the rise of the aluminium alloy temperature when it reaches 100 °C. This delay time should be determined by a method conforming with a prENV or ENV (when available).

NOTE: See 1.3 and 3.4

**Table 4.2 Section factor $A_p/V$ for structural aluminium alloy members insulated by fire protection materials when using the lumped mass method.**

| Sketch | Description | Section factor $(A_p/V)$ |
|---|---|---|
|  | Contour encasement of uniform thickness. | $\dfrac{\textit{aluminium perimeter}}{\textit{aluminium cross - section area}}$ |
|  | Hollow encasement of uniform thickness. | $\dfrac{2\,(b + h)}{\textit{aluminium cross - section area}}$ |
|  | Contour encasement of uniform thickness, exposed to fire on three sides. | $\dfrac{\textit{aluminium perimeter} - b}{\textit{aluminium cross - section area}}$ |
|  | Hollow encasement of uniform thickness, exposed to fire on three sides. | $\dfrac{2h + b}{\textit{aluminium cross - section area}}$ |

#### 4.2.3.3 Internal aluminium alloy structures in a void which is protected by heat screens.

(1)P The provisions given below apply to both of the following cases:

- aluminium alloy members in a void which is bordered by a floor on top and by a horizontal heat screen below

- aluminium alloy members in a void which is bordered by vertical heat screens on both sides.

(2)P The properties and performance of the heat screens shall be determined using a test procedure conforming with a prENV, ENV, prEN or EN.

NOTE: See 1.3

(3)P The temperature development in the void in which the aluminium alloy members are situated shall be determined from a standard fire test conforming with a prENV, ENV, prEN or EN,

NOTE: See 1.3

or calculated using an approved method.

(4) For internal aluminium alloy structures protected by heat screens, the calculation of the aluminium alloy temperature increase $\Delta\theta_{al}$ should be based on the methods given in 4.2.3.1 or 4.2.3.2 as appropriate, taking the ambient gas temperature $\theta_t$ as equal to the gas temperature in the void.

(5) Values of the heat transfer coefficients $\alpha_c$ and $\alpha_r$ determined from tests conforming with a prENV, ENV, prEN or EN

NOTE: See 1.3

may be used in the calculation of $\Delta\theta_{al}$ as an alternative to the values given in Eurocode 1: Part 2.2.

#### 4.2.3.4 External aluminium alloy structures.

(1)P The temperature in external aluminium alloy structures shall be determined taking into account:

- the radiative heat flux from the fire compartment

- the radiative heat flux and the convection heat flux from flames emanating from openings

- the radiative and convective heat loss from the aluminium alloy structure to the ambient atmosphere

- the sizes and locations of the structural members.

(2)P Heat screens may be provided on one, two or three sides of an external aluminium alloy member in order to protect it from radiative heat transfer.

(3) Heat screens should be either:

- directly attached to that side of the aluminium alloy member which they are intended to protect, or

- large enough to fully screen this side from the expected radiative heat flux.

(4) Heat screens should have a integrity which corresponds to the fire resistance required for the aluminium alloy member.

(5) The temperature in external aluminium alloy structures protected by heat screens should be determined as specified in (1), assuming that there is no radiative heat transfer to those sides which are protected by heat screens.

(6) Calculations may be based on steady state conditions resulting from a stationary heat balance using the methods given in Annex B.
(7) Design using Annex B should be based on the model given in Eurocode 1: Part 2.2 describing the compartment fire conditions and the flames emanating from openings, on which the calculation of the radiative and convective heat fluxes should be based.

## 4.3 General calculation methods

### 4.3.1 Basis

(1)P General calculation methods may be used for individual members; for sub-assemblies or for entire structures.

(2)P General calculation methods may be used with any type of cross-section.

(3)P General calculation methods shall provide a realistic analysis of structures exposed to fire. They shall be based on 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.

(4)P General calculation methods may include separate calculation models for the determination of:

a) the development and distribution of the temperature within structural members (thermal response model)
b) the mechanical behaviour of the structure or of any part of it (mechanical response model).

(5)P Any potential failure modes not covered by the general calculation method (including local buckling and failure in shear) shall be eliminated by appropriate means.

(6)P General calculation methods may be used in association with any heating curve, provided that the material properties are known for the relevant temperature range.

(7)P The validity of any specific general calculation method for a particular situation shall be agreed between the client, the designer and the competent authority.

### 4.3.2 Thermal response

1 (P) General calculation methods for thermal response shall be based on the acknowledged principles and assumptions of the theory of heat transfer.

2 (P) The thermal response model shall consider:

- the relevant thermal actions specified in ENV 1991-2-2:1995
- the variation of the thermal properties of the material with the temperature, see 3.3

(3) The effects of non-uniform thermal exposure and heat transfer to adjacent building components may be included where appropriate.

(4) The influence of any moisture content and of any migration of the moisture within the fire protection material may conservatively be neglected.

### 4.3.3 Mechanical response

(1)P General calculation methods for mechanical response shall be based on the acknowledged principles and assumptions of the theory and structural mechanics, taking into account the changes of mechanical properties with temperature.

(2)P The effects of thermally induced strains and stresses both due to temperature rise and due to temperature differentials, shall be considered.

(3)P Where relevant, the mechanical response of the model shall also take account of:

- the combined effects of mechanical actions, geometrical imperfections and thermal actions
- the temperature dependent mechanical properties of the material, see 3.2.
- geometrical non-linear effects
- the effects of non-linear material properties, including the beneficial effects of loading and unloading on the structural stiffness
- the transient time thermal dependent creep.

(4)P The deformations at ultimate limit state implied by the calculation methods shall be limited as necessary to ensure that compatibility is maintained between all parts of the structure.

(5) If necessary, the design should be based on the ultimate limit state beyond which the calculated deformations of the structure would cause failure due to the loss of adequate support to one of the members.

# Annex A (informative)

# Properties of aluminium alloys not listed in ENV 1999-1-1

**Table A.1. 0.2% proof stress ratios $k_{0.2,\theta}$ for aluminium alloys at elevated temperature for a 2 hour exposure period.**

| Alloy | Temper | Temperature °C | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 20 | 100 | 150 | 200 | 250 | 300 | 350 |
| EN AW-3003 | O | 1,00 | 1.00 | 0.90 | 0.79 | 0.64 | 0.46 | 0.38 |
| EN AW-3003 | H14 | 1,00 | 1,00 | 0.76 | 0.51 | 0.26 | 0.16 | 0.10 |
| EN AW-5086 | O | 1,00 | 1,00 | 0.89 | 0.78 | 0.63 | 0.47 | 0.29 |
| EN AW-5086 | H112 | 1,00 | 1.00 | 0.99 | 0.91 | 0.73 | 0.46 | 0.30 |
| EN AW-7075 | T6 | 1,00 | 1,00 | 0.79 | 0.43 | 0.24 | 0.16 | 0,10 |

As a first order approximation the values of $k_{0,2,\theta}$ for alloy EN AW-3003 may be used for alloy EN AW-3103.

# Annex B (informative)

# Heat transfer to external aluminium structures.

## B.1 General

### B.1.1 Basis

(1) In this Annex B, the fire compartment is assumed to be confined to one storey only. All windows or other similar openings in the fire compartment are assumed to be rectangular.

(2) Annex C of ENV 1991-2-2:1995 should be used to determine the temperature of the compartment fire, the dimensions and temperatures of the flames projecting from the openings, and the radiation and convection parameters.

(3) A distinction should be made between members not engulfed in flame and members engulfed in flame, depending on their locations relative to the openings in the walls of the fire compartment.

(4) A member which is not engulfed in flame should be assumed to receive radiative heat transfer from all the openings in that side of the fire compartment and from the flames projecting from all these openings.

(5) A member which is engulfed in flame should be assumed to receive convective heat transfer from the engulfing flame, plus radiative heat transfer from the engulfing flame and from the fire compartment opening from which it projects. The radiative heat transfer from other flames and from other openings may be neglected.

### B.1.2 Member dimensions and faces

(1) The convention used for the dimensions $d_1$ and $d_2$ of a member and the notation used to identify its four faces are indicated in figure B.1.

### B.1.3 Heat balance

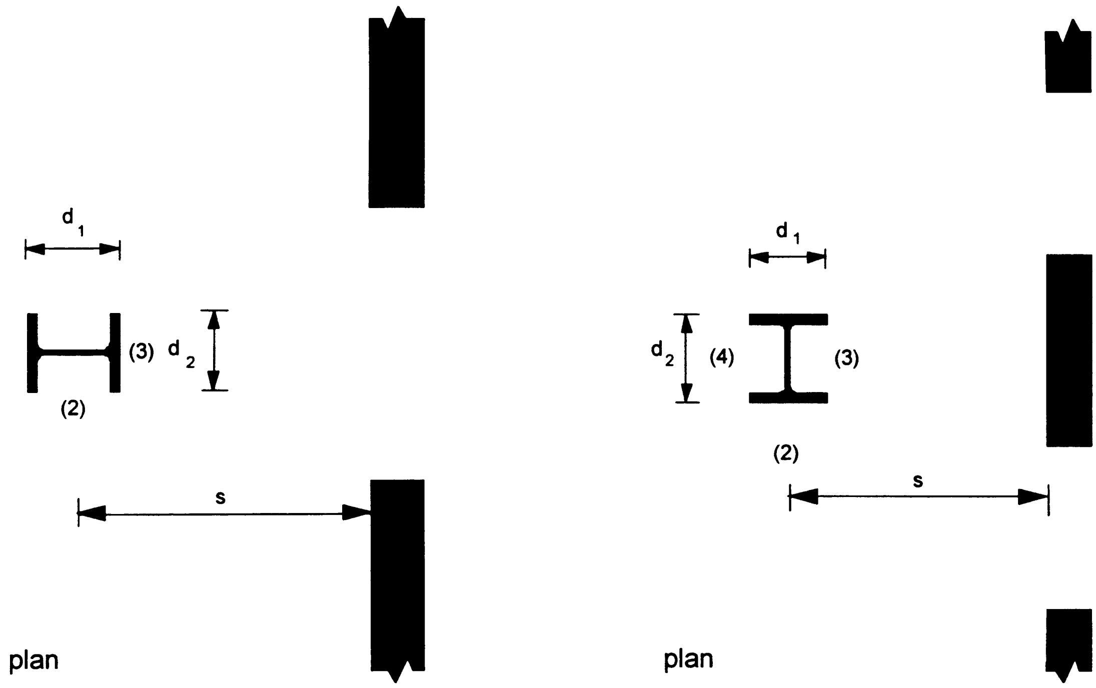
(1) For a member not engulfed in flame, the average temperature of the member $T_M$ [K] should be determined from the solution of the following heat balance:

$$\sigma T_M^4 + \alpha T_M = \Sigma I_z + \Sigma I_f + 293\alpha \qquad \text{(B.1)}$$

where:

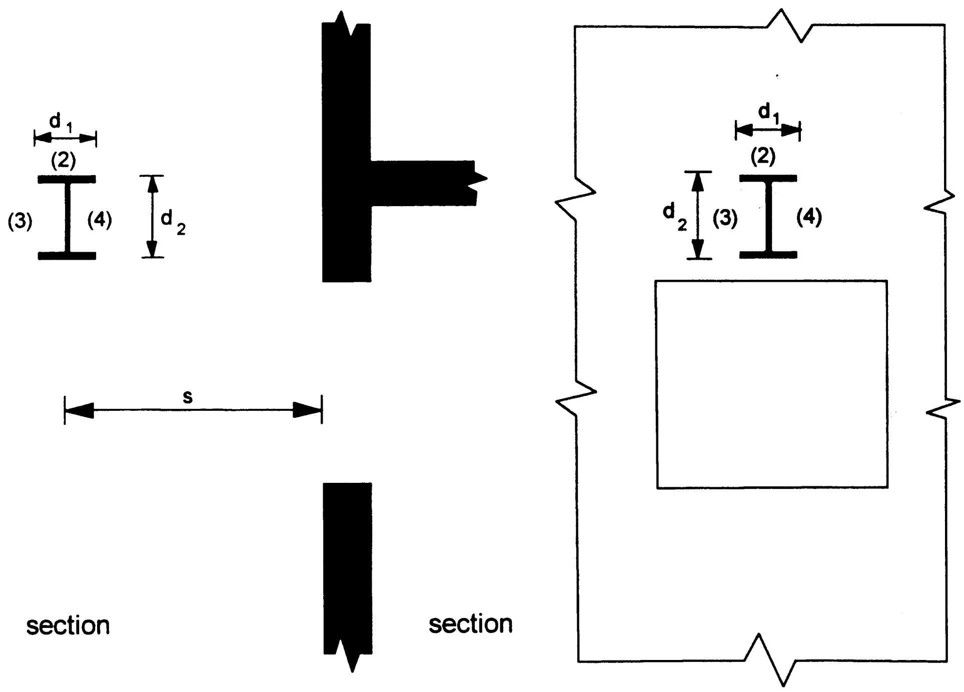
$\sigma$ is the Stefan Boltzmann constant [56,7 x $10^{-12}$ kW/m$^2$K$^4$];
$\alpha$ is the convective heat transfer coefficient [kW/m$^2$K];
$I_z$ is the radiative heat flux from a flame [kW/m$^2$];
$I_f$ is the radiative heat flux from an opening [kW/m$^2$].

(2) The convective heat transfer coefficient $\alpha$ should be obtained from Annex C of ENV 1991-2-2:1995 for the "no forced draught" or the "forced draught" condition as appropriate, using an effective cross-sectional dimension $d = (d_1 + d_2)/2$ .




1) Column opposite opening

2) Column between openings




1) Beam parallel to wall

2) Beam perpendicular to wall

**Figure B.1: Member dimensions and faces**

(3) For a member engulfed in flame, the average temperature of the member $T_M$ [K] should be determined from the solution of the following heat balance:

$$\sigma T_M^4 + \alpha T_M = I_z + I_f + \alpha T_z \quad \text{(B.2)}$$

where:

$T_z$ is the flame temperature [K];
$I_z$ is the radiative heat flux from the flame [kW/m$^2$];
$I_f$ is the radiative heat flux from the corresponding opening [kW/m$^2$].

(4) The radiative heat flux $I_z$ from flames should be determined according to the situation and type of member as follows:

- Columns not engulfed in flame: see B.2;
- Beams not engulfed in flame: see B.3;
- Columns engulfed in flame: see B.4;
- Beams fully or partially engulfed in flame: see B.5.

Other cases may be treated analogously, using appropriate adaptations of the treatments given in B.2 to B.5.

(5) The radiative heat flux $I_f$ from an opening should be determined from:

$$I_f = \phi_f \varepsilon_f (1 - a_z) \sigma T_f^4 \quad \text{(B.3)}$$

where:

$\phi_f$ is the overall configuration factor of the member for radiative heat transfer from that opening;
$\varepsilon_f$ is the emissivity of the opening;
$a_z$ is the absorptivity of the flames;
$T_f$ is the temperature of the fire [K] from Annex C of ENV 1991-2-2.

(6) The emissivity $\varepsilon_f$ of an opening should be taken as unity, see Annex C of ENV 1991-2-2.

(7) The absorptivity $a_z$ of the flames should be determined from B.2 to B.5 as appropriate.

## B.1.4 Overall configuration factors

(1) The overall configuration factor $\phi_f$ of a member for radiative heat transfer from an opening should be determined from:

$$\phi_f = \frac{(C_1\phi_{f,1} + C_2\phi_{f,2})d_1 + (C_3\phi_{f,3} + C_4\phi_{f,4})d_2}{(C_1 + C_2)d_1 + (C_3 + C_4)d_2} \text{A} \quad \text{(B.4)}$$

where:

$\phi_{f,i}$ is the configuration factor of member face $i$ for that opening, see Annex C;
$d_i$ is the cross-sectional dimension of member face $i$ ;
$C_i$ is the protection coefficient of member face $i$ as follows:
- for a protected face: $C_i = 0$
- for an unprotected face: $C_i = 1$

(2) The configuration factor $\phi_{f,i}$ for a member face from which the opening is not visible should be taken as zero.

(3) The overall configuration factor $\phi_z$ of a member for radiative heat transfer from a flame should be determined from:

$$\phi_z = \frac{(C_1\phi_{z,1} + C_2\phi_{z,2})d_1 + (C_3\phi_{z,3} + C_4\phi_{z,4})d_2}{(C_1 + C_2)d_1 + (C_3 + C_4)d_2} \text{B} \tag{B.5}$$

where:

$\phi_{z,i}$ is the configuration factor of member face $i$ for that flame, see Annex C.

(4) The configuration factors $\phi_{z,i}$ of individual member faces for radiative heat transfer from flames may be based on equivalent rectangular flame dimensions. The dimensions and locations of equivalent rectangles representing the front and sides of a flame for this purpose should be determined as given in B.2 for columns and B.3 for beams. For all other purposes, the flame dimensions from Annex C of ENV 1991-2-2 should be used.

(5) The configuration factor $\phi_{z,i}$ for a member face from which the flame is not visible should be taken as zero.

(6) A member face may be protected by a heat screen, see 4.2.3.3. A member face which is immediately adjacent to the compartment wall may also be treated as protected, provided that there are no openings in that part of the wall. All other member faces should be treated as unprotected.

## B.2 Column not engulfed in flame

### B.2.1 Radiative heat transfer

(1) A distinction should be made between a column located opposite an opening and a column located between openings, see figure B.2.

(2) If the column is opposite an opening, see figure B.3, the radiative heat flux $I_z$ from the flame should be determined from:

$$I_z = \phi_z \, \varepsilon_z \sigma T_z^4 \tag{B.6}$$

where:

$\phi_z$ is the overall configuration factor of the column for heat from the flame, see B.1.4;
$\varepsilon_z$ is the emissivity of the flame, see B.2.2;
$T_z$ is the flame temperature [K] from B.2.3.

(3) If the column is between openings, see figure B.4, the total radiative heat flux $I_z$ from the flames on each side should be determined from:

$$I_z = (\phi_{z,m}\varepsilon_{z,m} + \phi_{z,n}\varepsilon_{z,n})\sigma T_z^4 \tag{B.7}$$

where:

$\phi_{z,m}$ is the overall configuration factor of the column for heat from flames on side $m$, see B.1.4;
$\phi_{z,n}$ is the overall configuration factor of the column for heat from flames on side $n$, see B.1.4;
$\varepsilon_{z,m}$, is the total emissivity of the flames on side $m$, see B.2.2;
$\varepsilon_{z,n}$ is the total emissivity of the flames on side $n$, see B.2.2.

### B.2.2 Flame emissivity

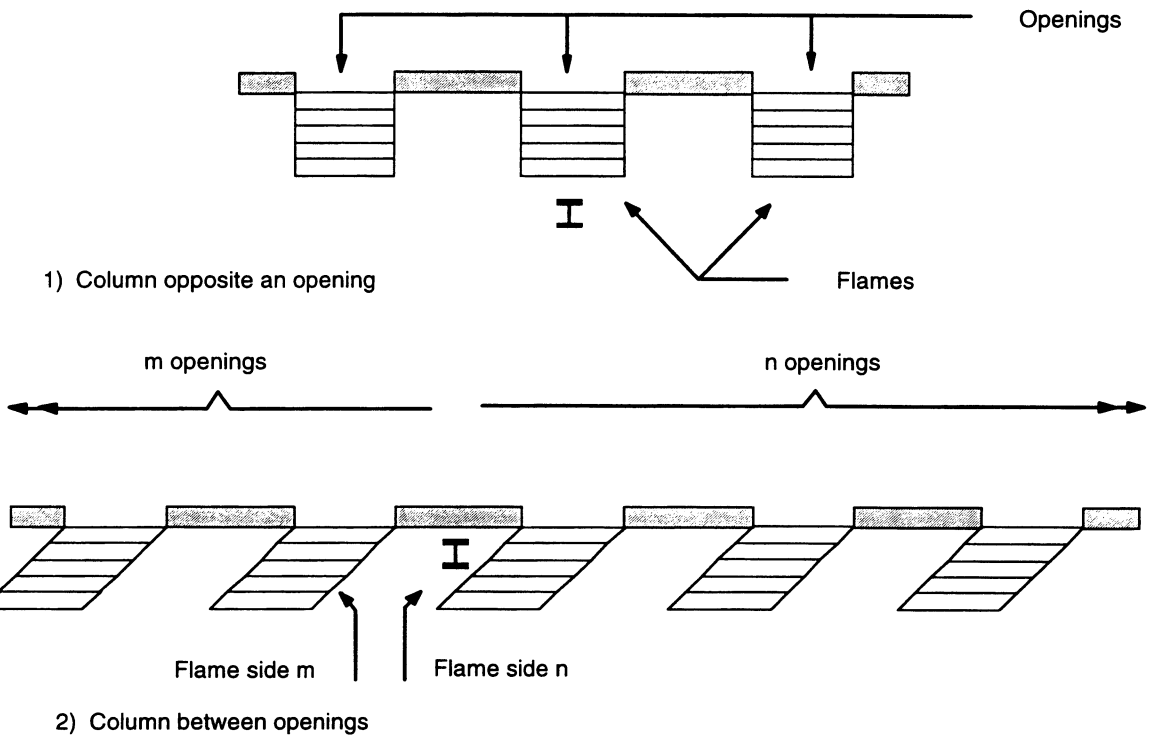
(1) If the column is opposite an opening, the flame emissivity $\varepsilon_z$ should be determined from the expression for $\varepsilon$ given in Annex C of ENV 1991-2-2, using the flame thickness $\lambda$ at the level of the top of the openings. Provided that there is no awning or balcony above the opening $\lambda$ may be taken as follows:

- for the 'no forced draught' condition: $\lambda = 2h/3$ (B.8a)

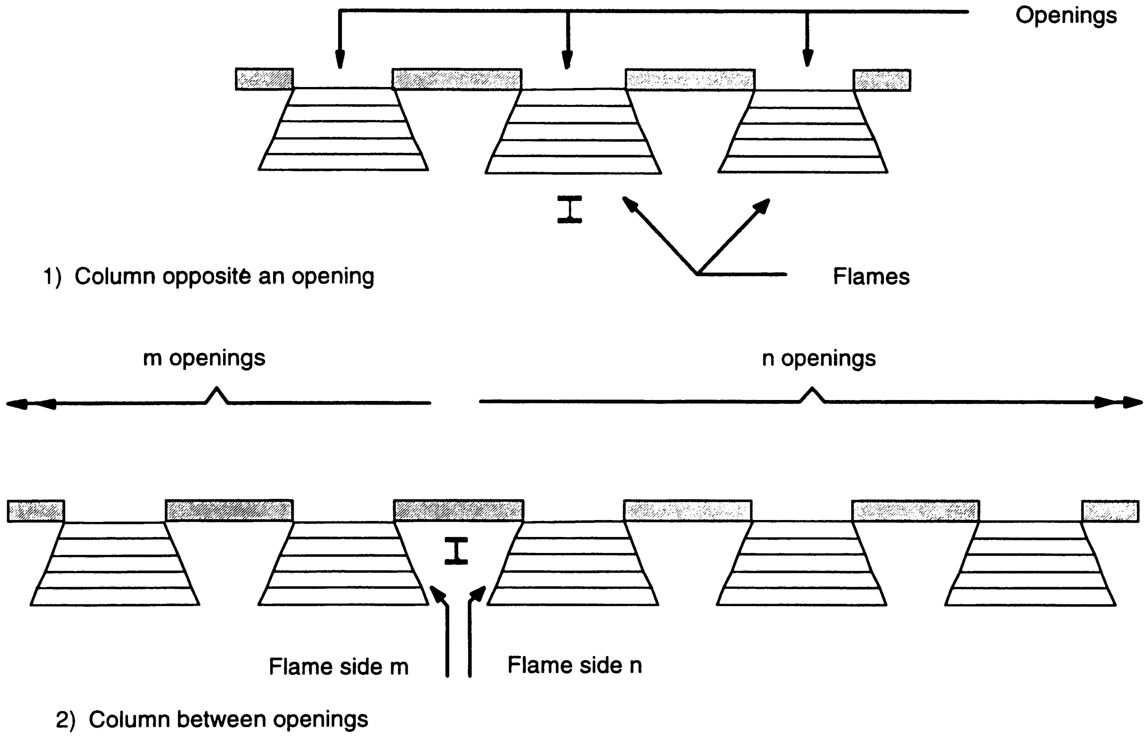
- for the 'forced draught' condition: $\lambda = x$ but $\lambda \leq hx/z$ (B.8b)

where:

*h*, *x* and *z* are as given in Annex C of ENV 1991-2-2

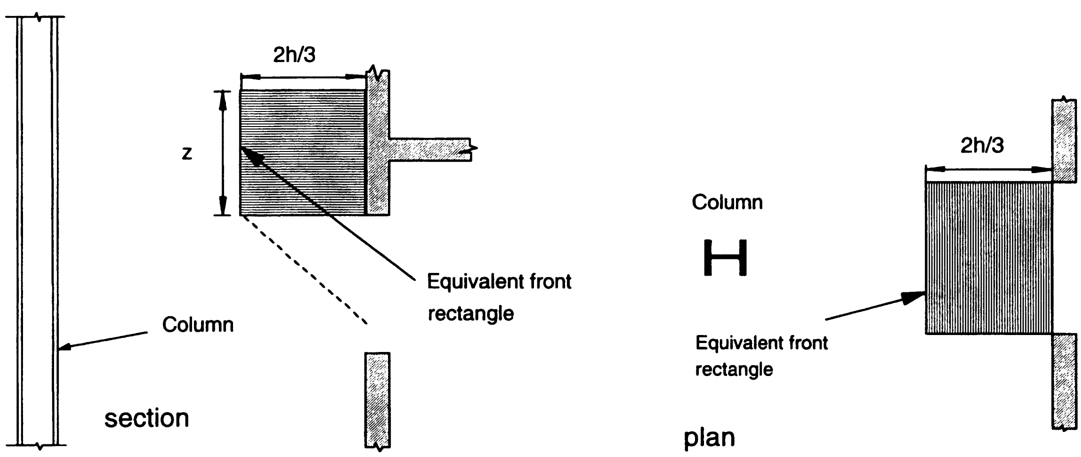



a) "No forced draught" condition

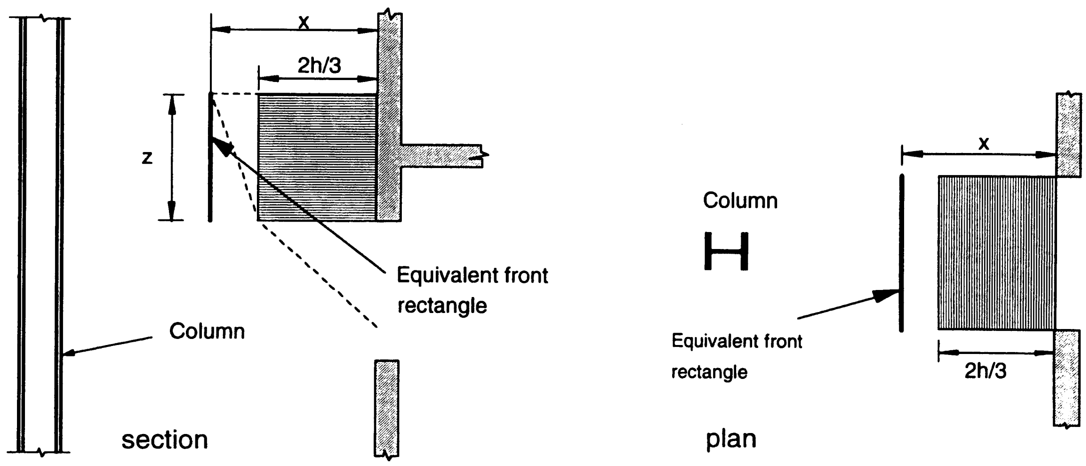



b) "Forced draught" condition

**Figure B.2: Column positions**

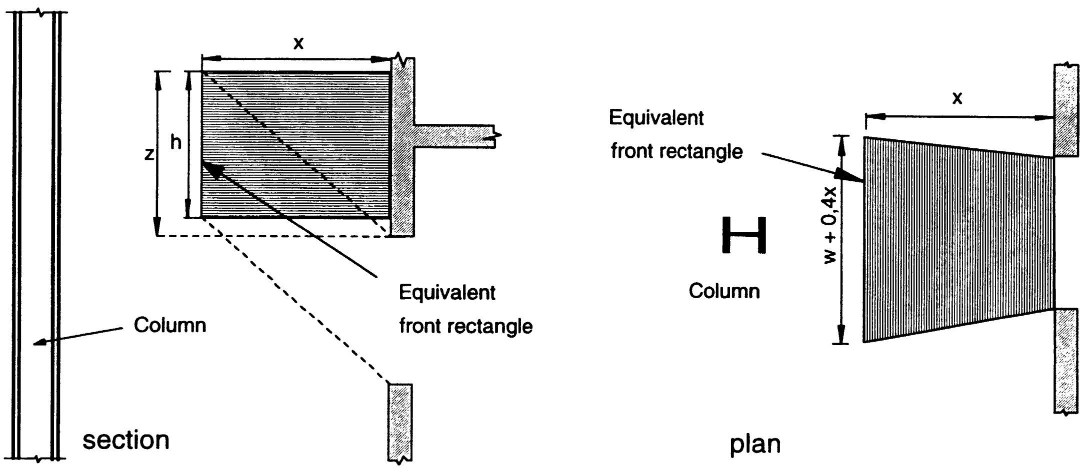



1) wall above and h < 1,25w



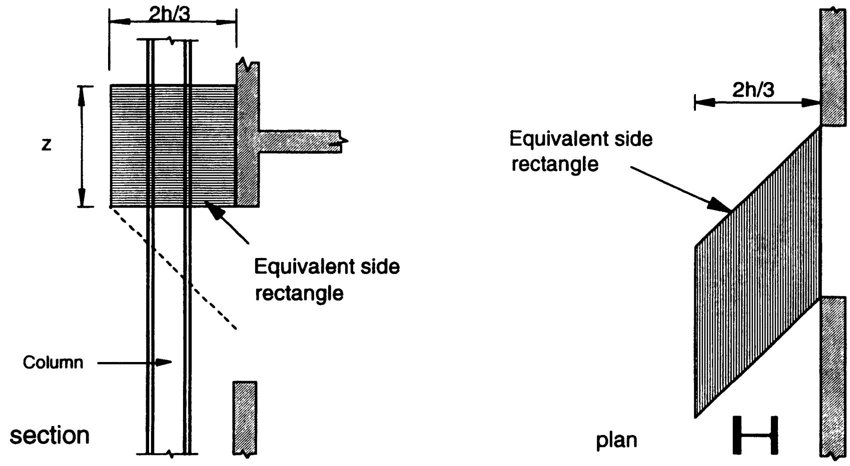

2) wall above and h > 1,25w or no wall above

a) "No forced draught"

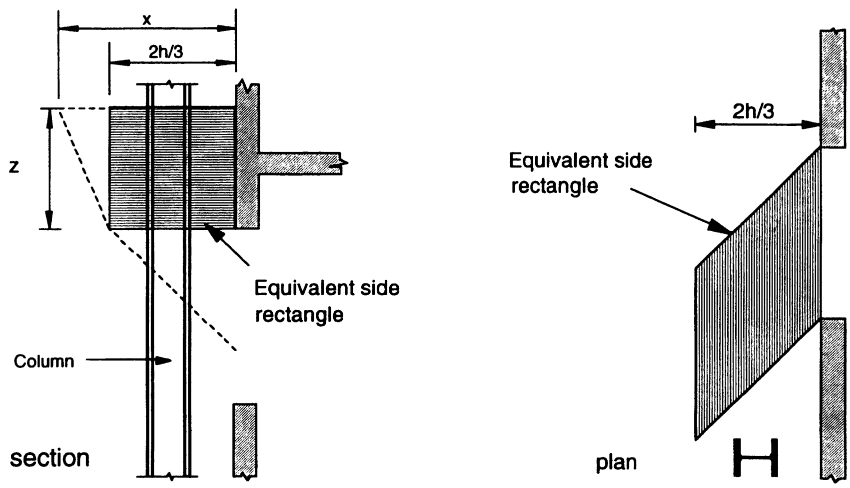



b) "Forced draught"

**Figure B.3: Column opposite opening**

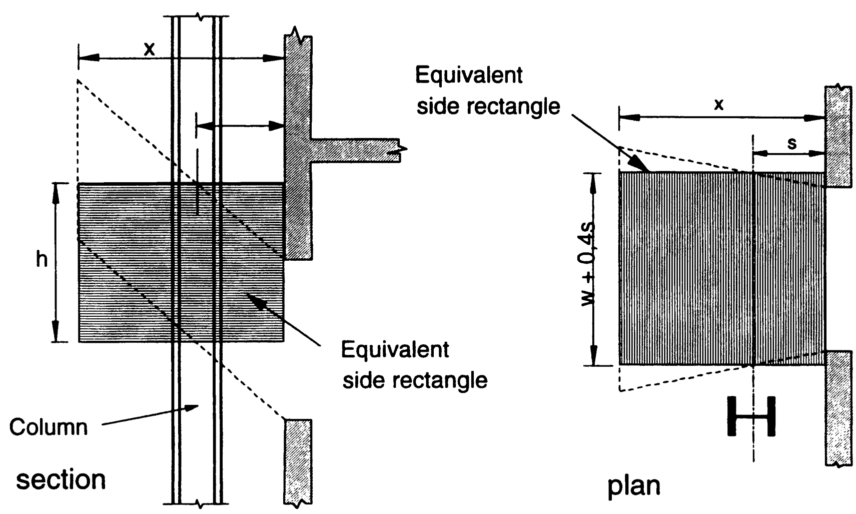



1) wall above and h < 1,25w




2) wall above and h > 1,25w or no wall above

a) "No forced draught"




b) "Forced draught"

**Figure B.4: Column between openings**

(2) If the column is between two openings, the total emissivities $\varepsilon_{z,m}$ and $\varepsilon_{z,n}$ of the flames on sides $m$ and $n$ should be determined from the expression for $\varepsilon$ given in Annex C of ENV 1991-2-2 using a value for the total flame thickness $\lambda$ as follows:

- for side $m$: $\lambda = \sum_{i=1}^{m} \lambda_i C$ (B.9a)

- for side $n$: $\lambda = \sum_{i=1}^{n} \lambda_i D$ (B.9b)

where:

$m$ is the number of openings on side $m$;
$n$ is the number of openings on side $n$;
$\lambda_i$ is the flame thickness for opening $i$.

(3) The flame thickness $\lambda_i$ should be taken as follows:

- for the "no forced draught" condition:
  $\lambda_i = w_i$ (B.10a)

- for the "forced draught" condition:
  $\lambda_i = w_i + 0{,}4s$ (B.10b)

where:

$w_i$ is the width of the opening;
$s$ is the horizontal distance from the centreline of the column to the wall of the fire compartment, see figure B.1.

### B.2.3 Flame temperature

(1) The flame temperature $T_z$ should be taken as the temperature at the flame axis obtained from the expression for $T_z$ given in Annex C of ENV 1991-2-2, for the "no forced draught" condition or the "forced draught" condition as appropriate, at a distance $\ell$ from the opening, measured along the flame axis, as follows:

- for the "no forced draught" condition: $\ell = h/2$ (B.11a)

- for the "forced draught" condition:

- for a column opposite an opening: $\ell = 0$ (B.11b)

- for a column between openings $\ell$ is the distance along the flame axis to a point at a horizontal distance $s$ from the wall of the fire compartment. Provided that there is no awning or balcony above the opening:

$\ell = sX/x$ (B.11c)

where $X$ and $x$ are as given in Annex C of ENV 1991-2-2.

### B.2.4 Flame absorptivity

(1) For the "no forced draught" condition, the flame absorptivity $a_z$ should be taken as zero.

(2) For the "forced draught" condition, the flame absorptivity $a_z$ should be taken as equal to the emissivity $\varepsilon_z$ of the relevant flame, see B.2.2.

## B.3 Beam not engulfed in flame

### B.3.1 Radiative heat transfer

(1) Throughout B.3 it is assumed that the level of the bottom of the beam is not below the level of the top of the openings in the fire compartment.

(2) A distinction should be made between a beam which is parallel to the external wall of the fire compartment and a beam which is perpendicular to the external wall of the fire compartment, see figure B.5.

(3) If the beam is parallel to the external wall of the fire compartment, the average temperature of the member $T_M$ should be determined for a point in the length of the beam directly above the centre of the opening. For this case the radiative heat flux $I_z$ from the flame should be determined from:

$$I_z = \phi_z \varepsilon_z \sigma T_z^4$$

where:

$\phi_z$ is the overall configuration factor for the flame directly opposite the beam, see B.1.4;
$\varepsilon_z$ is the flame emissivity, see B.3.2;
$T_z$ is the flame temperature from B.3.3 [K].

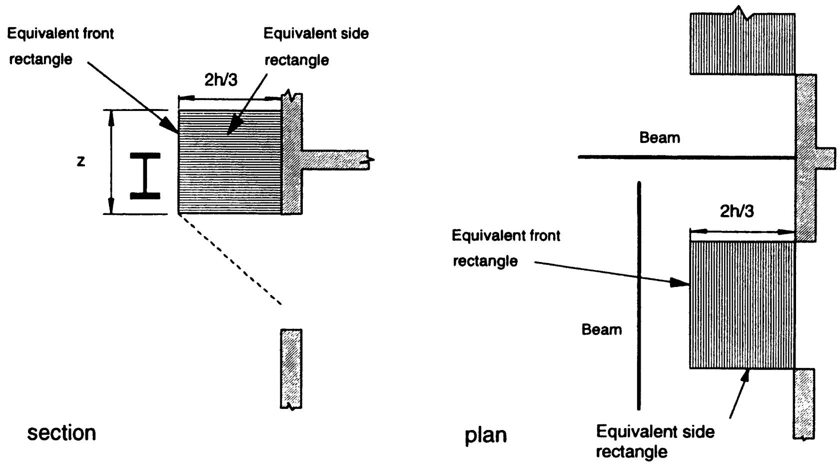
(4) If the beam is perpendicular to the external wall of the fire compartment, the average temperature in the beam should be determined at a series of points every 100 mm along the length of the beam. The average temperature of the member $T_M$ should then be taken as the maximum of these values. For this case the radiative heat flux $I_z$ from the flames should be determined from:

$$I_z = (\phi_{z,m} \varepsilon_{z,m} + \phi_{z,n} \varepsilon_{z,n}) \sigma T_z^4$$

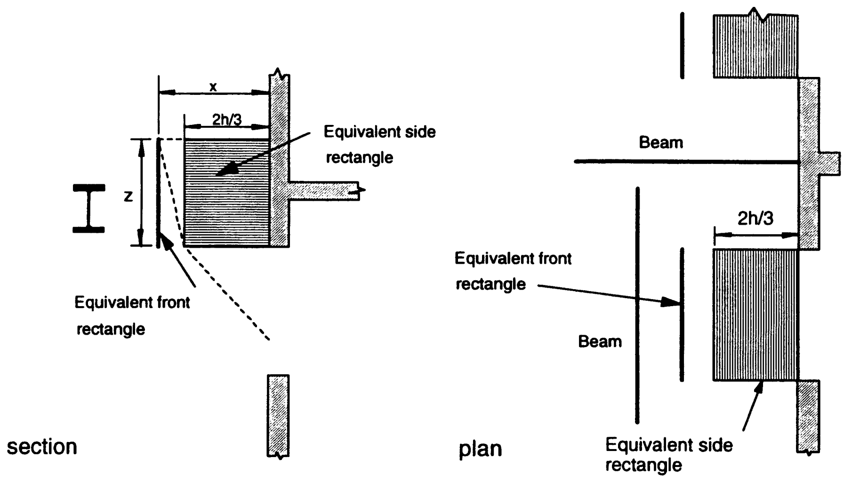
(B.13)

where:

$\phi_{z,m}$ is the overall configuration factor of the beam for heat from flames on side $m$ , see B.3.2;
$\phi_{z,n}$ is the overall configuration factor of the beam for heat from flames on side $n$, see B.3.2;
$\varepsilon_{z,m}$ is the total emissivity of the flames on side $m$ , see B.3.3;
$\varepsilon_{z,n}$ is the total emissivity of the flames on side $n$, see B.3.3;
$T_z$ is the flame temperature [K], see B.3.4.

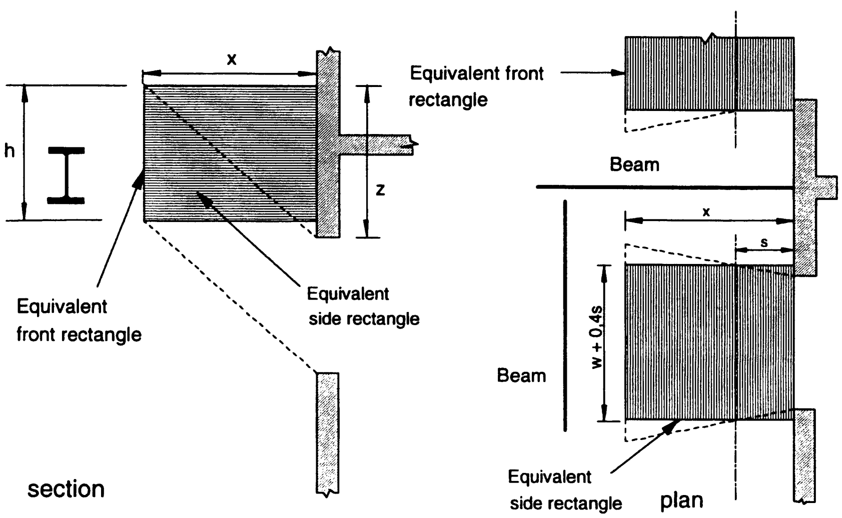



1) wall above and h < 1,25w




2) wall above and h > 1,25w or no wall above

a) "No forced draught"




b) "Forced draught"

**Figure B.5: Beam not engulfed in flame**

### B.3.2 Flame emissivity

(1) If the beam is parallel to the external wall of the fire compartment, above an opening, the flame emissivity $\varepsilon_z$ should be determined from the expression for $\varepsilon$ given in Annex C of ENV 1991-2-2, using a value for the flame thickness $\lambda$ at the level of the top of the openings. Provided that there is no awning or balcony above the opening $\lambda$ may be taken as follows:

- for the "no forced draught" condition: $\lambda = 2h/3$ (B.14a)
- for the "forced draught" condition: $\lambda = x$ but $\lambda \leq hx/z$ (B.14b)

where:

$h$, $x$ and $z$ are as given in Annex C of ENV 1991-2-2

(2) If the beam is perpendicular to the external wall of the fire compartment, between two openings, the total emissivities $\varepsilon_{z,m}$ and $\varepsilon_{z,n}$ of the flames on sides $m$ and $n$ should be determined from the expression for $e$ given in Annex C of ENV 1991-2-2 using a value for the flame thickness $\lambda$ as follows:

- for side $m$ : $\lambda = \sum_{i=1}^{m} \lambda_i$ E (B.15a)

- for side $n$: $\lambda = \sum_{i=1}^{n} \lambda_i$ F (B.15b)

where:

$m$ is the number of openings on side $m$ ;
$n$ is the number of openings on side $n$;
$\lambda_i$ is the width of opening $i$.

(3) The flame thickness $\lambda_i$ should be taken as follows:

- for the "no forced draught" condition: $\lambda_i = w_i$ (B.16a)

- for the "forced draught" condition: $\lambda_i = w_i + 0{,}4s$ (B.16b)

where:

$w_i$ is the width of the opening;
$s$ is the horizontal distance from the wall of the fire compartment to the point under consideration on the beam, see figure B.5.

### B.3.3 Flame temperature

(1) The flame temperature $T_z$ should be taken as the temperature at the flame axis obtained from the expression for $T_z$ given in Annex C of ENV 1991-2-2, for the "no forced draught" or "forced draught" condition as appropriate, at a distance $\ell$ from the opening, measured along the flame axis, as follows:

- for the "no forced draught" condition: $\ell = h/2$ (B.17a)

- for the "forced draught" condition:

-for a beam parallel to the external wall of the fire compartment, above an opening: $\ell = 0$ (B.17b)

- for a beam perpendicular to the external wall of the fire compartment, between openings $\ell$ is the distance along the flame axis to a point at a horizontal distance $s$ from the wall of the fire compartment. Provided that there is no awning or balcony above the opening: $\ell = sX/x$ (B.17c)

where $X$ and $x$ are as given in Annex C of ENV 1991-2-2.

### B.3.4 Flame absorptivity

(1) For the "no forced draught" condition, the flame absorptivity $a_z$ should be taken as zero.

(2) For the "forced draught" condition, the flame absorptivity $a_z$ should be taken as equal to the emissivity $\varepsilon_z$ of the relevant flame, see B.3.2.

## B.4 Column engulfed in flame

(1) The radiative heat flux $I_z$ from the flames should be determined from:

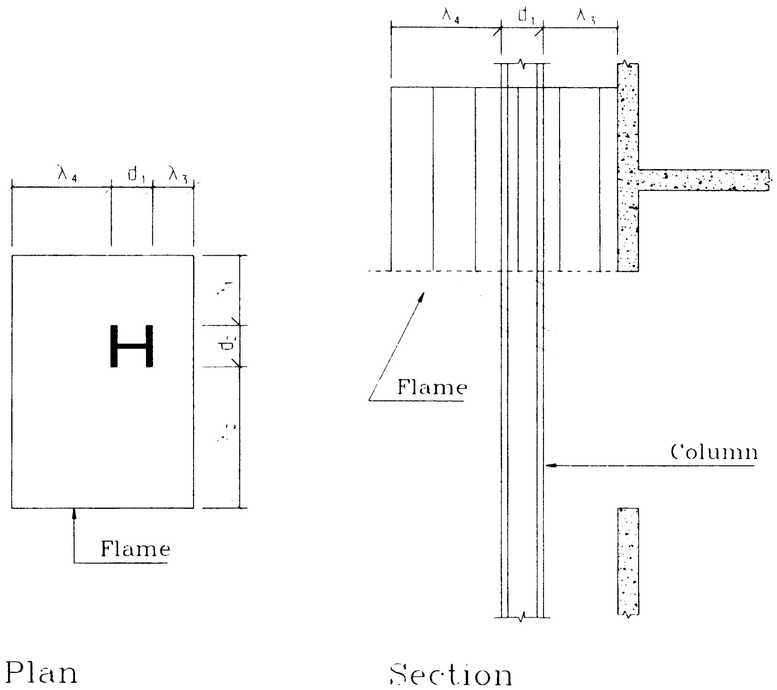
$$I_z = \frac{(I_{z,1} + I_{z,2})d_1 + (I_{z,3} + I_{z,4})d_2}{2(d_1 + d_2)} \text{G} \qquad \text{(B.18)}$$

with:

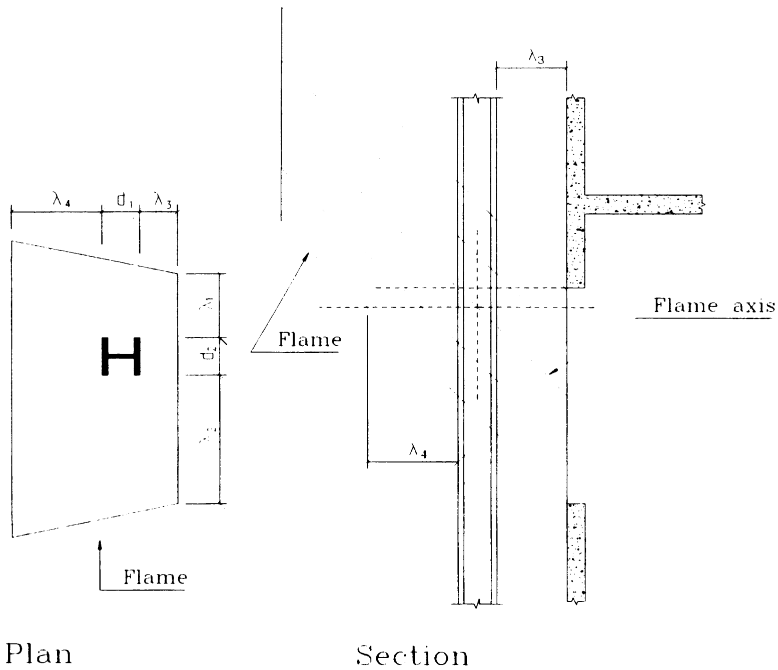
$$I_{z,1} = C_1 \varepsilon_{z,1} \sigma T_z^4$$
$$I_{z,2} = C_2 \varepsilon_{z,2} \sigma T_z^4$$
$$I_{z,3} = C_3 \varepsilon_{z,3} \sigma T_o^4$$
$$I_{z,4} = C_4 \varepsilon_{z,4} \sigma T_z^4$$

where:

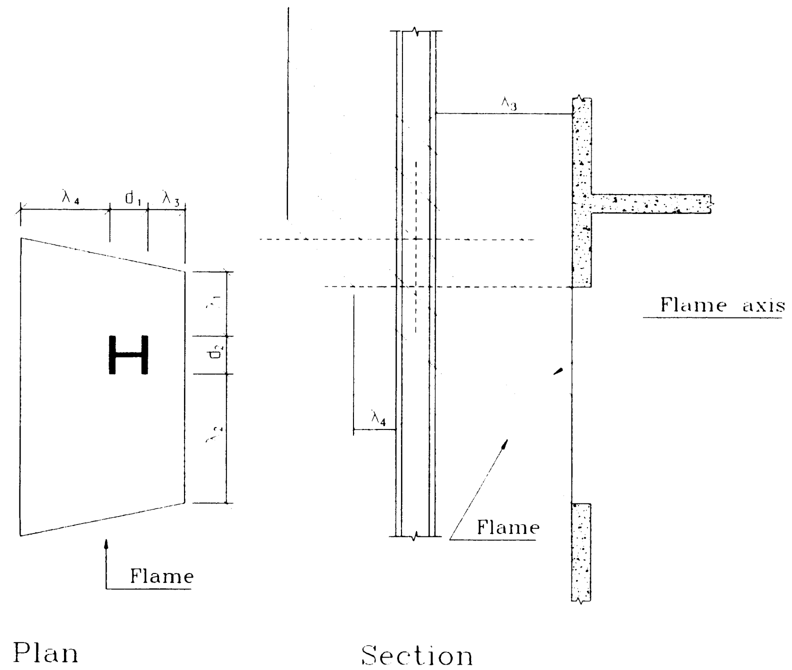
$I_{z,i}$ is the radiative heat flux from the flame to column face $i$;
$\varepsilon_{z,i}$ is the emissivity of the flames with respect to face $i$ of the column;
$i$ is the column face indicator (1), (2), (3) or (4);
$C_i$ is the protection coefficient of member face $i$, see B.1.4;
$T_z$ is the flame temperature [K];
$T_o$ is the flame temperature at the opening [K] from Annex C of ENV 1991-2-2.




a) "No forced draught" condition




1) Flame axis intersects column axis below top of opening




2) Flame axis intersects column axis above top of opening

b) "Forced draught" condition

**Figure B.6: Column engulfed in flame**

(2) The emissivity of the flames $\varepsilon_{z,i}$ for each of the faces 1, 2, 3 and 4 of the column should be determined from the expression for $\varepsilon$ given in Annex C of ENV 1991-2-2, using a flame thickness $\lambda$ equal to the dimension $\lambda_i$ indicated in figure B.6 corresponding to face $i$ of the column.

(3) For the "no forced draught" condition the values of $\lambda_i$ at the level of the top of the opening should be used, see figure B.6(a).

(4) For the "forced draught" condition, if the level of the intersection of the flame axis and the column centreline is below the level of the top of the opening, the values of $\lambda_{oi}$ at the level of the intersection should be used, see figure B.6(b)(1). Otherwise the values of $\lambda_{oi}$ at the level of the top of the opening should be used, see figure B.6(b)(2), except that if $\lambda_4 < 0$ at this level, the values at the level where $\lambda_{o4} = 0$ should be used.

(5) The flame temperature $T_z$ should be taken as the temperature at the flame axis obtained from the expression for $T_z$ given in Annex C of ENV 1991-2-2 for the "no forced draught" or "forced draught" condition as appropriate, at a distance $\ell$ from the opening, measured along the flame axis, as follows:

- for the "no forced draught" condition:

$$\ell = h/2 \tag{B.19a}$$

- for the "forced draught" condition, $\ell$ is the distance along the flame axis to the level where $\lambda_i$ is measured.

Provided that there is no balcony or awning above the opening:

$$\ell = (\lambda_3 + 0{,}5 d_1) X/x \text{ but } \ell \leq 0{,}5\, hX/z \tag{B.19b}$$

where $h$, $X$, $x$ and $z$ are as given in Annex C of ENV 1991-2-2.

(6) The absorptivity $a_z$ of the flames should be determined from:

$$a_z = \frac{\varepsilon_{z,1} + \varepsilon_{z,2} + \varepsilon_{z,3}}{3} \quad \text{H} \qquad \text{(B.20)}$$

where $\varepsilon_{z,1}$, $\varepsilon_{z,2}$ and $\varepsilon_{z,3}$ are the emissivities of the flame for column faces 1, 2, and 3.

## B.5 Beam fully or partially engulfed in flame

### B.5.1 Radiative heat transfer

#### B.5.1.1 General

(1) Throughout B.5 it is assumed that the level of the bottom of the beam is not below the level of the top of the adjacent openings in the fire compartment.

(2) A distinction should be made between a beam which is parallel to the external wall of the fire compartment and a beam which is perpendicular to the external wall of the fire compartment, see figure B.7.

(3) If the beam is parallel to the external wall of the fire compartment, its average temperature $T_M$ should be determined for a point in the length of the beam directly above the centre of the opening.

(4) If the beam is perpendicular to the external wall of the fire compartment, the value of the average temperature should be determined at a series of points every 100 mm along the length of the beam. The maximum of these values should then be adopted as the average temperature of the steel member $T_M$.

(5) The radiative heat flux $I_z$ from the flame should be determined from:

$$I_z = \frac{(I_{z1} + I_{z2})\, d_1 + (I_{z3} + I_{z4})\, d_2}{2(d_1 + d_2)} \text{I} \tag{B.21}$$

where:

$I_{z,i}$ is the radiative heat flux from the flame to beam face $i$;
$i$ is the beam face indicator (1), (2), (3) or (4).

#### B.5.1.2 "No forced draught" condition

(1) For the "no forced draught" condition, a distinction should be made between those cases where the top of the flame is above the level of the top of the beam and those where it is below this level.

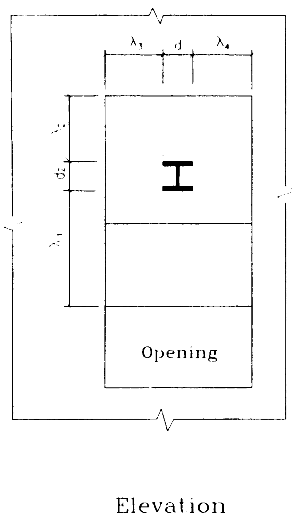
(2) If the top of the flame is above the level of the top of the beam:

$$I_{z,1} = C_1 \varepsilon_{z,1} \sigma T_o^4 \tag{B.22a}$$
$$I_{z,2} = C_2 \varepsilon_{z,2} \sigma T_{z,2} \tag{B.22b}$$
$$I_{z,3} = C_3 \varepsilon_{z,3} \sigma (T_{z,1}^4 + T_{z,2}^4)/2 \tag{B.22c}$$
$$I_{z,4} = C_4 \varepsilon_{z,4} \sigma (T_{z,1}^4 + T_{z,2}^4)/2 \tag{B.22d}$$

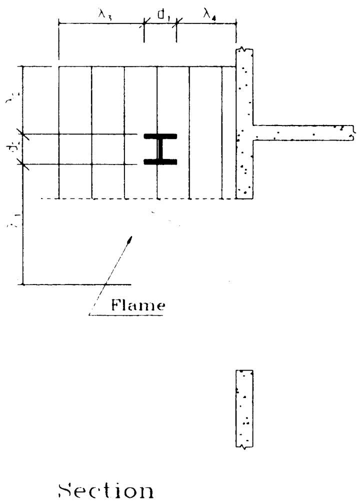
where:

$e_{z,i}$ is the emissivity of the flame with respect to face $i$ of the beam, see B.5.2;
$T_o$ is the temperature at the opening [K] from Annex C of ENV 1991-2-2;
$T_{z,1}$ is the flame temperature [K] from Annex C of ENV 1991-2-2, level with the bottom of the beam;
$T_{z,2}$ is the flame temperature [K] from Annex C of ENV 1991-2-2, level with the top of the beam.

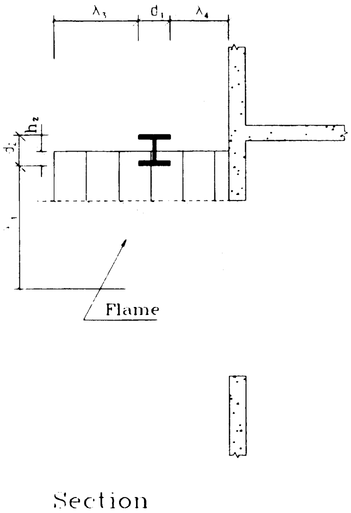
(3) In the case of a beam parallel to the external wall of the fire compartment $C_4$ may be taken as zero if the beam is immediately adjacent to the wall, see figure B.7.



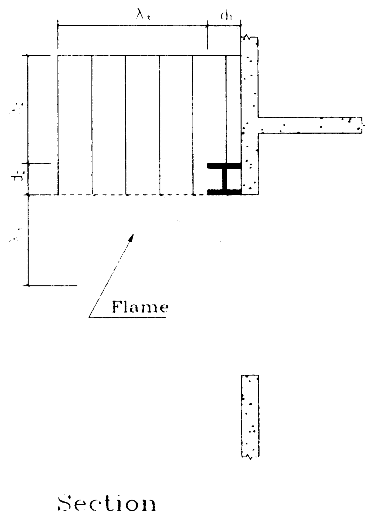

1) Beam perpendicular to wall




2) Beam parallel to wall

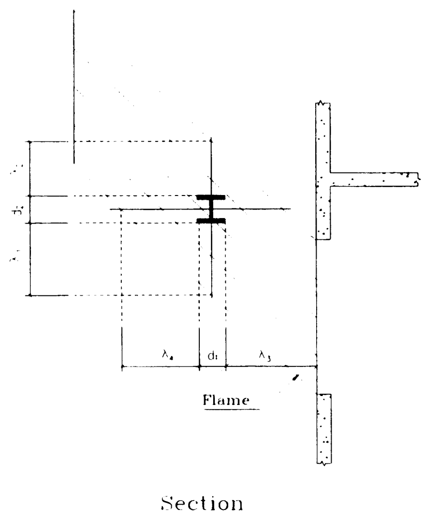



3) Top of flame below top of beam

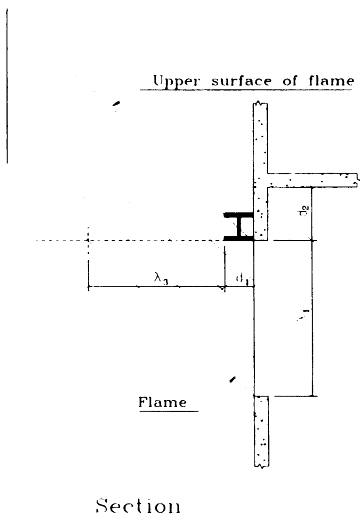



4) Beam immediately adjacent to wall

a) "No forced draught" condition




1) Beam not adjacent to wall




2) Beam immediately adjacent to wall

b) "Forced draught" condition

**Figure B.7: Beam engulfed in flame**

(4) If the top of the flame is below the level of the top of the beam:

$I_{z,1} = C_1 \varepsilon_{z,1} \sigma T_o^4$ (B.23a)
$I_{z,2} = 0$ (B.23b)
$I_{z,3} = (h_z/d_2) C_3 \varepsilon_{z,3} \sigma (T_{z,1}^4 + T_x^4)/2$ (B.23c)
$I_{z,4} = (h_z/d_2) C_4 \varepsilon_{z,4} \sigma (T_{z,1}^4 + T_x^4)/2$ (B.23d)

where:

$T_x$ is the flame temperature at the flame tip [813 K];
$h_z$ is the height of the top of the flame above the bottom of the beam.

### B.5.1.3 "Forced draught" condition

(1) For the "forced draught" condition, in the case of beams parallel to the external wall of the fire compartment a distinction should be made between those immediately adjacent to the wall and those not immediately adjacent to it, see figure B.7.

(2) For a beam parallel to the wall, but not immediately adjacent to it, or for a beam perpendicular to the wall:

$I_{z,1} = C_1 \varepsilon_{z,1} \sigma T_o^4$ (B.24a)
$I_{z,2} = C_2 \varepsilon_{z,2} \sigma T_{z,2}^4$ (B.24b)
$I_{z,3} = C_3 \varepsilon_{z,3} \sigma (T_{z,1}^4 + T_{z,2}^4)/2$ (B.24c)
$I_{z,4} = C_4 \varepsilon_{z,4} \sigma (T_{z,1}^4 + T_{z,2}^4)/2$ (B.24d)

(3) If the beam is parallel to the wall and immediately adjacent to it, only the bottom face should be taken as engulfed in flame but one side and the top should be taken as exposed to radiative heat transfer from the upper surface of the flame, see figure B.7(b)(2). Thus:

$I_{z,1} = C_1 \varepsilon_{z,1} \sigma T_o^4$ (B.25a)
$I_{z,2} = \phi_{z,2} C_2 \varepsilon_{z,2} \sigma T_{z,2}^4$ (B.25b)
$I_{z,3} = \phi_{z,3} C_3 \varepsilon_{z,3} \sigma (T_{z,1}^4 + T_{z,2}^4)/2$ (B.25c)
$I_{z,4} = 0$ (B.25d)

where:

$\phi_{z,i}$ is the configuration factor relative to the upper surface of the flame, for face $i$ of the beam, from Annex C.

### B.5.2 Flame emissivity

(1) The emissivity of the flame $\varepsilon_{z,i}$ for each of the faces 1, 2, 3 and 4 of the beam should be determined from the expression for $\varepsilon$ given in Annex C of ENV 1991-2-2, using a flame thickness $\lambda$ equal to the dimension $\lambda_i$ indicated in figure B.7 corresponding to face $i$ of the beam.

### B.5.3 Flame absorptivity

(1) The absorptivity of the flame $a_z$ should be determined from:

$$a_z = 1 - e^{-0,3h} \qquad \text{(B.26)}$$

# Annex C (informative)

# Configuration factor

(1) The configuration factor $\phi$ is defined in 1.3(1)P. It measures the fraction of the total radiative heat leaving a given radiating surface which arrives at a given receiving surface. Its value depends on the size of the radiating surface, on the distance from the radiating surface to the receiving surface and on their relative orientation.

(2) In this Annex all radiating surfaces are assumed to be rectangular in shape. They comprise the windows and other openings in fire compartment walls and the equivalent rectangular surfaces of flames, see B.1.4.

(3) In calculating the configuration factor for a given situation, a rectangular envelope should first be drawn around the cross-section of the member receiving the radiative heat transfer, as indicated in figure C.1. The value of $\phi$ should then be determined for the mid-point P of each face of this rectangle.

(4) The configuration factor for each receiving surface should be determined as the sum of the contributions from each of the zones on the radiating surface (normally four) which are visible from the point P on the receiving surface, as indicated in figures C.2 and C.3. These zones should be defined relative to the point $X$ where a horizontal line perpendicular to the receiving surface meets the plane containing the radiating surface. No contribution should be taken from zones such as the shaded zones on figure C.3 which are not visible from the point P.

(5) If the point $X$ lies outside the radiating surface, the effective configuration factor should be determined by adding the contributions of the two rectangles extending from $X$ to the farther side of the radiating surface, then subtracting the contributions of the two rectangles extending from $X$ to the nearer side of the radiating surface.

(6) The contribution of each zone should be determined as follows:

- receiving surface parallel to radiating surface:

$$\phi = \frac{1}{2\pi}\left[\frac{a}{\left(1+a^2\right)^{0,5}}\tan^{-1}\left(\frac{b}{\left(1+a^2\right)^{0,5}}\right) + \frac{b}{\left(1+b^2\right)^{0,5}}\tan^{-1}\left(\frac{a}{\left(1+b^2\right)^{0,5}}\right)\right] \qquad \text{(C.1)}$$

with:

$a = h/s$

$b = w/s$

where:

$s$ is the distance from P to $X$

$h$ is the height of the zone on the radiating surface

$w$ is the width of that zone

- receiving surface perpendicular to radiating surface:

$$\phi = \frac{1}{2\pi}\left[ tan^{-1}(a) - \frac{1}{\left(1+b^2\right)^{0,5}} tan^{-1}\left(\frac{a}{\left(1+b^2\right)^{0,5}}\right)\right] \tag{C.2}$$

- receiving surface in a plane at angle θ to the radiating surface:

$$\phi = \frac{1}{2\pi}\left[ \tan^{-1}(a) - \frac{(1-b\cdot\cos\theta)}{\left(1+b^2-2b\cdot\cos\theta\right)^{0,5}} \tan^{-1}\left(\frac{a}{\left(1+b^2-2b\cdot\cos\theta\right)^{0,5}}\right)\right.$$

$$\left. + \frac{a\cdot cos\,\theta}{\left(a^2+sin^2\,\theta\right)^{0,5}}\left[ tan^{-1}\left(\frac{(b-cos\,\theta)}{\left(a^2+sin^2\,\theta\right)^{0,5}}\right) + tan^{-1}\left(\frac{cos\,\theta}{\left(a^2+sin^2\,\theta\right)^{0,5}}\right)\right]\right] \tag{C.3}$$

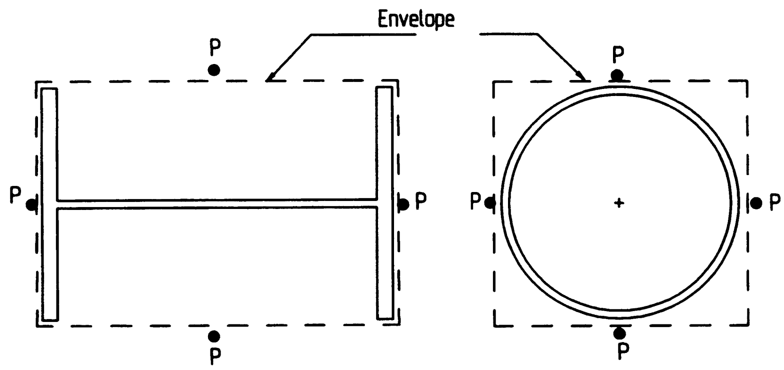
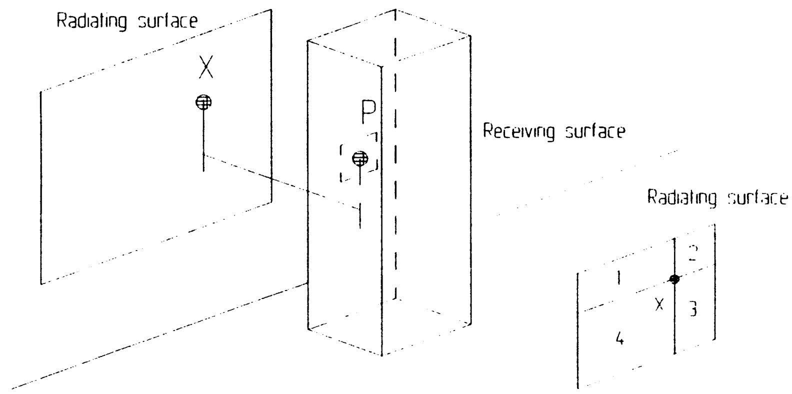
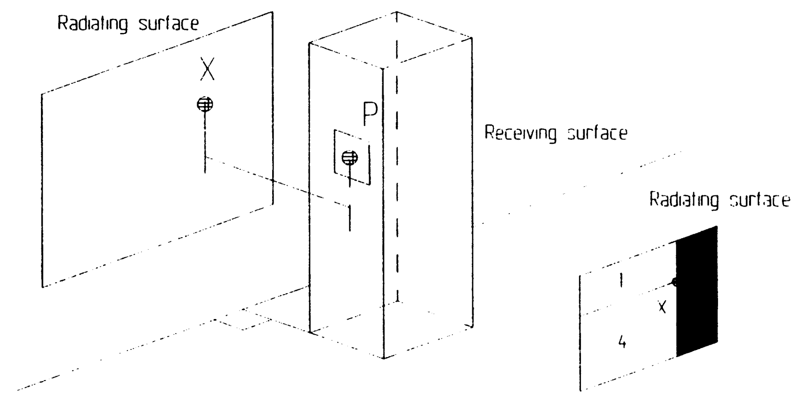



**Figure C.1 Envelope of receiving surfaces.**




$\phi = (\phi_1 + \phi_2 + \phi_3 + \phi_4)$

**Figure C.2 Receiving surface in a plane parallel to the plane of the radiating surface.**




$\phi = (\phi_1 + \phi_4)$

**Figure C.3 Receiving surface in a plane perpendicular to the plane of the radiating surface.**

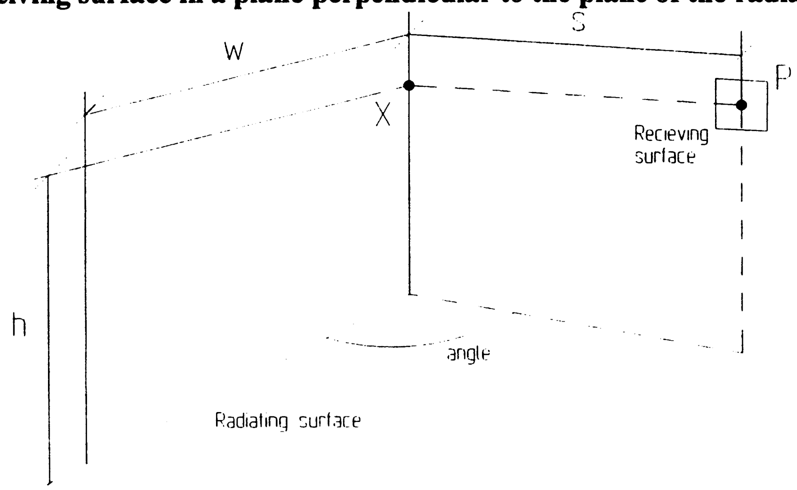



**Figure C.4 Receiving surface in a plane at angle to the plane of the radiating surface.**

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