



BSI Standards Publication

Eurocode 2 — Design of concrete structures

Part 1-2: Structural fire design

National foreword

This British Standard is the UK implementation of EN 1992-1-2:2023. It supersedes BS EN 1992-1-2:2004+A1:2019, which will be withdrawn on 30 March 2028.

The UK participation in its preparation was entrusted to Technical Committee B/525/2, Structural use of concrete.

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

National choice is allowed in this standard where explicitly stated within notes. The National Annex to this standard contains the national choices to be used for buildings and civil engineering works constructed in the UK.

The first generation of EN Eurocodes was published between 2002 and 2007, with conflicting British Standards withdrawn in 2010. This document forms part of the second generation of EN Eurocodes.

The second generation of EN Eurocodes is expected to be published between 2023 and 2026. These documents are being published as soon as they are available. This is being done to enable users to prepare for the transition from the first generation to second generation of EN Eurocodes.

UK adoptions of the first generation of EN Eurocodes will be withdrawn by BSI on 30 March 2028. Until that date, the first generation documents should be considered as the applicable standards for buildings and civil engineering works constructed in the UK unless otherwise specified by the relevant authority or in the specification for a particular project.

This standard is intended to be used with its National Annex and other referenced documents, including other second generation Eurocodes, as an interdependent suite of documents.

While the use of provisions in this standard in conjunction with first generation Eurocodes is not precluded, it should be undertaken with care and should only be done when users are satisfied that it will not result in a lower level of reliability than the minimum level set in the first generation Eurocodes and associated UK National Annexes.

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Date	Text affected
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English Version

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

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

This European Standard was approved by CEN on 23 July 2023.

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Contents

Page

European foreword	5
0 Introduction.....	6
1 Scope.....	9
1.1 Scope of EN 1992-1-2	9
1.2 Assumptions	9
2 Normative references.....	9
3 Terms, definitions and symbols	10
3.1 Terms and definitions	10
3.2 Symbols	10
3.2.1 Latin upper case letters	10
3.2.2 Latin lower case letters.....	12
3.2.3 Greek lower case letters.....	14
3.2.4 Units.....	16
3.2.5 Sign conventions	16
4 Basis of design.....	17
4.1 General rules	17
4.2 Nominal fire exposure.....	17
4.3 Physically based fire exposure	18
4.4 Actions	18
4.5 Design values of material properties	18
4.6 Verification methods	18
4.7 Member analysis	19
4.8 Analysis of parts of the structure	19
4.9 Global structural analysis	20
4.10 Detailing.....	20
4.11 Spalling	20
4.12 Protective layers	20
5 Material properties.....	21
5.1 General.....	21
5.2 Concrete thermal properties.....	21
5.2.1 Emissivity coefficient.....	21
5.2.2 Thermal conductivity.....	21
5.2.3 Specific heat.....	21
5.2.4 Density	23
5.3 Mechanical properties	23
5.3.1 Concrete	23
5.3.2 Reinforcing steel	26
5.3.3 Prestressing steel.....	28
6 Tabulated design data.....	30
6.1 General.....	30
6.2 General design rules	31
6.3 Columns.....	33
6.3.1 General.....	33

6.3.2	Method A	33
6.3.3	Method B	37
6.4	Walls	37
6.4.1	Non load-bearing walls (partitions)	37
6.4.2	Load-bearing solid walls	37
6.5	Tensile members	39
6.6	Beams.....	39
6.6.1	General	39
6.6.2	Simply supported beams exposed to fire on one, two or three sides	41
6.6.3	Continuous beams exposed to fire on one, two or three sides	42
6.6.4	Beams exposed on all sides	44
6.7	Slabs.....	44
6.7.1	General	44
6.7.2	Simply supported slabs	45
6.7.3	Continuous solid slabs	46
6.7.4	Flat slabs	46
6.7.5	Ribbed slabs.....	46
7	Simplified design methods.....	49
7.1	General	49
7.2	Temperature profiles.....	49
7.2.1	General	49
7.2.2	Basic solution for one side exposure.....	49
7.2.3	Walls, slabs and rectangular cross-sections	51
7.2.4	Circular cross-sections	53
7.3	Structural analysis	54
7.3.1	General	54
7.3.2	Reduction of cross-section	54
7.3.3	Bending	56
7.3.4	Bending and axial load	59
7.3.5	Shear and torsion	63
8	Advanced design methods.....	66
8.1	General	66
8.2	Thermal analysis	66
8.3	Mechanical analysis	66
8.4	Validation of advanced design methods.....	67
9	Detailing.....	68
9.1	General	68
9.2	Detailing of reinforcing and prestressing steel	68
9.3	Detailing of members	68
9.4	Joints.....	69
9.5	Connections	70
9.6	Fire protection systems.....	70
10	Rules for spalling	71
Annex A (normative)	Lightweight aggregate concrete structures.....	73
A.1	Use of this annex	73
A.2	Scope and field of application	73
A.3	Material properties.....	73
A.4	Tabulated design data.....	74

A.5	Rules for spalling	74
Annex B (informative)	Steel fibre reinforced concrete structures	75
B.1	Use of this annex	75
B.2	Scope and field of application	75
B.3	Design rules	75
Annex C (informative)	Recycled aggregates concrete structures	76
C.1	Use of this annex	76
C.2	Scope and field of application	76
C.3	Design rules	76
Annex D (normative)	Buckling of columns under fire conditions	77
D.1	Use of this annex	77
D.2	Scope and field of application	77
Annex E (informative)	Load-bearing solid walls — complementary tables	85
E.1	Use of this annex	85
E.2	Scope and field of application	85
E.3	Complementary tables	85
Bibliography		87

European foreword

This document (EN 1992-1-2:2023) has been prepared by Technical Committee CEN/TC 250 “Structural Codes”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by September 2027, and conflicting national standards shall be withdrawn at the latest by March 2028.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document supersedes EN 1992-1-2:2004 and its amendments and corrigenda.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

The main changes compared to the previous edition are listed below:

- simplified design methods were improved and amended and provisions were updated in tabulated data to ensure consistency between tabulated design data, simplified and advanced design methods;
- simplified analytical formulae were added for the determination of temperature profiles in members;
- specific rules for spalling were integrated;
- informative annexes provide guidance for fire design of steel fibre reinforced concrete structures and of recycled aggregates concrete structures;
- the number of alternative design rules was reduced;
- the structure and table of contents was harmonized with other fire parts.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

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

0 Introduction

0.1 Introduction to the Eurocodes

The Structural Eurocodes comprise the following standards generally consisting of a number of Parts:

- EN 1990, *Eurocode: Basis of structural and geotechnical design*
- EN 1991, *Eurocode 1: 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*
- New Eurocodes under development, e.g. Eurocode for design of structural glass

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1992 (all parts)

(1) EN 1992 applies to the design of buildings, bridges and civil engineering structures in plain, reinforced and prestressed concrete. It complies with the principles and requirements for the safety and serviceability of structures, the basis of their design and verification that are given in EN 1990.

(2) EN 1992 is only concerned with the requirements for resistance, serviceability, durability and fire resistance of concrete structures. Other requirements, e.g. concerning thermal or sound insulation, are not considered.

(3) EN 1992 is subdivided into various parts:

- EN 1992-1-1, Design of concrete structures — Part 1-1: General rules and rules for buildings, bridges and civil engineering structures,
- EN 1992-1-2, Design of concrete structures — Part 1-2: Structural fire design,
- EN 1992-4, Design of concrete structures — Part 4: Design of fastenings for use in concrete.

0.3 Introduction to EN 1992-1-2

- (1) EN 1992-1-2 describes the requirements and rules for the structural design of buildings and civil engineering works exposed to fire.
- (2) EN 1992-1-2 is intended for clients (e.g. for the formulation of their specific requirements), designers, contractors and relevant authorities.
- (3) The general objectives of fire protection are to limit risks with respect to the individual and society, neighbouring property, and where required, environment or directly exposed property, in the case of fire.
- (4) The fire parts of the Structural Eurocodes deal with specific aspects of passive fire protection in terms of designing structures and parts thereof for adequate loadbearing resistance and for limiting fire spread as relevant.
- (5) Required functions and levels of performance can be specified either in terms of nominal (standard) fire resistance rating, generally given in national fire regulations or by referring to fire safety engineering for assessing passive and active measures, see EN 1991-1-2:—¹.
- (6) Supplementary requirements concerning, e.g.:
 - the possible installation and maintenance of sprinkler systems;
 - conditions on occupancy of building or fire compartment;
 - the use of approved insulation and coating materials, including their maintenance;
 are not given in this standard, because they are subject to specification by the competent authority.

0.4 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National annex for EN 1992-1-2

National choice is allowed in this standard where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing EN 1992-1-2 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

When no national choice is given, the default choice given in this standard is to be used.

When no national choice is made and no default is given in this standard, the choice can be specified by a relevant authority or, where not specified, agreed for a specific project by appropriate parties.

EN 1992-1-2:2023 (E)

National choice is allowed in EN 1992-1-2 through the following clauses:

4.5(1) 9.2(1) 10(10)

National choice is allowed in EN 1992-1-2 on the application of the following informative annexes:

Annex B Annex C Annex E

The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of EN 1992-1-2

- (1) This document deals with the design of concrete structures for the accidental situation of fire exposure and is intended to be used in conjunction with EN 1992-1-1 and EN 1991-1-2:—¹. This document identifies differences from, or supplements to, normal temperature design.
- (2) This document applies to concrete structures required to fulfil a loadbearing function, separating function, insulation function or all of them.
- (3) This document gives principles and application rules for the design of structures for specified requirements in respect of the aforementioned functions and the levels of performance.
- (4) This document applies to structures, or parts of structures, that are within the scope of EN 1992-1-1 and are designed accordingly.

1.2 Assumptions

- (1) In addition to the general assumptions of EN 1990 the following assumptions apply:
- the choice of the relevant design fire scenario is made by appropriate qualified and experienced personnel or is given by the relevant national regulation;
 - any fire protection measure taken into account in the design shall be adequately maintained for the duration of the intended use of the construction.

2 Normative references

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

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. in 'should' clauses), permissions ('may' clauses), possibilities ('can' clauses), and in notes.

EN 1363-2, *Fire resistance tests - Part 2: Alternative and additional procedures*

EN 1990, *Eurocode - Basis of structural design*

EN 1991-1-2:—¹, *Eurocode 1 — Actions on structures — Part 1-2: Actions on structures exposed to fire*

EN 1992-1-1:2023, *Eurocode 2 — Design of concrete structures — Part 1-1: General rules and rules for buildings, bridges and civil engineering structures*

EN 1991-1-7:—², *Eurocode 1 — Actions on structures — Part 1-7: Accidental actions*

¹ Under preparation. Stage at the time of publication: FprEN 1991-1-2:2023.

² Under preparation. Stage at the time of publication: prEN 1991-1-7:2023.

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, EN 1991-1-2:—¹ and EN 1992-1-1 and the following apply.

3.1.1

axis distance

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

3.1.2

critical temperature of reinforcement

temperature of reinforcement at which loadbearing failure of the member under fire conditions is expected to occur at a given stress level

3.1.3

maximum stress level

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

3.1.4

part of structure

isolated part of a structure with appropriate support and boundary conditions

3.1.5

fire protection material

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

3.1.6

reduced cross-section

cross-section of the member used in structural fire design when parts of the cross-section with assumed zero strength and stiffness are removed

3.1.7

spalling

fire induced spalling of concrete consists of the breaking off of layers or fragments of concrete from the surface of a structural member

Note 1 to entry: Depending on the severity of the phenomenon, it can influence the performance of the structural member.

3.2 Symbols

3.2.1 Latin upper case letters

For the purposes of this document, the following symbols and units apply.

A_c	Cross-sectional area of concrete
A_{cij}	Elemental concrete area for refined assessment of members subjected to bending and axial load
A_s	Cross-sectional area of steel reinforcement

A_{s0}	Cross-sectional area of longitudinal reinforcement at axis distance a from the most compressed side of the column
A_{s1}	Cross-sectional area of longitudinal reinforcement at axis distance a from the tensile/least compressed side of the column
$A_{s,i}$	Cross-sectional area of steel reinforcement i
$A_{s,prov}$	Provided cross-sectional area of longitudinal reinforcement
$A_{s,req}$	Required cross-sectional area of longitudinal reinforcement for the design at ambient temperature according to EN 1992-1-1
E	Integrity
E_d	Design effect of actions
$E_{d,fi}$	Design effect of actions under fire conditions
E_p	Slope of the linear elastic range in the stress-strain relationship of prestressing steel
$E_{p,\theta}$	Slope of the linear elastic range in the stress-strain relationship of prestressing steel at temperature θ
E_s	Slope of the linear elastic range in the stress-strain relationship of reinforcing steel
$E_{s,\theta}$	Slope of the linear elastic range in the stress-strain relationship of reinforcing steel at temperature θ
$F_{sd,0c,fi}$	Resisting compression force of longitudinal reinforcement at axis distance a from the most compressed side of the column
$F_{sd,1t,fi}$	Resisting tensile force of longitudinal reinforcement at axis distance a from the tensile side of the column
$F_{sd,1c,fi}$	Resisting compression force of longitudinal reinforcement at axis distance a from the least compressed side of the column
I	Insulation
M_{Ed}	Design value of the bending moment at ambient temperature
$M_{Ed,fi}$	Design value of the bending moment under fire conditions
$M_{Rd,fi}$	Ultimate moment capacity in the fire situation
$M_{0Ed,fi}$	Design value of first order moment under fire conditions including the effect of imperfections
$M_{0Rd,fi}$	Ultimate first order moment in the fire situation
M_{2fi}	Nominal second order moment in the fire situation
$N_{Ed,fi}$	Design value of the axial load in the fire situation
N_{Rd}	Design value of axial resistance
R	Design resistance
R	Loadbearing function / capacity
R_{XXX}	Fire resistance time in minutes ($15 \leq X \leq 240$)
R_a, R_b	Coefficients to determine loadbearing capacity R
$R_{d,fi,t}$	Design resistance in the fire situation at time t
$R_{\mu fi}, R_n, R_n$	Coefficients to determine loadbearing capacity R

$X_{d,\theta}$ Design value of a strength or stiffness property at temperature θ

X_k Characteristic value of a strength or stiffness property

3.2.2 Latin lower case letters

a Nominal axis distance measured between the centre of the reinforcement and the exposed surface

a_c Dimension of corner zone affected by two-sided heat transfer

a_{eff} Increased nominal axis distance

a_{fi} Reduced axis distance of the reinforcement

a_i Nominal axis distance for the reinforcement “i”

a_m Average axis distance

a_{sd} Nominal axis distance measured between the centre of the reinforcement and lateral surface exposed to fire

a_z Thickness of rim zone

b_{min} Minimum member width/minimum beam width

b_{mod} Increased minimum width of tensile member or tensile zone of beams

b_w Web width

$b_{w,\text{min}}$ Minimum web width

c Curvature

$c_{1/r}$ Curvature distribution factor

c_p Specific heat of concrete

$c_{p,\text{peak}}$ Specific heat (peak value)

d Effective depth of a cross-section

d_1, d_2 Height of section element

d_{eff} Effective height of the bottom flange of I-shaped beams

d_{fi} Reduced effective depth of a cross-section under fire conditions

e_0 Total first order eccentricity

e_1 Additional eccentricity due to imperfections

e_2 Eccentricity due to deformation of compression member

e_d Maximum distance between the compression resultant and the deformed axis of the compression member

e_{thermal} Eccentricity attributed to thermal effects

$f_{c,\theta}$ Characteristic value of cylinder compressive strength of concrete at temperature θ

f_{ck} Characteristic compressive concrete strength

$f_{ct,\theta}$ Characteristic value of tensile strength of concrete at temperature θ

$f_{ctk,0,05}$ Characteristic tensile strength of concrete

f_{ctm} Mean tensile strength of concrete

$f_{\text{Ft1,ef}}$	Stress at 0,5/ l_{cs} strain
$f_{\text{Ft3,ef}}$	Stress at the ultimate strain
$f_{\text{pc},\theta}$	Strength between the proportional limit and the yield strength at temperature θ
$f_{\text{pp},\theta}$	Proportionality limit of prestressing steel at temperature θ
$f_{\text{py},\theta}$	Maximum stress level of prestressing steel at temperature θ
$f_{\text{p0,1k}}$	Characteristic 0,1 % proof-stress of prestressing steel
$f_{\text{sd},\theta}$	Design strength of reinforcing steel at temperature θ
$f_{\text{sc},\theta}$	Strength between the proportional limit and the yield strength at temperature θ
$f_{\text{sp},\theta}$	Proportionality limit of reinforcing steel at temperature θ
$f_{\text{sy},\theta}$	Maximum stress level of reinforcing steel at temperature θ
$f_{\text{sy},\theta_{\text{p}}}$	Maximum stress level of reinforcing steel at the reference temperature θ_{p}
f_{yk}	Characteristic value of yield strength of reinforcement or, if yield phenomenon is not present, the characteristic value of 0,2 % proof strength
h	Depth of cross-section
h'	Depth of T-beam and I-beam webs for the evaluation of shear resistance
h_1, h_2, h_i	Thickness of section element
h_{fi}	Overall reduced depth of a cross-section used under fire conditions
h_{w}	Wall thickness
k	Coefficient for one-dimensional heat transfer
$k_{\text{c},\theta}$	Temperature-dependent reduction factor for concrete compressive strength
$k_{\text{ct},\theta}$	Temperature-dependent reduction factor for concrete tensile strength
$k_{\text{Es},\theta}$	Temperature-dependent reduction factor for reinforcing steel
k_{lb}	Coefficient for anchorage length
$k_{\text{pc},\theta}$	Temperature-dependent reduction factor for prestressing steel
k_{pp}	Content of monofilament fibres
$k_{\text{pp},\theta}$	Temperature-dependent reduction factor for prestressing steel
$k_{\text{py},\theta}, k_{\text{sc},\theta}$	Temperature-dependent reduction factor for reinforcing steel
$k_{\text{sy},\theta}$	Temperature-dependent reduction factor for reinforcing steel
k_{θ}	Temperature-dependent reduction factor
l	Length of an element
l_0	Effective length of column at ambient temperature
l_0'	Modified effective length of column
$l_{0,\text{fi}}$	Effective length of a column or wall for the fire design situation
$l_{0,\text{max}}$	Maximum effective length of a column or wall for the fire design situation
l_{bd}	Anchorage length
$l_{\text{bd,fi}}$	Anchorage length under fire conditions

l_{pbd}	Anchorage length l_{pbd} , over which the tendon force, in the ultimate limit state is fully anchored in concrete
$l_{\text{pbd,fi}}$	Anchorage length l_{pbd} , over which the tendon force, in the ultimate limit state is fully anchored in concrete under fire conditions
l_{pt}	Transmission length for prestressing force
$l_{\text{pt,fi}}$	Transmission length for prestressing force under fire conditions
l_{sd}	Lap length
$l_{\text{sd,fi}}$	Lap length under fire conditions
l_x and l_y	Spans of a two-way slab (two directions at right angles) where l_y is the longer span
n	Number of reinforcing bars in the cross-section or number of zones on reduced cross-section methods
n_{sc}	Number of effective reinforcing bars in the compression zone
n_{st}	Number of effective reinforcing bars in the tension reinforcing layer
r	Radius of curvature
t	Time
t	Duration of the standard fire
u	Moisture content
w	Reduced cross-section depending on the fire exposure
x	Location variable, coordinate
$x_{\text{e,fi}}$	Effective depth of concrete in compression under fire conditions
x_{fi}	Reduced depth of concrete in compression under fire conditions
y	Location variable, coordinate
y'	Local coordinate for evaluating the temperature at corners of sections exposed to fire on two sides
y_{fi}	Distance of centroid of compression zone of concrete to neutral axis under fire conditions
y_{ij}	Coordinate of the center of gravity (or centroid) of the concrete element along the y-axis
y_{T}	Coordinate of reference point T
z	Location variable, coordinate
z'	Local coordinate for evaluating the temperature at corners of sections exposed to fire on two sides
z_{ij}	Coordinate of the center of gravity (or centroid) of the concrete element along the z-axis

3.2.3 Greek lower case letters

α_{RA}	Substitution rate of recycled aggregates
γ_{S}	Partial factor for reinforcing steel
$\gamma_{\text{S,fi}}$	Partial factor for reinforcing or prestressing steel under fire conditions
Δt	Temperature increase in circular sections

$\Delta\theta$	Local temperature increase at corners of members expose on two sides
$\Delta\theta_M$	Temperature increase in circular sections
ε_c	Concrete strain
$\varepsilon_c(\theta_c)$	Concrete thermal strain due to thermal expansion
$\varepsilon_{c,ij}$	Concrete strain in elemental zone
ε_{c0}	Concrete strain at the member's most compressed side
$\varepsilon_{c1,\theta}$	Concrete strain at maximum stress at temperature θ
ε_{creep}	Creep strain
ε_{cth}	Thermal strain in concrete
ε_{cu}	Concrete ultimate strain
$\varepsilon_{cu1,\theta}$	Ultimate limit concrete strain at temperature θ
ε_{inf}	Strain in the bottom fibre of the cross-section
$\varepsilon_p(\theta_s)$	Prestressing steel thermal strain due to thermal expansion
$\varepsilon_{pp,\theta}$	Prestressing steel strain corresponding to the proportional limit at temperature θ
$\varepsilon_{pt,\theta}$	Prestressing steel strain corresponding to the maximal stress level at the end of the plastic plateau at temperature θ
$\varepsilon_{pu,\theta}$	Ultimate strain of the prestressing steel
ε_{s0}	Compressive strain in the longitudinal reinforcement in the compression zone
$\varepsilon_{s1,c}$	Strain in the longitudinal reinforcement in the compression zone
$\varepsilon_{s1,t}$	Strain in the longitudinal reinforcement in the tension zone
$\varepsilon_{sp,\theta}$	Steel strain corresponding to the proportional limit at temperature θ
$\varepsilon_{st,\theta}$	Steel strain corresponding to the maximal stress level at the end of the plastic plateau at temperature θ
$\varepsilon_{sth}(\theta_s)$	Reinforcing steel thermal strain due to thermal expansion
$\varepsilon_{su,\theta}$	Ultimate steel strain at temperature θ
ε_{sup}	Strain in the upper fiber of the cross-section
$\varepsilon_{sy,\theta}$	Steel strain corresponding to the maximal stress level at the beginning of the plastic plateau at temperature θ
ε_{th}	Thermal strain
ε_{tr}	Transient state strain
ε_{θ}	Instantaneous stress-dependent strain
η_1	Reference load level
η_{fi}	Reference load level under fire conditions
θ_1	Temperature increase in rectangular sections exposed to fire on one side

θ_2	Temperature increase in rectangular sections exposed to fire on two sides
θ_c	Temperature in concrete at the position considered
$\theta_{c,max}$	Maximum temperature in concrete
θ_i	Average temperature of each parallel zone
θ_{ij}	Average temperature of each zone
θ_M	Temperature in the centroid of the cross-section
θ_P	Concrete temperature in the reference point P
θ_{sc}	Average temperature of all effective reinforcing bars in the compression zone
$\theta_{sc,i}$	Temperature of effective reinforcing bar “i” in the compression zone
θ_{st}	Average temperature of all effective reinforcing bars in the tension zone
$\theta_{st,i}$	Temperature of effective reinforcing bar “i” in the tension zone
θ_T	Concrete temperature in the reference point T
λ_c	Thermal conductivity of concrete
μ_{fi}	Degree of utilization under fire conditions
$\sigma_c(\theta)$	Concrete stress for actions
$\sigma_{s,fi}$	Steel stress for actions under fire conditions
ω_{mod}	Modified mechanical reinforcement degree
$\rho(\theta_c)$	Concrete density at temperature θ_c
ρ_{LC}	Density for lightweight concrete
ϕ_{sl}	Diameter of a longitudinal reinforcing bar

3.2.4 Units

Stresses and material strengths	For unit dependent formulae, MPa is used
Geometric data	For unit dependent formulae, mm is used
Relative humidity	%
Time	Days, unless otherwise stated
Temperature	°C and K
Angle	Degrees

3.2.5 Sign conventions

- Tension forces, tension stresses, elongations and strains are considered positive
- Compression forces, compression stresses, elongations and strains are considered negative
- All material strengths (both tension and compression) are considered positive
- Forces are positive when acting in the direction defined by the vectors shown in the respective figures.

4 Basis of design

4.1 General rules

- (1) Where mechanical resistance in the case of fire is required, concrete structures shall be designed and constructed in such a way that they maintain their loadbearing function during the relevant fire exposure.
- (2) Where compartmentation is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure. This shall ensure that:
 - integrity failure does not occur;
 - insulation failure does not occur.
- (3) Deformation criteria shall be applied where the means of protection require consideration of the deformation of the loadbearing structure.
- (4) Consideration of the deformation of the loadbearing structure may be omitted, when the efficiency of the means of protection has been evaluated according to Clause 9.
- (5) Deformation criteria shall be applied where the design criteria for separating elements require consideration of the deformation of the loadbearing structure.
- (6) Consideration of the deformation of the loadbearing structure may be omitted, when the separating elements fulfil requirements of a nominal fire exposure.
- (7) Concrete structures designed in accordance with EN 1992-1-1 should be considered to have sufficient minimum robustness for the accidental fire design case. Where additional requirements are necessary the procedures of EN 1991-1-7:—², Annex A, apply.

4.2 Nominal fire exposure

- (1) For standard fire exposure, elements shall comply with the following functions or combination of function defined in EN 1991-1-2:—¹ during the required time of fire exposure:
 - loadbearing function only: loadbearing capacity (R);
 - separating function only: integrity (E) and, when requested, insulation (I);
 - separating and loadbearing functions: R, E and, when requested, I.
- (2) The loadbearing function is assumed to be satisfied when loadbearing capacity is maintained.
- (3) The separating function is assumed to be satisfied when integrity and when requested insulation are maintained.
- (4) Integrity function is assumed to be maintained when a separating element of building construction, exposed to fire on one side, prevents the passage through it of flames and hot gases and the occurrence of flames on the unexposed side.
- (5) Insulation function is assumed to be maintained when the average temperature rise over the whole of the non-exposed surface is limited to 140 K, and the maximum temperature rise at any point of that surface does not exceed 180 K.
- (6) With the external fire exposure curve the same functions (R, E, I) shall apply, however the reference to this specific curve shall be identified by the letters “EF”.

(7) With the hydrocarbon fire exposure curve the same functions (R, E, I) shall apply, however the reference to this specific curve shall be identified by the letters "HC".

(8) Where a vertical separating element with or without loadbearing function has to comply with impact resistance requirement (function M), the element shall resist a transverse concentrated load as specified in EN 1363-2.

4.3 Physically based fire exposure

(1) The loadbearing function shall be maintained during the complete duration of the fire, including the cooling phase, or during a required period of time according to EN 1991-1-2:—¹, 4.4(4).

(2) For the verification of the separating function the following applies, assuming that the normal temperature is 20 °C:

- the average temperature rise of the unexposed side of the construction should be limited to 140 K and the maximum temperature rise of the unexposed side should not exceed 180 K during the heating phase until the maximum temperature in the fire compartment is reached;
- the average temperature rise of the unexposed side of the construction should be limited to 200 K and the maximum temperature rise of the unexposed side should not exceed 240 K during the cooling phase.

4.4 Actions

(1) Thermal and mechanical actions shall be taken from EN 1991-1-2:—¹.

4.5 Design values of material properties

(1) Design values of mechanical (strength and stiffness) material properties for the fire situation $X_{d,\theta}$ should be calculated from Formula (4.1):

$$X_{d,\theta} = k_{\theta} X_k / \gamma_{M,fi} \quad (4.1)$$

where

- X_k is the characteristic value of a strength or stiffness property (generally f_k or E_k) for normal temperature design according to EN 1992-1-1;
- k_{θ} is the temperature-dependent reduction factor ($X_{k,\theta}/X_k$) for a strength or stiffness property, see 5.3;
- $\gamma_{M,fi}$ is the partial factor for the relevant mechanical material property for the fire situation.

NOTE The value of $\gamma_{M,fi}$ is 1,0 unless the National Annex gives a different value.

(2) The design values of thermal material properties for the fire situation should be taken equal to their characteristic values.

NOTE The characteristic values of thermal properties correspond to mean values.

4.6 Verification methods

(1) The model of the structural system adopted for design shall reflect the performance of the structure in the fire situation.

(2) Mechanical resistance shall be verified for the required duration of fire exposure t according to Formula (4.2):

$$E_{d,fi} \leq R_{d,fi,t} \quad (4.2)$$

where

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

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

(3) The structural analysis for the fire situation should be carried out according to EN 1990:2022 7.1.5.

NOTE For verifying resistance requirements based on the standard fire curve, unless otherwise specified, a member analysis is sufficient.

(4) Where application rules given in this document are valid only for the standard fire curve, this is identified in the relevant clauses.

(5) The following design methods may be used in order to satisfy 4.6(2):

- Use of tabulated design data for specific types of members, see Clause 6;
- Use of simplified design methods for specific types of members, see Clause 7;
- Use of advanced design methods for the analysis of members, parts of the structure or the entire structure, see Clause 8.

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

4.7 Member analysis

(1) The design effect of actions should be determined for time $t = 0$ using combination factors according to EN 1991-1-2:—¹, 6.3.

(2) As a simplification, the value of $\eta_{fi} = 0,7$ should be used.

(3) The effects of thermal deformations resulting from thermal gradients across the cross-section shall be considered.

(4) The effects of axial or in-plane thermal expansions may be neglected.

(5) The kinematic boundary conditions at supports and ends of members, applicable at time $t = 0$, may be assumed to remain unchanged throughout the fire exposure.

(6) Tabulated design data, simplified or advanced design methods given in Clause 6, Clause 7 and Clause 8 respectively are suitable for verifying members under fire conditions.

4.8 Analysis of parts of the structure

(1) The effect of actions should be determined for time $t = 0$ using combination factors according to EN 1991-1-2:—¹, 6.3.

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

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

(4) As an alternative to 4.8(1), the reactions at supports and internal forces and moments at boundaries of part of the structure may be obtained from structural analysis for normal temperature design as given in 4.7.

4.9 Global structural analysis

(1) A global structural analysis for the fire situation shall take into account:

- The relevant failure mode in fire exposure;
- The temperature-dependent material properties and member stiffness;
- Effects of thermal expansions and deformations (indirect fire actions).

4.10 Detailing

(1) Requirements related to detailing of reinforcing and prestressing steel, detailing of members, joints and fire protection systems given in Clause 9 shall be considered.

4.11 Spalling

(1) Severe spalling shall be avoided, or its influence on performance (R and/or EI) shall be taken into account.

NOTE 1 Fire-induced spalling can be influenced by several inter-related parameters including the thermal exposure, the external load and restraint conditions, the geometry, the concrete composition and properties. Examples of composition and properties are aggregate (type and size), additions (type and amount), air content, fibres content, moisture content, permeability and strength properties.

NOTE 2 Severe spalling is considered to be spalling that compromises the required loadbearing, the separating or the insulation function of a member.

(2) Clause 10 shall be considered for requirements related to spalling when the standard temperature/time curve or any curve with equivalent or lower temperature-time rate are used. For any other curve, especially hydrocarbon curves or other tunnel fire curves, experimental evidence should be provided.

4.12 Protective layers

(1) Required fire performance may also be provided by the application of protective layers.

(2) The properties and performance of the material for protective layers should be assessed using appropriate European test standards (see 9.6).

5 Material properties

5.1 General

(1) Unless given as design values, the values of material properties given in Clause 5 shall be treated as characteristic values.

(2) The properties given in Clause 5 should be used for tabulated data, simplified or advanced design methods.

NOTE Where applicable, mechanical properties are specified according to the relevant verification methods.

(3) Alternative formulations of material laws may be applied, provided the solutions are within the range of experimental evidence.

(4) When needed, thermal properties of reinforcing steel may be defined according to EN 1993-1-2.

NOTE These properties can be used when 8.2(5) does not apply.

(5) The properties given in this standard should be considered to apply for temperatures up to 1 200 °C.

(6) For the properties of stainless steel reinforcement at elevated temperatures, EN 1993-1-2 may be applied for simplified design method (Clause 7) and advanced design method (Clause 8). Tabulated design methods are not applicable with stainless steel.

(7) Properties of lightweight aggregate concrete at high temperature may be taken according to Annex A.

NOTE 1 Specific rules for fibre reinforced concrete are given in Informative Annex B.

NOTE 2 Specific rules for recycled aggregates concrete are given in Informative Annex C.

5.2 Concrete thermal properties

5.2.1 Emissivity coefficient

(1) In reference to EN 1991-1-2:—1, 5.1, Note, the emissivity related to the concrete surface should be taken as 0,7.

5.2.2 Thermal conductivity

(1) The thermal conductivity $\lambda_c(\theta_c)$ of concrete should be taken as:

$$\lambda_c(\theta_c) = 2 - 0,2451 (\theta_c/100) + 0,0107 (\theta_c/100)^2 \text{ (W/(m K))} \quad \text{for } \theta_c \leq 140 \text{ °C} \quad (5.1)$$

$$\lambda_c(\theta_c) = -0,02604 \theta_c + 5,324 \text{ (W/(m K))} \quad \text{for } 140 < \theta_c < 160 \text{ °C} \quad (5.2)$$

$$\lambda_c(\theta_c) = 1,36 - 0,136 (\theta_c/100) + 0,0057 (\theta_c/100)^2 \text{ (W/(m K))} \quad \text{for } 160 \text{ °C} \leq \theta_c \leq 1\,200 \text{ °C} \quad (5.3)$$

5.2.3 Specific heat

(1) The specific heat $c_p(\theta_c)$ of normal dry concrete (moisture content $u = 0 \%$) should be taken as, (see Figure 5.1):

$$c_p(\theta_c) = 900 \text{ (J/(kg K))} \quad \text{for } 20 \text{ °C} \leq \theta_c \leq 100 \text{ °C} \quad (5.4)$$

$$c_p(\theta_c) = 900 + (\theta_c - 100) \text{ (J/(kg K))}$$

for
 $100\text{ }^{\circ}\text{C} < \theta_c \leq 200\text{ }^{\circ}\text{C}$

(5.5)

$$c_p(\theta_c) = 1\,000 + (\theta_c - 200)/2 \text{ (J/(kg K))}$$

for
 $200\text{ }^{\circ}\text{C} < \theta_c \leq 400\text{ }^{\circ}\text{C}$

(5.6)

$$c_p(\theta_c) = 1\,100 \text{ (J/(kg K))}$$

for
 $400\text{ }^{\circ}\text{C} < \theta_c \leq 1\,200\text{ }^{\circ}\text{C}$

(5.7)

where

θ_c is the concrete temperature ($^{\circ}\text{C}$) (see Figure 5.1).

(2) Where the moisture content is not considered explicitly in the calculation method, the function given for the specific heat of concrete may be modelled by a constant value, $c_{p,\text{peak}}$, between $100\text{ }^{\circ}\text{C}$ and $115\text{ }^{\circ}\text{C}$ (see Figure 5.1):

$$c_{p,\text{peak}} = 900 \text{ J/(kg K) for moisture content of } u = 0\text{ \% of concrete weight}$$

(5.8)

$$c_{p,\text{peak}} = 1\,470 \text{ J/(kg K) for moisture content of } u = 1,5\text{ \% of concrete weight}$$

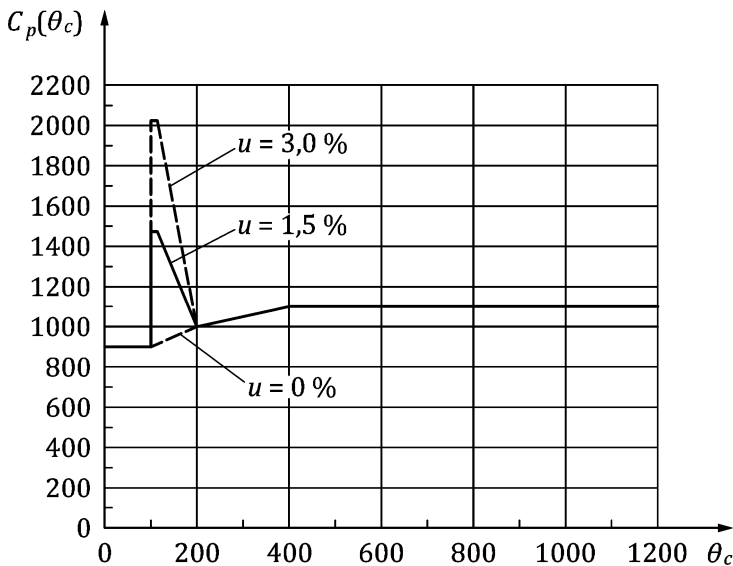
(5.9)

$$c_{p,\text{peak}} = 2\,020 \text{ J/(kg K) for moisture content of } u = 3,0\text{ \% of concrete weight}$$

(5.10)

and a linear relationship between $(115\text{ }^{\circ}\text{C}, c_{p,\text{peak}})$ and $(200\text{ }^{\circ}\text{C}, 1\,000 \text{ J/(kg K)})$. For $\theta_c > 200\text{ }^{\circ}\text{C}$, $c_p(\theta_c)$ may be taken according to (1). For other moisture contents a linear interpolation may be done.

NOTE When no data is provided, a moisture content of $u = 1,5\text{ \%}$ can be assumed for thermal analysis.



Key

$c_p(\theta_c)$ in J/(kgK)
 θ in $^{\circ}\text{C}$

Figure 5.1 — Specific heat, $c_p(\theta_c)$, as function of temperature at 3 different moisture contents, u , of 0 %, 1,5 % and 3 % by weight of concrete

5.2.4 Density

(1) The variation of concrete density with temperature is influenced by water loss and should be taken as follows

$$\rho(\theta_c) = \rho(20\text{ °C}) \text{ (kg/m}^3\text{)} \quad \text{for } 20\text{ °C} \leq \theta_c \leq 115\text{ °C} \quad (5.11)$$

$$\rho(\theta_c) = \rho(20\text{ °C}) \cdot (1 - 0,02(\theta_c - 115)/85) \text{ (kg/m}^3\text{)} \quad \text{for } 115\text{ °C} < \theta_c \leq 200\text{ °C} \quad (5.12)$$

$$\rho(\theta_c) = \rho(20\text{ °C}) \cdot (0,98 - 0,03(\theta_c - 200)/200) \text{ (kg/m}^3\text{)} \quad \text{for } 200\text{ °C} < \theta_c \leq 400\text{ °C} \quad (5.13)$$

$$\rho(\theta_c) = \rho(20\text{ °C}) \cdot (0,95 - 0,07(\theta_c - 400)/800) \text{ (kg/m}^3\text{)} \quad \text{for } 400\text{ °C} < \theta_c \leq 1\,200\text{ °C} \quad (5.14)$$

5.3 Mechanical properties

5.3.1 Concrete

5.3.1.1 Concrete under compression

(1) The strength and deformation properties of uniaxially stressed concrete at elevated temperatures should be obtained from stress-strain relationships as presented in Figure 5.2.

(2) The stress-strain relationships given in Figure 5.2 should be defined by three parameters:

- the compressive strength $f_{c,\theta}$;
- the strain $\varepsilon_{c1,\theta}$ corresponding to $f_{c,\theta}$;
- the ultimate strain $\varepsilon_{cu1,\theta}$.

(3) Values for each of these parameters should be taken from Table 5.1 as a function of concrete temperatures. For intermediate values of the temperature, linear interpolation may be used.

(4) The parameters specified in Table 5.1 for $f_{ck} < 70\text{ MPa}$ and for $f_{ck} \geq 70\text{ MPa}$ should be used for normal weight concrete with siliceous or calcareous (containing at least 80 % calcareous aggregate by weight) aggregates.

Table 5.1 — Values for the main parameters of the stress-strain relationships of normal weight concrete with siliceous or calcareous aggregates at elevated temperatures

Concrete temp. θ	$k_{c,\theta} = f_{c,\theta}/f_{ck}$			$\varepsilon_{c1,\theta}$	$\varepsilon_{cu1,\theta}$
	$f_{ck} < 70$ MPa Siliceous aggregates	Calcareous aggregates	$f_{ck} \geq 70$ MPa any type of aggregates		
[°C]	[-]	[-]	[-]	[-]	[-]
1	2	3	4	5	6
20	1,00	1,00	1,00	0,0025	0,0200
100	1,00	1,00	0,75	0,0040	0,0225
200	0,95	0,97	0,75	0,0055	0,0250
300	0,85	0,91	0,75	0,0070	0,0275
400	0,75	0,85	0,75	0,0100	0,0300
500	0,60	0,74	0,60	0,0150	0,0325
600	0,45	0,60	0,45	0,0250	0,0350
700	0,30	0,43	0,30	0,0250	0,0375
800	0,15	0,27	0,15	0,0250	0,0400
900	0,08	0,15	0,08	0,0250	0,0425
1 000	0,04	0,06	0,04	0,0250	0,0450
1 100	0,01	0,02	0,01	0,0250	0,0475
1 200	0,00	0,00	0,00	—	—
NOTE The values at 20°C are conventional values to be used for calculations in a fire situation. The softening branch is indicated for the purpose of numerical calculations.					

(5) For thermal actions in accordance with EN 1991-1-2:—1, 5.3 (Physically based models), when considering the cooling phase, the strength of concrete heated to a maximum temperature $\theta_{c,max}$ and having cooled down to 20 °C may be taken according to Formula (5.15):

$$f_{c,\theta,20\text{ °C}} = \varphi f_{ck} \quad (5.15)$$

where for:

— $f_{ck} < 70$ MPa

$$\varphi = f_{c,\theta_{max}}/f_{ck} \quad \text{for } 20\text{ °C} \leq \theta_{max} < 100\text{ °C} \quad (5.16)$$

$$\varphi = (-0,0005 \times \theta_{max} + 1,05) (f_{c,\theta_{max}}/f_{ck}) \quad \text{for } 100\text{ °C} \leq \theta_{max} < 300\text{ °C} \quad (5.17)$$

$$\varphi = 0,9 (f_{c,\theta_{max}}/f_{ck}) \quad \text{for } \theta_{max} \geq 300\text{ °C} \quad (5.18)$$

— $f_{ck} \geq 70$ MPa

$$\varphi = f_{c,\theta_{max}}/f_{ck} \quad \text{for } 20\text{ °C} \leq \theta_{max} < 1\,200\text{ °C} \quad (5.19)$$

The reduction factor ($f_{c,\theta_{max}}/f_{ck}$), which corresponds to the coefficient ($f_{c,\theta}/f_{ck}$) at the maximum temperature $\theta_{c,max}$, should be taken according to Table 5.1.

The values of $\varepsilon_{c1,\theta}$ and $\varepsilon_{cu1,\theta}$ of the stress-strain relationship may both be maintained equal to the corresponding value for $\theta_{\max}$.

During the cooling down of concrete with $\theta_{\max} \geq \theta \geq 20^\circ\text{C}$, the corresponding compressive cylinder strength $f_{c,\theta}$ may be interpolated in a linear way between $f_{c,\theta_{\max}}$ and $f_{c,\theta,20^\circ\text{C}}$.

(6) The relation between $\sigma_c(\theta)$ and ε_c shown in Figure 5.2 and described by Formula (5.20) may be used to model the response of concrete to uniaxial compression at elevated temperatures.

$$\text{for } \varepsilon_c \leq \varepsilon_{c1,\theta} : \sigma_c(\theta) = \frac{3\varepsilon_c \cdot f_{c,\theta}}{\varepsilon_{c1,\theta} \left(2 + \left(\frac{\varepsilon_c}{\varepsilon_{c1,\theta}} \right)^3 \right)} \quad (5.20)$$

For numerical purposes a descending branch may be used. Linear or nonlinear models may be used for $\varepsilon_{c1,\theta} < \varepsilon_c \leq \varepsilon_{cu1,\theta}$.

NOTE The model implicitly includes effects from creep strain and transient state strain developed during heating. It can have some limitations in case of loading-unloading scenarios or cooling phase.

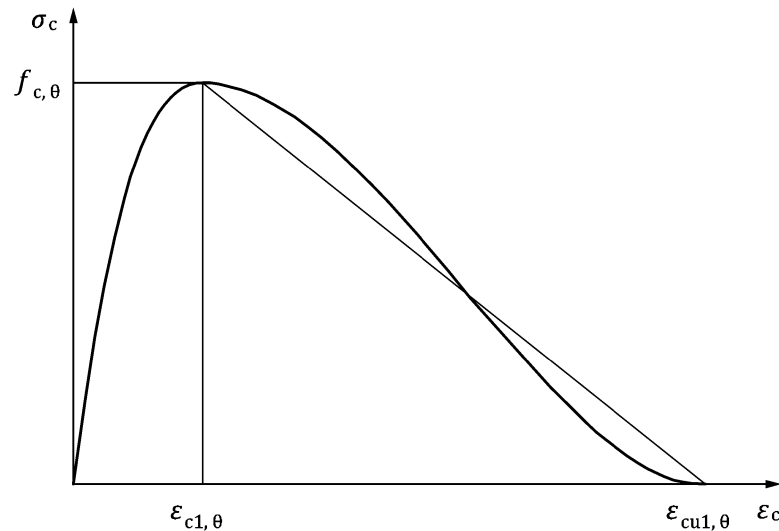


Figure 5.2 — Mathematical model for stress-strain relationships of concrete under compression at elevated temperatures

5.3.1.2 Tensile strength

(1) Unless otherwise specified, the tensile strength of concrete should be ignored.

(2) If the tensile strength is taken into account when using the simplified or advanced calculation method, the reduction of the characteristic tensile strength of concrete may be obtained by the coefficient $k_{ct,\theta} = f_{ct,\theta}/f_{ct}$. In absence of more accurate information the following values should be used:

$$k_{ct,\theta} = 1,0 \quad \text{for } 20^\circ\text{C} \leq \theta_c \leq 100^\circ\text{C} \quad (5.21)$$

$$k_{ct,\theta} = (600 - \theta_c)/500 \quad \text{for } 100^\circ\text{C} < \theta_c \leq 600^\circ\text{C} \quad (5.22)$$