EUROCODES
Background and Applications

"Dissemination of information for training" workshop

18-20 February 2008

Brussels

Structural fire design

Organised by
European Commission: DG Enterprise and Industry, Joint Research Centre

with the support of
CEN/TC250, CEN Management Centre and Member States

Wednesday, February 20 – Palais des Académies

Structural fire design
Roi Baudoin room

9:00-9:30	General presentation of Eurocode Fire Parts	J. Kruppa *CTICM*
9:30-10:15	Eurocode 1 - 1.2 Action in case of fire	T. Lennon *BRE*
10:15-10:30	Coffee	
10:30-11:45	Eurocode 2 - 1.2 concrete structures	T. Hietanen *RT Betonikeskus*
11:45-13.00	Eurocode 3 - 1.2 steel structures	L. Twilt *TNO*
13:00-14:30	Lunch	
14:30-15:45	Eurocode 4 - 1.2 composite structures	J. B. Schleich *University of Liege*
15:45-16:00	Coffee	
16:00-17:00	Eurocode 5 - 1.2 timber structures	H. Hartl *University Innsbruck* J. Fornather *Austrian Standards Institute*
17:00-17:45	Eurocode 9 - aluminium alloys structures	N. Forsén *Multiconsult*
17:45-18:00	Discussion and close	

All workshop material will be available at
http://eurocodes.jrc.ec.europa.eu

GENERAL PRESENTATION OF EUROCODE FIRE PARTS

J. Kruppa
CTICM

Structural Fire Design according to Eurocodes

Joël KRUPPA
CTICM
Coordinator CEN TC 250 / Horizontal Group "FIRE"

SAFETY in CASE of FIRE
concerning the construction work :

- Load bearing capacity of the construction can be assumed for a specific period of time
- The generation and spread of fire and smoke within the works are limited
- The spread of fire to neighbouring construction works is limited
- The occupants can leave the works or be rescued by other means
- The safety of rescue teams is taken into consideration

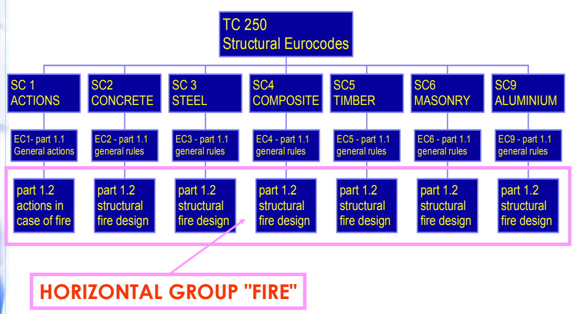
To prove compliance with Essential Requirements :

- Tests + extended applications of results
- calculation and/or design methods
- combination of tests and calculations

Fire parts within :

EC 1 : ACTIONS on STRUCTURES

EC 2 : CONCRETE STRUCTURES
EC 3 : STEEL STRUCTURES
EC 4 : COMPOSITE STRUCTURES
EC 5 : TIMBER STRUCTURES
EC 6 : MASONRY
EC 9 : ALUMINIUM ALLOYS STRUCTURES



Selection thermal actions

- nominal fires
- parametric fire (simple fire models)
- advanced fire models

Some coefficients for load combination
Default value for reduction factor for the design load level in fire situation
Use of advanced calculation models
Some material properties
Use of informative annex on simple calculation method

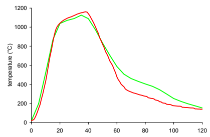
2.1 General

(1) A structural fire design analysis should take into account the following steps as relevant :

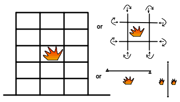
- selection of the relevant design fire scenarios,
- determination of the corresponding design fires,
- calculation of temperature evolution within the structural members,
- calculation of the mechanical behaviour of the structure exposed to fire.

Various Steps for Assessments

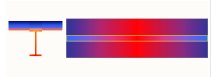
Fire Development and propagation



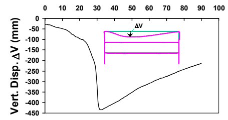
Structural schematisation



Heat Transfer to structural elements



Mechanical behaviour at elevated temperatures



2.2 Design fire scenario

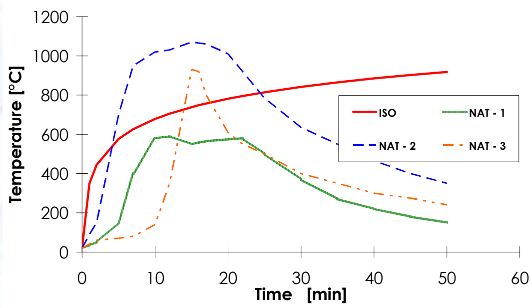
- (1) To identify the accidental design situation, the relevant design fire scenarios and the associated design fires should be determined on the basis of a fire risk assessment.
- (2) For structures where particular risks of fire arise as a consequence of other accidental actions, this risk should be considered when determining the overall safety concept.
- (3) Time- and load-dependent structural behaviour prior to the accidental situation needs not be considered, unless (2) applies.

Real scale fires

2.3 Design fire

- (1) For each design fire scenario, a design fire, in a fire compartment, should be estimated according to section 3 of this Part.
- (2) The design fire should be applied only to one fire compartment of the building at a time, unless otherwise specified in the design fire scenario.
- (3) For structures, where the national authorities specify structural fire resistance requirements, it may be assumed that the relevant design fire is given by the standard fire, unless specified otherwise .

ISO fire versus "natural" fires



2.4 Temperature Analysis

- (1)P When performing temperature analysis of a member, the position of the design fire in relation to the member shall be taken into account.
- (2) For external members, fire exposure through openings in facades and roofs should be considered.
- (3) For separating external walls fire exposure from inside (from the respective fire compartment) and alternatively from outside (from other fire compartments) should be considered when required.

2.4 Temperature Analysis (cont'd)

- (4) Depending on the design fire chosen in section 3, the following procedures should be used :
  - with a nominal temperature-time curve, the temperature analysis of the structural members is made for a specified period of time, without any cooling phase;
  - *NOTE 1 The specified period of time may be given in the National Regulations or obtained from Annex F following the specifications of the National Annex.*
  - with a fire model, the temperature analysis of the structural members is made for the full duration of the fire, including the cooling phase.
  - *NOTE 2 Limited periods of fire resistance may be set in the National Annex.*

2.5 Mechanical Analysis

(1)P The mechanical analysis shall be performed for the same duration as used in the temperature analysis.

(2) Verification of fire resistance should be in the time domain:
- $t_{fi,d} \geq t_{fi,requ}$

- or in the strength domain:
  - $R_{fi,d,t} \geq E_{fi,d,t}$
- or in the temperature domain:
  - $\Theta_d \leq \Theta_{cr,d}$
- where
  - $t_{fi,d}$ design value of the fire resistance
  - $t_{fi,requ}$ required fire resistance time
  - $R_{fi,d,t}$ design value of the resistance of the member in the fire situation at time t
  - $E_{fi,d,t}$ design value of the relevant effects of actions in the fire situation at time t
  - Θ_d design value of material temperature
  - $\Theta_{cr,d}$ design value of the critical material temperature

EUROCODES
2 to 6 and 9

parts 1. 2

The parts dealing with structural fire resistance in EC2 to EC6 & EC9 have the following layout:

- General (scope, definitions, symbols and units)
- Basic principles (performances requirements, design values of material properties and assessment methods)
- Material properties (strength and deformation and thermal properties)
- Assessment methods
- Constructional details (if any)
- Annexes (additional information)

2.1.1 General

- (1)P 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 load bearing function during the relevant fire exposure.
- (2)P Where compartmentation is required, the elements forming the boundaries of the fire compartment, including joints, shall be designed and constructed in such a way that they maintain their separating function during the relevant fire exposure. This shall ensure, where relevant, that:
  - integrity failure does not occur, see EN 1991-1-2
  - insulation failure does not occur, see EN 1991-1-2
  - thermal radiation from the unexposed side is limited.

Exemple from EC2-1.2

2.1.1 General (cont'd)

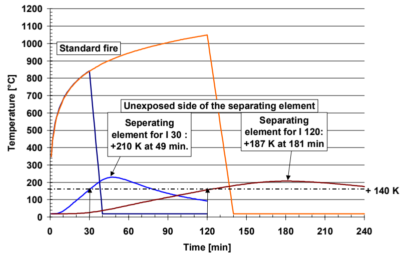
- (3)P Deformation criteria shall be applied where the means of protection, or the design criteria for separating elements, require consideration of the deformation of the load bearing structure.
- (4) Consideration of the deformation of the load bearing structure is not necessary in the following cases, as relevant:
  - the efficiency of the means of protection has been evaluated according to […],
  - the separating elements have to fulfil requirements according to nominal fire exposure.

2.1.3 Parametric fire exposure

- (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 gas temperature in the fire compartment is reached;
  - the average temperature rise of the unexposed side of the construction should be limited to $\Delta\theta_1$ and the maximum temperature rise of the unexposed side should not exceed $\Delta\theta_2$ during the decay phase.

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

1



2

Experimentations carried out in the 80s ("Investigating the unexposed surface temperature criteria of standard ASTM E 119", by K. J. Schwartz and T.T. Lie, Fire technology, vol 21, N0 3, August 1985):
- concluded the self-ignition temperatures of ordinary combustibles, in contact with unexposed surface of separating element are in excess of 520 °F (271°C),
- suggested to use 400°F (222 K) for average temperature rise and 450°F (250 K) for maximum temperature rise at any point

2.3 Design values of material properties

(1)P Design values of mechanical (strength and deformation) material properties Xd,fi are defined as follows:

$$X_{d,fi} = k_\theta X_k / \gamma_{M,fi}$$

- X_k characteristic value of a strength or deformation property
- k_θ reduction factor for a strength or deformation property dependent on temperature
- $\gamma M_{,fi}$ partial safety factor for the relevant material property, for the fire situation

(2)P Design values of thermal material properties Xd,fi are defined as follows:

$$X_{d,fi} = X_{k,\theta} / \gamma_{M,fi} \quad \text{or} \quad X_{d,fi} = \gamma_{M,fi} X_{k,\theta}$$

- $X_{k,\theta}$ value of a material property in fire design
- $\gamma_{M,fi}$ partial safety factor for the relevant material property, for the fire situation.

Note 1: The value of $\gamma_{M,fi}$ for use in a Country may be found in its National Annex. The recommended value is: $\gamma_{M,fi}$ = 1,0

Note 2: If the recommended values are modified, the tabulated data may require modification

Load-bearing function of a structure shall be assumed for the relevant duration of fire exposure *t* if :

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

where :

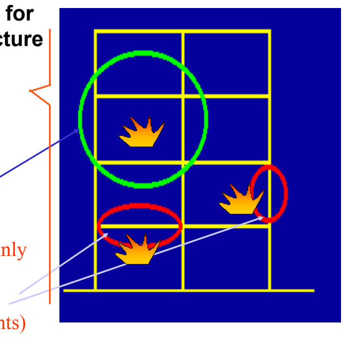
- $E_{d,t,fi}$: design effect of actions (Eurocode 1 part 1.2)
- $R_{d,t,fi}$: design resistance of the structure at time t

Various possibilities for analysis of a structure

global structural analysis

analysis of parts of the structure

member analysis (mainly when verifying standard fire resistance requirements)



Member Analysis

(1) The effect of actions should be determined for time t = 0 using combination factors $\psi_{1,1}$ or $\psi_{1,2}$ according to EN 1991-1-2 Section 4.

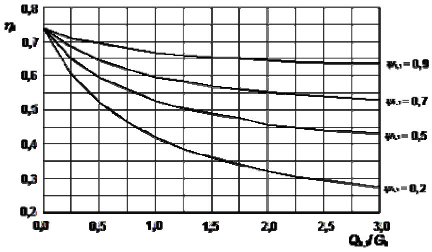
(2) As a simplification to (1) the effects of actions may be obtained from a structural analysis for normal temperature design as:

$$E_{d,fi} = \eta_{fi} E_d$$

Where

E_d is the design value of the corresponding force or moment for normal temperature design, for a fundamental combination of actions (see EN 1990);
η_{fi} is the reduction factor for the design load level for the fire situation.

η_{fi}



assumptions: γ_{GA} = 1,0, γ_G = 1,35 and γ_Q = 1,5.

Note 2: As a simplification a recommended value of η_{fi} = 0,7 may be used.

Exemple from EC2-1.2

Member Analysis (cont'd)

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

(5) The boundary conditions at supports and ends of member, applicable at time t = 0, are assumed to remain unchanged throughout the fire exposure.

Exemple from EC2-1.2

Global structural analysis

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

Assessment methods

covering both thermal model and mechanical model

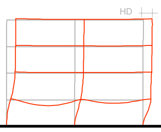
tabulated data

standard fire resistance [min]	dimension on axis distance	Minimum dimensions [mm]				
		Possible combinations of a (average axis distance) and b_{min} (width of beam)				Web thickness
R 30	b_{min} a	80 25	120 15	160 10	200 10	80
R 60	b_{min} a	120 40	160 35	200 30	300 25	100
R 90	b_{min} a	150 55	200 45	250 40	400 35	100
R 120	b_{min} a	200 65	240 55	300 50	500 45	120
R 180	b_{min} a	240 80	300 70	400 65	600 60	140
R 240	b_{min} a	280 90	250 80	500 75	500 70	160

simple calculation models

$$\Delta \theta_{a,t} = \frac{\lambda_p A_p / V}{d_p c_a \rho_a} \frac{(\theta_{g,t} - \theta_{a,t})}{(1 + \phi/3)} \Delta t - (e^{\phi/10} - 1) \Delta \theta_{g,t}$$

advanced calculation models



Data on fire protection systems

Membrane protection

- TS 13381-1 : horizontal membranes
- ENV 13381 -2 : vertical membranes

Fire protection to :

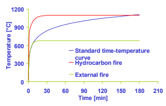
- ENV 13381 -3 : concrete members
- ENV 13381 -4 (& -8 ?) : steel members
- ENV 13381 -5 : concrete/profiled steel sheet
- ENV 13381 -6 : concrete filled hollow steel columns
- ENV 13381 -7 : timber members

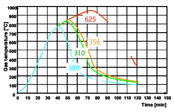
Possible Design Procedures

Project Design

Prescriptive Regulation *(Thermal Actions given by a Nominal Fire)*

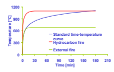
Performance-Based Code *(Physically Based Thermal Actions)*





Possible Design Procedures (cont'd)

Prescriptive Regulation *(Thermal Actions given by a Nominal Fire)*



- Member analysis → Mechanical actions at boundaries
- Analysis of part of the structure → Mechanical actions at boundaries
- Analysis of the entire structure → Selection of mechanical actions

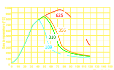
Tabulated data

Simple calculation models

Advanced calculation models

Possible Design Procedures (cont'd)

Performance-Based Code



Fire development Model

- Member analysis → Mechanical actions at boundaries
- Analysis of part of the structure → Mechanical actions at boundaries
- Analysis of the entire structure → Selection of mechanical actions

Simple calculation models

Advanced calculation models

ISO Concept vs FSE* Approach

Model	ISO – concept (current approach)	FSE* Approach
fire model	**ISO-fire** 1100°C @ 120min	**all design fires** 300°C @120min 1300°C @ 20min … And cooling phase
structural model	isolated elements	part of structure with interaction between elements
heat transfert model	uniform temperature over the whole surface	thermal gradient in 2 , 3 directions
mechanical model	mainly ultimate load bearing capacity	ultimate and "deformation" limit states

* : Fire Safety Engineering

Tank you for your attention

EUROCODE 1 - 1.2 ACTION IN CASE OF FIRE

T. Lennon
BRE

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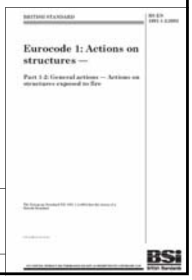
Eurocode 1: Actions on structures – Part 1-2: General actions – Actions on structures exposed to fire



Tom Lennon
Principal Consultant, BRE, UK

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Scope of presentation

Introduction to structural fire engineering design

Section 3 **Thermal actions for temperature analysis**
- 3.2 **Nominal temperature-time curves**
- 3.3 **Natural fire models**

Section 4 **Mechanical actions for structural analysis**
- 4.2 **Simultaneity of actions**
- 4.3 **Combination rules for actions**

Annex A Parametric time-temperature curves
Annex B Thermal actions for external members
Annex C Localised fires
Annex D Advanced fire models
Annex E Fire load densities
Annex F Equivalent time of fire exposure
Annex G Configuration factor

Worked example – Equivalent time of fire exposure

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Introduction to structural fire engineering design

Why structural fire engineering?

What is structural fire engineering design?

How do we do it?

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Structural fire engineering design – Do we need it?

Existing body of data

Tried and tested solutions

Accepted levels of safety and reliability

Tabulated data generally conservative

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Structural fire engineering design – Do we need it? – YES!

Levels of safety unknown
Degree of conservatism unknown
No account of interaction between structural elements
No account of alternative load carrying mechanisms
No account of alternative modes of failure

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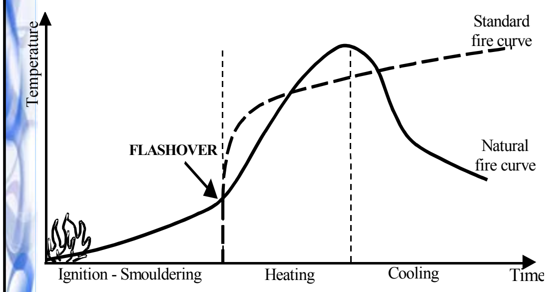
Structural fire engineering design – Do we need it? – YES!

Complex structures not covered by existing regulatory requirement – "fire engineering may be the only suitable approach"
Provides for a more rational approach to the design of buildings for fire if undertaken as part of an overall fire safety strategy
Change of use or renovation of existing structure – possible increased fire resistance requirement, removal of existing means of ensuring fire resistance
Uncertainties in existing prescriptive approach

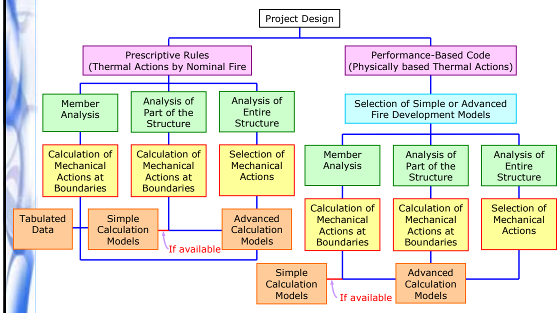
Structural fire engineering design – what is it?



Life safety

Structural damage – risk of collapse – structural fire engineering only concerned with this phase of the fire

General - Design Procedures



Structural fire design procedure

- Structural fire design procedure takes into account:
- Selection of relevant design fire scenarios
- Determination of corresponding design fires
- Calculation of temperature within the structural members
- Calculation of mechanical behaviour of the structure exposed to fire
- EN1991-1-2 is principally concerned with the first two above. Fire parts of the material codes cover the remaining two.

Consider relevant design fire scenario

- Building fire / **tunnel fire / petrochemical fire**
- **Localised fire /** fully developed fire
- **Identification of suitable compartment size/occupancy/ventilation condition for subsequent analysis – representative of "reasonable worst case scenario"**
- **The choice of the design fire scenario will dictate the choice of the design fire to be used in subsequent analysis.**
- **The choice of a particular fire design scenario should be based on a risk assessment taking into account the likely ignition sources and any fire detection/suppression systems available.**

Choose appropriate design fire

- For fully developed post-flashover building (compartment) fires the usual choice is between nominal and natural fire exposures
- Nominal fires are representative fires for the purposes of classification and comparison but bear no relationship to the specific characteristics (fire load, thermal properties of compartment linings, ventilation condition) of the building considered
- Natural fires are calculation techniques based on a consideration of the physical parameters specific to a particular building.

Modelling compartment fires

- In compartment fires it is often assumed that the whole compartment is fully involved in the fire at the same time and the same temperature applies throughout. Such a scenario is the basis of a one zone model.
- Two zone models exist in which the height of the compartment is separated into two gaseous layers each with their own thermal environment
- Three zone models exist in which there is a mixed gas layer separating the upper and lower gas levels
- Computational Fluid Dynamics (CFD) may be used to analyse fires in which there are no definite boundaries to the gaseous state. This type of analysis would be suitable for very large compartments such as airport terminals, atria and sports stadia. It is often used to model smoke movement.

Post-Flashover Fire Models

In a compartment flashover occurs when sustained flaming from combustibles reach the ceiling and the temperature of the hot gas layer is between 550°C and 600°C.

After flashover the rate of heat release will increase rapidly until it reaches a maximum value for the enclosure. To simplify design, the growth period between the onset of flashover and the maximum heat release rate is usually ignored and it may be assumed that when flashover occurs the rate of heat release instantaneously increases to the maximum value set by the available air.

Section 3 Thermal actions for temperature analysis

Thermal actions are given by the net heat flux:

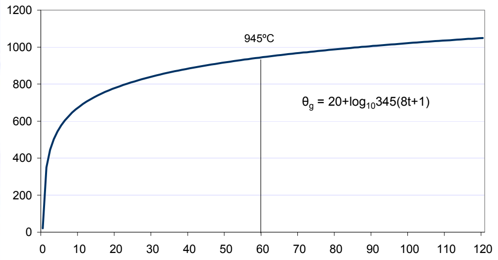
$$\dot{h}_{net} = \dot{h}_{net,c} + \dot{h}_{net,r}$$

Convective heat flux

Radiative heat flux

2.2 Nominal temperature-time curves

Standard temperature-time curve



Nominal fire curves

Other nominal curves include:
Smouldering fire curve

"Semi-Natural" fire curve

External fire exposure curve*

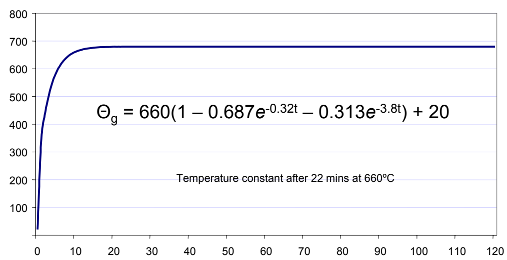
Hydrocarbon curve*

Modified hydrocarbon curve

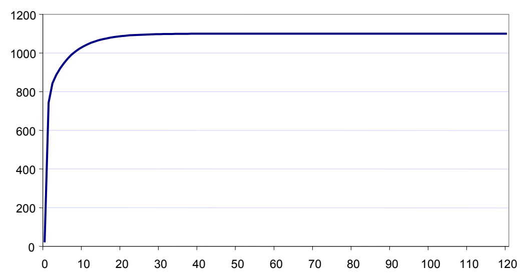
Tunnel lining curves – RWS/RABT

*** Included in the Eurocode**

External fire temperature-time curve



Hydrocarbon temperature-time curve



2.3 Natural fire models

Natural fire models are based on specific physical parameters with a limited field of application

For compartment fires a uniform temperature distribution as a function of time is generally assumed

For localised fires a non-uniform temperature distribution as a function of time is assumed

Natural fire models

Simplified fire models – compartment fires

Any appropriate fire model may be used considering at least the fire load density and the ventilation conditions

The parametric approach in Annex A of the code is one example of a simplified natural fire model

Natural fire models

Simplified fire models – external members

For external members the radiative heat flux should be calculated from the sum of the radiation from the compartment and from the flames emerging from the opening

An example of a simplified calculation method for external members is given in Annex B of the Code

Natural fire models

Simplified fire models – localised fires

In many cases flashover is unlikely to occur. In such cases a localised fire should be considered.

Annex C presents an example of a procedure for calculating temperatures in the event of a localised fire

Section 4 Mechanical actions for structural analysis

If they are likely to occur during a fire the same actions assumed for normal design should be considered.

Indirect actions can occur due to constrained expansion and deformation caused by temperature changes within the structure caused by the fire.

Section 4 Mechanical actions for structural analysis

INDIRECT thermal actions should be considered. EXCEPT where the resulting actions are:

recognized *a priori* to be negligible or favourable.

accounted for by conservatively chosen models and boundary conditions or implicitly considered by conservatively specified fire safety requirements.

The indirect actions should be determined using the thermal and mechanical properties given in the fire parts of EN1992 to EN1996 and EN1999.

For member design subjected to the standard fire only indirect actions arising from the thermal distribution through the cross-section needs to be considered.

Actions considered for ‘normal’ design should also be considered for fire design if they are likely to act at the time of a possible fire.

Variable actions should be defined for the accidental design situation, with associated partial load factors, as given in EN1990.

Simultaneous action with other independent accidental actions does not need to be considered

Additional actions (i.e partial collapse) may need to be considered during the fire exposure

Fire walls may be required to resist horizontal impact loading according to EN1363-2

When indirect actions do not need to be considered, and there is no prestressing force, the total design action (load) considering permanent and the leading variable action is given by;

$$\sum_{j\geq 1} G_{k,j} \text{ "+" } (\psi_{1,1} or \psi_{2,1}) Q_{k,1}$$

The use of $\psi 1,1$ or $\psi 2,1$ is defined in the National Annex

The values of $\psi 1,1$ and $\psi 2,1$ are given in Annex A of EN1990:2002

Action	ψ_0	ψ_1	ψ_2
Imposed loads in buildings, category (see EN 1991-1-1)			
Category A : domestic, residential areas	0,7	0,5	0,3
Category B : office areas	0,7	0,5	0,3
Category C : congregation areas	0,7	0,7	0,6
Category D : shopping areas	0,7	0,7	0,6
Category E : storage areas	1,0	0,9	0,8
Category F : traffic area, vehicle weight ≤ 30kN	0,7	0,7	0,6
Category G : traffic area, 30kN < vehicle weight ≤ 160kN	0,7	0,5	0,3
Category H : roofs	0	0	0
Snow loads on buildings (see EN 1991-1-3)*			
Finland, Iceland, Norway, Sweden	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H > 1000 m a.s.l.	0,70	0,50	0,20
Remainder of CEN Member States, for sites located at altitude H ≤ 1000 m a.s.l.	0,50	0,20	0
Wind loads on buildings (see EN 1991-1-4)	0,6	0,2	0
Temperature (non-fire) in buildings (see EN 1991-1-5)	0,6	0,5	0

NOTE The ψ values may be set by the National annex.
* For countries not mentioned below, see relevant local conditions.

As a simplification, the effect of actions in the fire condition can be determined from those used in normal temperature design

$$E_{fi,d,t} = E_{fi,d} = \eta_{fi} E_d$$

Where $\eta_{fi} = \frac{E_{fi,d,t}}{R_d}$

EUROCODES Background and Applications — Annex A Parametric Temperature-Time Curves

Brussels, 18-20 February 2008 – Dissemination of information workshop 31

EN 1991-1-2 Annex A- Parametric Equation

$\theta_g = 1325(1-0.324e^{-0.2t^*}-0.204e^{-1.7t^*}-0.472e^{-19t^*})$

where $t^* = t.\Gamma$

and $\Gamma = (O/b)^2/(0.04/1160)^2$

O is the opening factor

and b relates to the thermal inertia $\sqrt{(\rho c \lambda)}$

Where ρ = density (kg/m³)

c = specific heat (J/kgK)

Λ = thermal conductivity (W/mK)

EUROCODES Background and Applications — Parametric equation (contd)

Brussels, 18-20 February 2008 – Dissemination of information workshop 32

O = opening factor $A_v\sqrt{h}/A_t$ ($m^{1/2}$)

A_v = area of vertical openings (m²)

h = height of vertical openings (m)

A_t = total area of enclosure – walls, ceiling and floor including openings (m²)

EUROCODES Background and Applications — Parametric Equation

Brussels, 18-20 February 2008 – Dissemination of information workshop 33

Scope of Equation

- $0.02 \le O \le 0.2$ ($m^{1/2}$) (lower limit of 0.01 in UK NA)
- $100 \le b \le 2000$ (J/m² s$^{1/2}$ °K)
- $A_f \le 500$m² (No restriction in UK NA)

- mainly cellulosic fire loads
- maximum compartment height = 4m (No restriction in UK NA)
- concept of limiting duration (20 minutes for offices)

EUROCODES Background and Applications — EC1 Parametric exposure

Brussels, 18-20 February 2008 – Dissemination of information workshop 34

Cooling phase

$\Theta_g = \theta_{max} - 625(t^*-t^*_{max}.x)$ for $t^*_{max} \le 0.5$

$\Theta_g = \theta_{max} - 250(3-t^*_{max})(t^*-t^*_{max}.x)$ for $t^*_{max} < 2$

$\Theta_g = \theta_{max} - 250(t^*-t^*_{max}.x)$ for $t^*_{max} \ge 2$

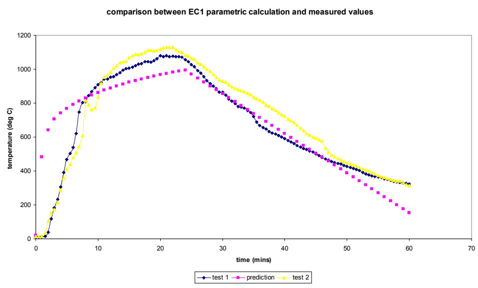
Where $t^*_{max} = (0.2\times10^{-3}.\ q_{t,d}/O).\Gamma$

And t_{max} = maximum of $(0.2\times10^{-3}.\ q_{t,d}/O)$ and t_{lim}

With t_{lim} = 25 minutes for slow fire growth rate, 20 minutes for medium fire growth rate and 15 minutes for fast fire growth rate

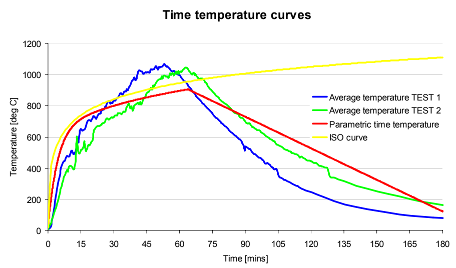
EUROCODES Background and Applications

Brussels, 18-20 February 2008 – Dissemination of information workshop 35



EUROCODES Background and Applications

Brussels, 18-20 February 2008 – Dissemination of information workshop 36



Annex B Thermal actions for external members – Simplified calculation method

Allows for the determination of:

Maximum temperatures of a compartment fire

The size and temperatures of the flames emerging from the openings

Radiation and convection parameters

Takes into account effect of wind through inclusion of forced draught and no forced draught calculations

Annex C Localised fires

Where a fully developed fire is not possible the thermal input from a localised fire source to the structural member should be considered.

Annex C provides one possible method – The UK NA specifies an alternative methodology based on existing National information

Annex D Advanced Fire Models

Annex D sets out general principles associated with advanced fire models (One zone, two zone or CFD)

There is no detailed guidance and such methods should only be used by experts

Annex E Fire load densities

Annex E presents a method for calculating design fire load densities based on characteristic values from survey data for different occupancies

The characteristic values are modified according to the risk of fire initiation and the consequence of failure related to occupancy and compartment floor area

Active fire safety measures are taken into account through a reduction in the design fire load density

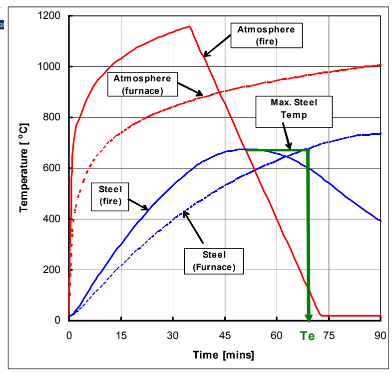
This approach is not accepted in the UK NA

Annex F Equivalent time of fire exposure

Provides a quick and easy method of relating a real fire exposure to an equivalent period in a standard fire resistance furnace

Mainly based on work on protected steel specimens

Recent analysis extended the use of the concept to unprotected steel for low fire resistance periods



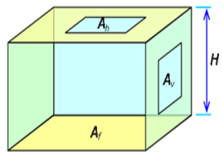
Time equivalent – calculation methods

CIB W14: $t_e = q_f\,c\,w$
Law: $t_e = kL/\sqrt{(A_v A_t)}$
Pettersson: $t_e = 0.067 q_f (A_v \sqrt{h}/A_t)^{-1/2}$
EC1: $t_{e,d} = q_{f,d}\,k_b\,w_f$

Where $q_{f,d}$ = design fire load density
k_b = factor to take into account the thermal properties of the enclosure
w_f = ventilation factor to take into account vertical and horizontal openings

Time equivalent – what is it? How does it work? How do you do it?

Worked example – fire compartment within an office building
Geometric data



Floor area (m²)	36 (6m x 6m)
Ventilation area A_v (m²)	7.2 (3.6m wide by 2m high)
Height of ventilation opening h (m)	2
Height of compartment H (m)	3.6
Area of horizontal opening (roof light) A_h	0

Time equivalent – thermal properties

Element	Material	Thermal inertia (b value – J/m²s½K)	Area (m²)
Roof	Concrete	2280	36
Floor	Plasterboard	520	36
Walls	Plasterboard	520	76.8

Time equivalent worked example

$t_{e,d} = (q_{f,d}.k_b.w_f)k_c$

Where $q_{f,d}$ = design fire load density (MJ/m²)

k_b is a factor dependent on thermal properties of the lining materials
And w_f is a ventilation factor given by:

$w_f = (6/H)^{0.3}\,[0.62 + 90(0.4-\alpha_v)^4]$ in the absence of vertical openings
Where H is the height of the compartment (m) and
$\alpha_v = A_v/A_f$

k_c = factor dependent on material = 1.0 for protected steel

Time equivalent worked example

$b = (\rho c \lambda)^{1/2}$ (J/m²s½K)	k_b (min.m²/MJ)
b > 2500	0.04 (0.055)
720≤b≤2500	0.055 (0.07)
b<720	0.07 (0.09)

Time equivalent worked example

Occupancy	Characteristic fire load density (MJ/m²) 80% fractile
Dwelling	948 (400)
Hospital	280 (350)
Hotel	377 (400)
Office	511 (570)
School classroom	347 (360)

Time equivalent worked example

$q_{f,d}$ = 570 MJ/m²

w_f = 0.863 (α_v = 0.2)

k_b = 0.07 (b = 945 ($\Sigma(b_j A_j / A_j)$))

k_c = 1.0 (protected steel beam)

$t_{e,d}$ = 570 x 0.863 x 0.07 = 34 minutes therefore 60 minutes fire protection would be appropriate

Time equivalent – important questions to ask

Have sensitivity studies been carried out on % glazing removed during the fire. Breaking of glass during a fire is very difficult to predict. In reality the ventilation area will vary with time during the fire process.

What value has been used for the fire load density

What confidence is there in the final configuration of the compartment linings? In the absence of definite data then a figure of k_b = 0.09 should be used (UK National Annex)

Annex G Configuration Factor

Text book information on general principles for radiative heat transfer

Specific guidance for external members

Thank you for your attention!

EUROCODE 2 - 1.2 CONCRETE STRUCTURES

T. Hietanen
RT Betonikeskus

EN 1992-1-2
Fire design of concrete structures

Tauno Hietanen
Finnish Concrete Industry Association
convenor of Project Teams
- ENV 1992-1-2
- EN 1992-1-2

EN 1992-1-2 Fire design of concrete structures

- Sections 1 and 2 General, Basis of design
- Section 3 Material properties
- Section 4 Design procedures
  - **Simplified calculation method 4.2, Annex A, B and E**
  - **Shear, torsion and anchorage 4.4 and Annex D**
  - **Spalling 4.5**
- Section 5 Tabulated data
  - **Annex C**
- Section 6 High strength concrete

Project Team

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Mr. Robin T. Whittle *- structural design consultant,*	Ove Arup & Partners	United Kingdom Technical secretary

and National Technical Contacts

Technical background

- **CEB Bulletins "Fire design of concrete structure", latest N° 208 July 1991**
- **EC 2:Part 10, 1990, prepared for the Commission by experts J.C, Dotreppe (B), L. Krampf (D), J. Mathez (F)**
  - including material properties harmonized between EC 2, 3 and 4
- **ENV 1992-1-2 November 1995**
  - and national comments on ENV
- **Project Team started the revision 1999 and prEN was approved for Formal Vote 2002**

Scope of EN 1992-1-2

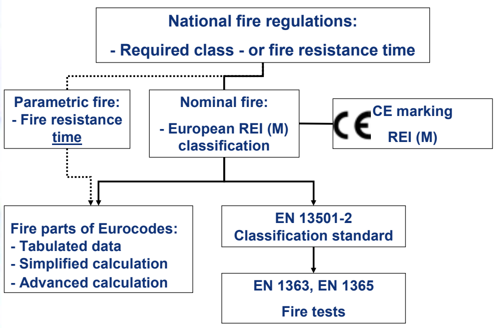
(5)P This Part 1-2 of EN 1992 applies to structures, or parts of structures, that are within the scope of EN 1992-1-1 and are designed accordingly. However, it does not cover:
- structures with prestressing by external tendons
- shell structures

(6)P The methods given in this Part 1-2 of EN 1992 are applicable to normal weight concrete up to strength class C90/105 and for lightweight concrete up to strength class LC55/60. Additional and alternative rules for strength classes above C50/60 are given in section 6.

Summary of alternative verification methods given in EN 1992-1-2

	Tabulated data	Simplified calculation methods	Advanced calculation methods
Member analysis	YES •Data given for Standard fire only	YES •Standard fire and parametric fire	YES •Only the principles are given
Analysis of part of the structure	NO	•Temperature profiles given for Standard fire only	
Global structural analysis	NO	NO	

Resistance to Fire CE-marking



EN 1992-1-2
Fire design of concrete structures

- Sections 1 and 2 General, Basis of design
- **Section 3 Material properties**
- Section 4 Design procedures
  - **Simplified calculation method 4.2, Annex A, B and E**
  - **Shear, torsion and anchorage 4.4 and Annex D**
  - **Spalling 4.5**
- Section 5 Tabulated data
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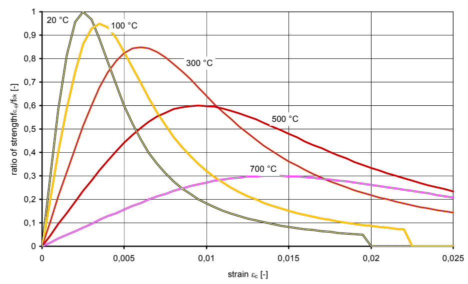
- Section 6 High strength concrete

Section 3 Material properties

- Strength and deformation properties in Section 3 are given for simplified and advanced calculation methods
- Strength reduction curves for Tabulated data (in Section 5) and Simplified calculation methods (in Section 4) are derived from material properties in section 3
- Thermal properties are given in Section 3 for calculation of temperature distribution inside the structure
- Material properties for lightweight concrete are not given due to wide range of lightweight aggregates
  - **this does not exclude use of lightweight aggregate concrete, see e.g. Scope and Tabulated data**
- Strength and deformation properties are applicable to heating rates similar to standard fire curve (between 2 and 50 K/min)
- Residual strength properties are not given

Concrete compressive strength

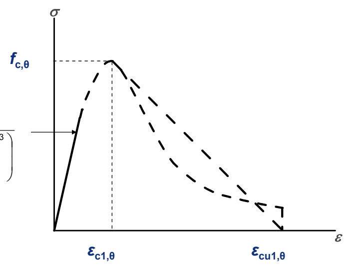


Concrete: Stress-strain relationship

Mathematical model and parameters $f_{c,\theta}$, $\varepsilon_{c1,\theta}$ and $\varepsilon_{cu1,\theta}$

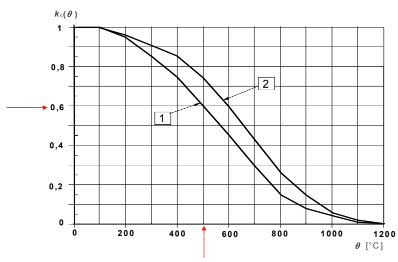
α_{CC} = 1,0 in fire design

$$\frac{3\varepsilon f_{c,\theta}}{\varepsilon_{c1,\theta}\left(2+\left(\frac{\varepsilon}{\varepsilon_{c1,\theta}}\right)^{3}\right)}$$



Strength reduction of concrete

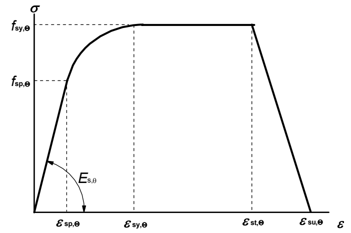
- **The same strength reduction values are given for simplified calculation methods in Section 4**
  1. Siliceous concrete
  2. Calcareous concrete



EUROCODES Background and Applications

Reinforcing and prestressing steel: Stress-strain relationship

- **Mathematical model and parameters $f_{sp,\theta}$, $f_{sy,\theta}$ and $E_{s,\theta}$**

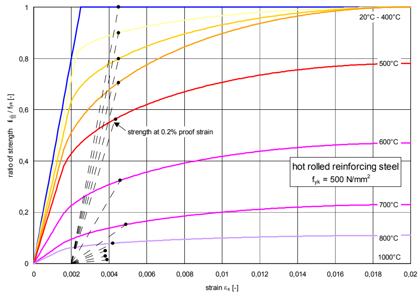


$\varepsilon_{sp,\theta} = f_{sp,\theta} / E_{s,\theta}$ $\varepsilon_{sy,\theta} = 0{,}02$ $\varepsilon_{st,\theta} = 0{,}15$ $\varepsilon_{su,\theta} = 0{,}20$

Class A reinforcement: $\varepsilon_{st,\theta} = 0{,}05$ $\varepsilon_{su,\theta} = 0{,}10$

EUROCODES Background and Applications

Reinforcing steel strength

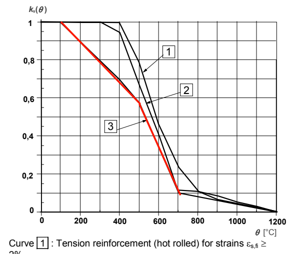


EUROCODES Background and Applications

Strength reduction of reinforcing steel

Strength reduction for simplified calculation methods in Section 4

- **Class N (normal)**



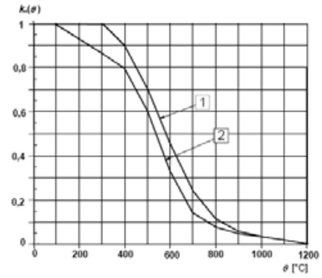
Curve 1 : Tension reinforcement (hot rolled) for strains $\varepsilon_{s,fi} \geq$ 2%
Curve 2 : Tension reinforcement (cold worked) for strains $\varepsilon_{s,fi} \geq 2\%$
Curve 3 : Compression reinforcement and tension reinforcement for strains $\varepsilon_{s,fi} < 2\%$

EUROCODES Background and Applications

Strength reduction of steel

Strength reduction for simplified calculation methods in Section 4

- **Class X: recommended only when there is experimental evidence**



Curve 1 : Tension reinforcement (hot rolled and cold worked) for strains $\varepsilon_{s,fi} \geq 2\%$

Curve 2 : Compression reinforcement and tension reinforcement (hot rolled and cold worked) for strains $\varepsilon_{s,fi} < 2\%$

EUROCODES Background and Applications

Reinforcing steel Class X

Class X was proposed by Finland because initial testing of steel strength at elevated temperatures is required in Finnish standard

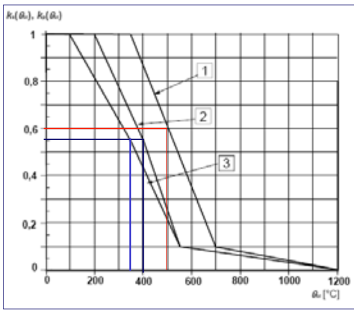
FINNISH NA:

- **Class X may be used with following additional conditions:**
- **Strength properties at elevated temperatures are determined by applying standard SFS-EN 10002-5.**
- **Strength properties of reinforcing steel at elevated temperatures are subject to initial type testing at temperatures 300 °C, 400 °C, 450 °C, 500 °C and 550 °C.**
- **Requirements for 0,2 % proof strength *Rp*0,2 are given in table 3.2-FI, where *fyk* is nominal yield strength or 0,2 % proof stress of the reinforcing steel at room temperature.**
- **Table 3.2-FI: 1 Strength requirements of reinforcing steel at elevated temperatures**

Temperature (°C)	$R_{p0,2}$ (% f_{yk})
300	87
400	80
450	70
500	60
550	45

EUROCODES Background and Applications

Reference curve for Tabulated data in Section 5



1. Reinforcing steel
$\theta_{cr} = 500$°C
0,6 stress level

2. Prestressing bars
θcr = 400°C
0,55 stress level

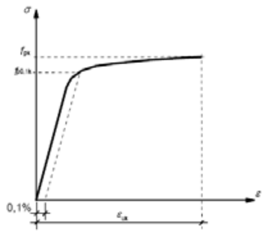
3. Prestressing wires and strands
θcr = 350°C
0,55 stress level

EUROCODES — Strength reduction of prestressing steel

Brussels, 18-20 February 2008 – Dissemination of information workshop 19

Strength reduction is given by $f_{py,\theta} / (\beta f_{pk})$ and $f_{pp,\theta} / (\beta f_{pk})$, where β is NDP

- Class A: $\beta = \left[\left(\frac{\varepsilon_{ud} - f_{p0,1k} / E_p}{\varepsilon_{uk} - f_{p0,1k} / E_p} \right) \times \left(\frac{f_{pk} - f_{p0,1k}}{f_{pk}} \right) + \frac{f_{p0,1k}}{f_{pk}} \right]$
- Class B: $\beta = 0,9$

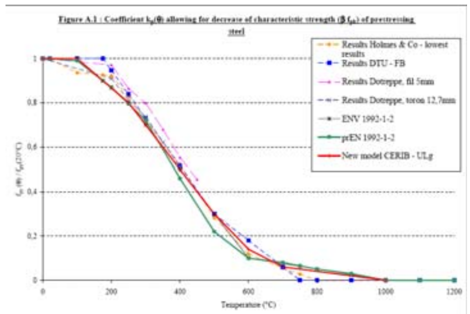


EUROCODES — Background for Class A

Brussels, 18-20 February 2008 – Dissemination of information workshop 20

Common new proposal from the University of Liege and CERIB for the general and simplified models for the mechanical properties of prestressing steel (wires and strands) at elevated temperatures,

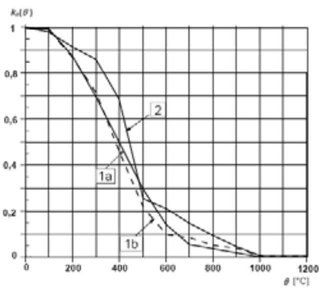
September 12th 2003



EUROCODES — Strength reduction of prestressing steel

Brussels, 18-20 February 2008 – Dissemination of information workshop 21

Strength reduction for simplified calculation methods in Section 4



Curve 1a : Cold worked prestressing steel (wires and strands) Class A

Curve 1b : Cold worked prestressing steel (wires and strands) Class B

Curve 2 : Quenched and tempered prestressing steel (bars)

EUROCODES — Thermal properties

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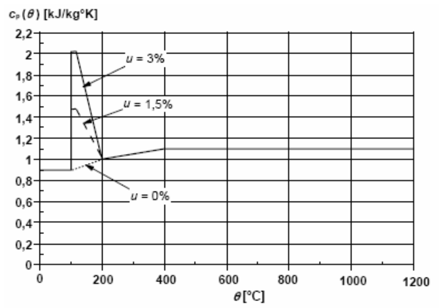
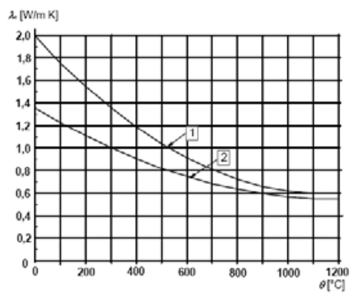
- **Specific heat of concrete, *u* is moisture % by weight**



EUROCODES — Thermal properties

Brussels, 18-20 February 2008 – Dissemination of information workshop 23

- **Thermal conductivity of concrete, NDP between upper and lower limit**



1 Upper limit

2 Lower limit

EUROCODES — Background for thermal conductivity

Brussels, 18-20 February 2008 – Dissemination of information workshop 24

- ***Project Team EN 1992-1-2 made a lot of calibrations to temperatures measured in fire tests of typical concrete structures, and the lower limit fits very well***
- ***Design rules for steel-concrete composite structures (mainly including heavy steel sections) seem to be calibrated to the upper limit***
- ***A compromise was made on TC 250 level: NDP between upper and lower limit***

- ***EN 1992-1-2, 3.3.3:***
- ***Note 2: Annex A is compatible with the lower limit. The remaining clauses of this part 1-2 are independent of the choice of thermal conductivity. For high strength concrete, see 6.3.***

EN 1992-1-2
Fire design of concrete structures

- Sections 1 and 2 General, Basis of design
- Section 3 Material properties
- Section 4 Design procedures
  - **Simplified calculation method 4.2, Annex A, B and E**
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  - **Spalling 4.5**
- Section 5 Tabulated data
  - **Annex C**
- Section 6 High strength concrete

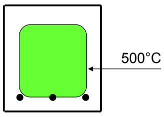
Design methods

- **advanced calculation methods for simulating the behaviour of structural members, parts of the structure or the entire structure, see 4.3**
  - only principles are given, no detailed design rules
- **simplified calculation methods for specific types of members, see 4.2**
  - **Annex B.1 "500°C isotherm method"**
    developed by Dr Yngve Anderberg, earlier published in Sweden and in CEB Bulletins
  - **Annex B.2 "Zone method"**
    developed by Dr Kristian Hertz, earlier published in Denmark and in ENV 1992-1-2
- **detailing according to recognised design solutions (tabulated data or testing), see Section 5**
- ***Shear, torsion and anchorage; spalling; joints***

Simplified calculation method

- **500°C isotherm method**

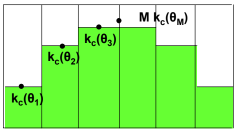
  Concrete with temperature below 500°C retains full strength and the rest is disregarded



- **Zone method**

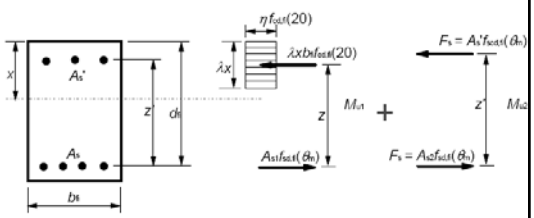
  Cross section is divided in zones. Mean temperature and corresponding strength of each zone is used

  This method is more accurate for small cross sections than 500°C isotherm method



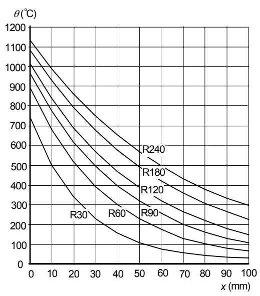
500°C isotherm method

- **Determine the 500°C isotherm and the reduced width b_{fi} and effective depth d_{fi}**
- **Determine the temperature of reinforcing bars and the reduced strength**
- **Use conventional calculation methods**



Temperature profiles

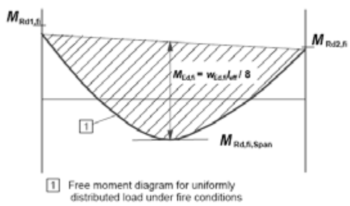
- **Temperature distribution in the cross section can be calculated from the thermal properties**
- **Annex A of EN 1992-1-2 gives temperature profiles for slabs, beams and columns**



Simplified calculation method for beams and slabs

- **Annex E**
- **Simplified method to calculate bending capacity for predominantly uniformly distributed loads**
- **This is some kind of extension of Tabulated data**

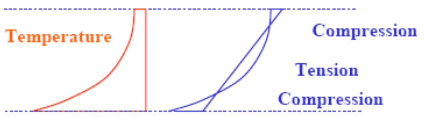
$$M_{Rd,fi} = (\gamma_s / \gamma_{s,fi}) \times k_s(\theta) \times M_{Ed} \, (A_{s,prov} / A_{s,req})$$



Shear, torsion and anchorage

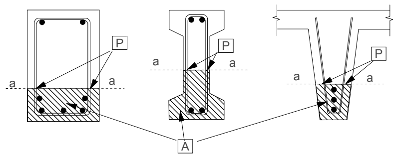
Annex D (informative)

- Shear failures due to fire are very uncommon. However, the calculation methods given in this Annex are not fully verified.
- For elements in which the shear capacity is dependent on the tensile strength, special consideration should be given where tensile stresses are caused by non-linear temperature distributions



Calculation for shear

The reference temperature θ_p should be evaluated at points P along the line 'a -a' for the calculation of the shear resistance. The effective tension area A may be obtained from EN 1992-1 (SLS of cracking).



Spalling of normal strength concrete

CALCULATION METHODS
Define exposure class
↓ X0 or XC1 (dry) → ↓ Moisture content ≤ 3 % → ↓ OK
↓ other → ↓ Is moisture content known — Yes ≤ 3 % ← (to Moisture content ≤ 3 %)
No, or yes but > 3 % ↓ Avoid spalling by more accurate assessment — Yes ← OK
Moisture content, type of aggregates, permeability of concrete, heating rate
No ↓ Has the correct behaviour been checked by tests — Yes ← OK
No → Assume loss of cover and calculate R
Solid slabs OK, some beams OK

TABULATED DATA
↓ Explosive spalling is covered by minimum requirements
No further check needed

Falling off of normal strength concrete

Shall be minimised or taken into account

c ≥ 70 mm — No → **OK**
↓ **Yes**
Tests to show that falling of does not occur — Yes → **OK**
No ↓
Provide surface reinforcement

EN 1992-1-2
Fire design of concrete structures

- Sections 1 and 2 General, Basis of design
- Section 3 Material properties
- Section 4 Design procedures
  - **Simplified calculation method 4.2, Annex A, B and E**
  - **Shear, torsion and anchorage 4.4 and Annex D**
  - **Spalling 4.5**
- Section 5 Tabulated data
  - **Annex C**
- Section 6 High strength concrete

Scope of Tabulated data

(1) This section gives recognised design solutions for the standard fire exposure up to 240 minutes. The rules refer to member analysis.

Note: The tables have been developed on an empirical basis confirmed by experience and theoretical evaluation of tests. The data is derived from approximate conservative assumptions for the more common structural elements and is valid for the whole range of thermal conductivity in 3.3. More specific tabulated data can be found in the product standards for some particular types of concrete products or developed, on the basis of the calculation method in accordance with 4.2, 4.3 and 4.4.

(2) The values given in the tables apply to normal weight concrete (2000 to 2600 kg/m3, made with siliceous aggregates.
If calcareous aggregates or lightweight aggregates are used in beams or slabs the minimum dimension of the cross-section may be reduced by 10%.

(3) When using tabulated data no further checks are required concerning shear and torsion capacity and anchorage details.

(4) When using tabulated data no further checks are required concerning spalling, except for surface reinforcement.

Tabulated data - General

Tabulated data are based on a reference load level η_{fi} = 0,7, unless otherwise stated in the relevant clauses.

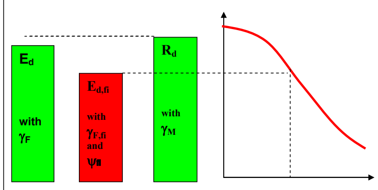
Note: Where the partial safety factors specified in the National Annexes of EN 1990 deviate from those indicated in 2.4.2, the above value η_{fi} = 0,7 may not be valid. In such circumstances the value of η_{fi} for use in a Country may be found in its National Annex.

For walls and columns load level η_{fi} or degree of utilisation μ_{fi} is included in the tables

Linear interpolation between the values in the tables may be carried out

Load level and degree of utilisation

ACTIONS **RESISTANCES**



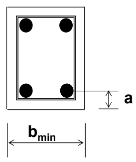
$E_d \times \eta_{fi}$ = $E_{d,fi}$ **R_d** **$R_{d,fi}$**

η_{fi} = load level

μ_{fi} = $E_{d,fi}$ / R_d = degree of utilisation

takes into account if the structure is not fully loaded

Tabulated data – main principle



Check minimum dimensions of concrete cross section and axis distance to steel

Axis distance is nominal value, no need to add tolerance

Axis distance is given for reinforcing steel (θ_{cr} = 500ºC), to be increased for prestressing steel (bars 10 mm, strands and wires 15 mm)

θ_{cr} = 500ºC is derived from load level 0,7 divided by partial factor for reinforcement γ_s = 1,15 → $\sigma_{s,fi}/f_{yk}$ = 0,60

For prestressing strands and wires θ_{cr} = 350ºC and $\sigma_{s,fi}/f_{p0,1k}$ = 0,55 ($E_{d,fi}$ = 0,7 E_d, $f_{p0,1k}/f_{pk}$ = 0,9, γ_s = 1,15)

Tabulated data in EN 1992-1-2

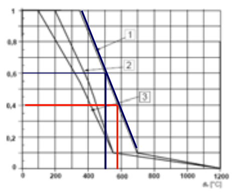
For beams and slabs degree of utilisation may be taken into account by following simple rule:

a) Calculate the actual steel stress

b) Evaluate the critical temperature using reference curve for steel strength

c´) Adjust the minimum axis distance by 1 mm for every 10˚C difference in temperature

$$\sigma_{s,fi} = \frac{E_{d,fi}}{E_d} \times \frac{f_{yk}(20°C)}{\gamma_s} \times \frac{A_{s,req}}{A_{s,prov}}$$



T_{cr} = 580˚C, Δa = - 8 mm

Tabulated data for columns

- **Completely revised**
- **Two optional methods are given**
  - **Method A** is derived from test results, but field of application is limited to buckling length ≤ 3 m and first order eccentricity ≤ 0,15h to 0,4h (depending on the National Annex)
  - **Method B** is based on calculations, it is more conservative and many interpolations are needed. Limitations for normative table: eccentricity ≤ 0,25h and $\lambda_{fi} \leq 30$
    9 pages of tables in Annex C

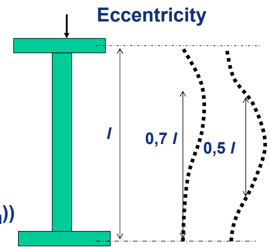
Parameters for columns

In Method A degree of utilisation:

$\mu_{fi} = N_{Ed.fi} / N_{Rd}$

In Method B load level is defined as:

$n = N_{0Ed,fi} / (0,7(A_c f_{cd} + A_s f_{yd}))$



Slenderness, $l_{o,fi}$

- upper floor 0,7 l

- intermediate floor 0,5 l

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Method A for columns

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Standard fire resistance	Minimum dimensions (mm) Column width b_{min}/axis distance a of the main bars			
	Column exposed on more than one side			Exposed on one side
	μ_{fi} = 0.2	μ_{fi} = 0.5	μ_{fi} = 0.7	μ_{fi} = 0.7
1	2	3	4	5
R 30	200/25	200/25	200/32 300/27	155/25
R 60	200/25	200/36 300/31	250/46 350/40	155/25
R 90	200/31 300/25	300/45 400/38	350/53 450/40**	155/25
R 120	250/40 350/35	350/45** 450/40**	350/57** 450/51**	175/35
R 180	350/45**	350/63**	450/70**	230/55
R 240	350/61**	450/75**	-	295/70

** Minimum 8 bars
For prestressed columns the increase of axis distance according to 5.2. (5) should be noted.

EUROCODES Background and Applications

Method B for columns

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Standard fire resistance	Mechanical reinforcement ratio ω	Minimum dimensions (mm). Column width b_{min}/axis distance a			
		n = 0,15	n = 0,3	n = 0,5	n = 0,7
1	2	3	4	5	6
R 30	0,100 0,500 1,000	150/25* 150/25* 150/25*	150/25* 150/25* 150/25*	200/30:250/25* 150/25* 150/25	300/30:350/25* 200/30:250/25* 200/30:300/25
R 60	0,100 0,500 1,000	150/30:200/25* 150/25* 150/25*	200/40:300/25* 150/35:200/25* 150/30:200/25*	300/40:500/25* 250/35:350/25* 250/40:400/25	500/25* 350/40:550/25* 300/50:600/30
R 90	0,100 0,500 1,000	200/40:250/25* 150/35:200/25* 200/25*	300/40:400/25* 200/45:300/25* 200/40:300/25*	500/50:550/25* 300/45:550/25* 250/40:550/25*	550/40:600/25* 550/50:600/40 500/50:600/45
R 120	0,100 0,500 1,000	250/50:350/25* 200/45:300/25* 200/40:250/25*	400/50:550/25* 300/45:550/25* 250/50:400/25*	550/25* 450/50:600/25 450/45:600/30	550/60:600/45 500/60:600/50 600/60
R 180	0,100 0,500 1,000	400/50:500/25* 300/45:450/25* 300/35:400/25*	500/60:550/25* 450/50:600/25* 450/50:550/25*	550/60:600/30 500/60:600/50 500/60:600/45	(1) 600/75 (1)
R 240	0,100 0,500 1,000	500/60:550/25* 450/45:500/25* 400/45:500/25*	550/40:600/25* 550/55:600/25* 500/40:600/30	600/75 600/70 600/60	(1) (1) (1)

* Normally the cover required by EN 1992-1-1 will control.
(1) Requires width greater than 600 mm. Particular assessment for buckling is required.

EUROCODES Background and Applications

Simple calculation for method A

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$R = 120\left((R_{\eta fi} + R_a + R_l + R_b + R_n)/120\right)^{1,8}$

$$R_{\eta fi} = 83\left[1{,}00 - \mu_{fi}\frac{(1+\omega)}{(0{,}85/\alpha_{cc})+\omega}\right]$$

R_a = 1,60 (a – 30)
R_l = 9,60 (5 – $l_{o,fi}$)
R_b = 0.09 b'
R_n = 0 for n = 4 (corner bars only)
= 12 for n > 4
a = axis distance to the longitudinal steel bars (mm); 25 mm $\leq a \leq$ 80 mm
$l_{0,fi}$ = effective length of the column under fire conditions; 2 m $\leq l_{0,fi} \leq$ 6 m;
b' = $2A_c/(b+h)$ for rectangular cross-sections
= ϕ_{col} for circular cross-sections (mm) ;
200 mm $\leq b' \leq$ 450 mm; $h \leq$ 1,5 b.
ω = mechanical reinforcement ratio at normal temperature conditions $= \frac{A_s f_{yd}}{A_c f_{cd}}$
α_{cc} = coefficient for compressive strength (see EN 1992-1-1)

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300 x 300 a = 35

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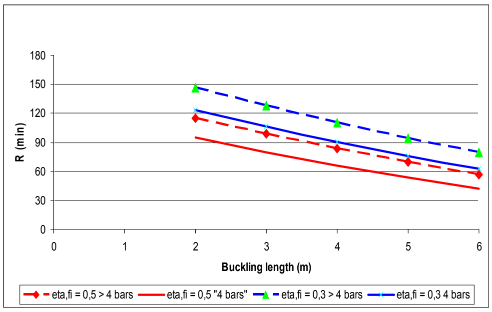

EUROCODES Background and Applications

Walls

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- **Tabulated data as in ENV**
- **Fire walls have been added**
  - Classification M, to be used only if there are national requirements
  - Data taken from DIN standard

EUROCODES Background and Applications

Beams, slabs, tensile members

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- **In principle the same as in ENV**
- **Some numerical values have been checked, e.g.**
  - Rule for increase of axis distance in I-beam web (validity of expression 5.10)
  - Three classes for I-beam web thickness (NDP)
  - Minimum width of continuous beams
  - Flat slab thicknesses have been checked (to more conservative direction)

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EN 1992-1-2
Fire design of concrete structures

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- Sections 1 and 2 General, Basis of design
- Section 3 Material properties
- Section 4 Design procedures
  - **Simplified calculation method 4.2, Annex A, B and E**
  - **Shear, torsion and anchorage 4.4 and Annex D**
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  - **Annex C**
- Section 6 High strength concrete

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Strength reduction of high strength concrete

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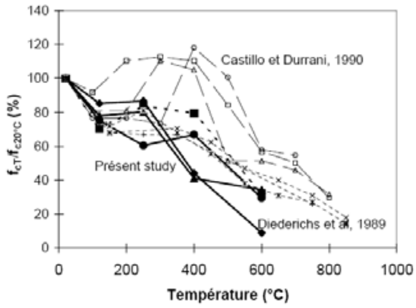
- **Large scatter in strength, composition of concrete has big influence**



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HSC strength reduction is NDP

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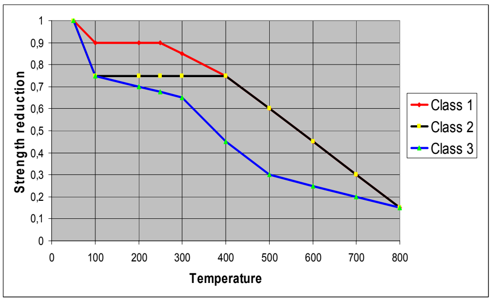

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HSC Tabulated data

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Increase of minimum cross section by factor	Class 1	Class 2
- Walls and slabs exposed on one side	1,1	1,3
- Other structural members	1,2	1,6
Increase of axis distance by factor	1,1	1,3
Note: Factors are recommended values, and may be modified in National Annex		
Factor for axis distance in Class 2 seems to be too high, and it should not depend on the strength reduction		

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HSC simplified calculation

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Moment capacity reduction factors for beams and slabs	k_m Class 1	k_m Class 2
Beams	0,98	0,95
Slabs exposed to fire in the compression zone	0,98	0,95
Slabs exposed to fire in the tension side, $h_s \geq 120$ mm	0,98	0,95
Slabs exposed to fire in the tension side, $h_s = 50$ mm	0,95	0,85

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Spalling of HSC

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- Up to C80/95 and silica fume content less than 6 % rules for normal strength concrete apply
- In other cases at least one of the following methods:
  - **A:** A reinforcement mesh with a nominal cover of 15 mm. This mesh should have wires with a diameter ≥ 2 mm with a pitch ≤ 50 x 50 mm. The nominal cover to the main reinforcement should be ≥ 40 mm.
  - **B:** A type of concrete for which it has been demonstrated (by local experience or by testing) that no spalling of concrete occurs under fire exposure.
  - **C:** Protective layers for which it is demonstrated that no spalling of concrete occurs under fire exposure
  - **D:** Include in the concrete mix more than 2 kg/m³ of monofilament propylene fibres.

Background documentation

- **Project Team has written ”Main background document” describing main changes to ENV**
- **It refers to other numbered documents called BDA (Background Document Annex)**
- **These documents have been delivered to CEN/TC 250/SC 2.**

End of presentation

EUROCODE 3 - 1.2 STEEL STRUCTURES

L. Twilt
TNO

Eurocode 3-1.2
Fire Design of Steel Structures

Leen Twilt
Convenor Project Team EC3-1.2
(formerly) TNO Centre for Fire Research),*
The Netherlands

*) Starting from July 1st 2006, the TNO department Centre for Fire Research continues its activities as a TNO company named Efectis Nederland B.V.

Contents

- Introduction
- Historical review
- Fire Design of Steel Structures: main route
- Design procedures
- Literature

Project Team EC3-1.2 Membership

- Niels Andersen (DK)
- Mario Fontana (CH)
- Jean-Marc Franssen (B)
- David Moore (UK)
- Christoph Heinemeyer (secretary) (D)
- Leen Twilt (convenor) (NL)

Historical review

- 1995 Release ENV version of EC3-1.2
- 1999 Start of conversion ENV → EN
- 2001 Availability of prEN
- 2003 Enactment of EN version by SC3

EUROCODES Background and Applications — Fire Design Structures - *History*

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Conversion from ENV → EN

- CEN MS's involved 19
- Comments received
  - editorial 108
  - technical 106
  - legal 3

  \+ -----

total: → 217

Emphasis on modification ENV→EN version

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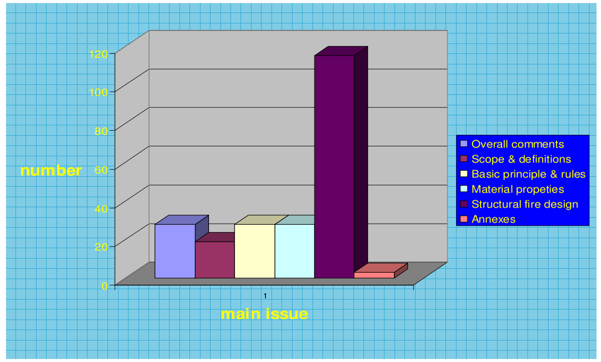
Comments per main issue



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Global set up of EC3-1.2

- General
  - scope, definitions, symbols etc.
- Basic principles and rules
  - performance requirements (e.g.. deformation criteria), assessment methods etc.
- Material properties
  - thermal & mechanical (steel and protection)
- Structural fire design
  - simple & advanced calculation models
- Annexes

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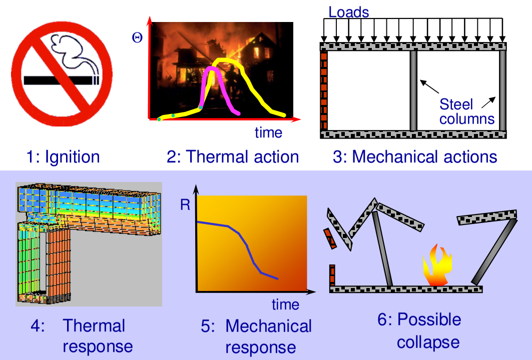
Resistance to fire - Chain of events



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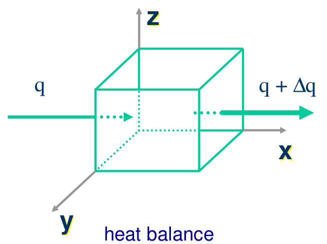
Thermal response
Basics

Thermal conduction (= λ)
Thermal capacity (= $\rho \cdot c_p$)

DV: (shown for 1direction only)

$$\frac{\partial(\rho_{c_p}\Theta)}{\partial t} + \frac{\partial(\lambda\frac{\partial\Theta}{\partial x})}{\partial x} = 0$$



heat balance

$\Delta q / \Delta x + \Delta(\rho c_p \Theta) / \Delta t = 0$

boundary condition: incoming/outgoing flux at surface: $h_{net,tot}$

initial condition: room temperature

Fourier's law

$q = \lambda \, \Delta \Theta / \Delta x$

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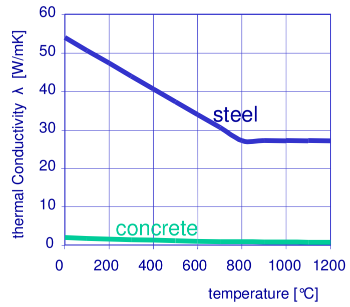
Thermal conductivity
Steel vs. concrete



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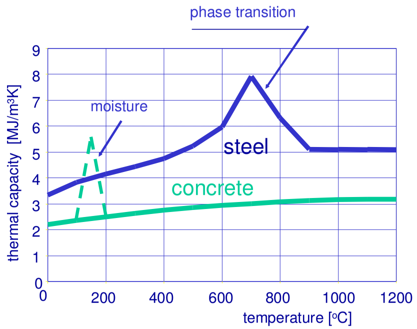
Thermal capacity
Steel vs. concrete



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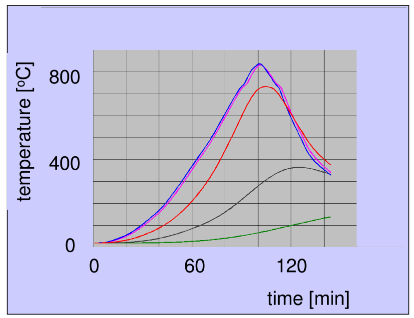
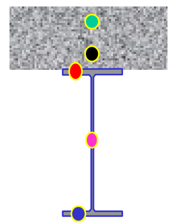
Thermal response
Steel beam/concrete slab (2D)





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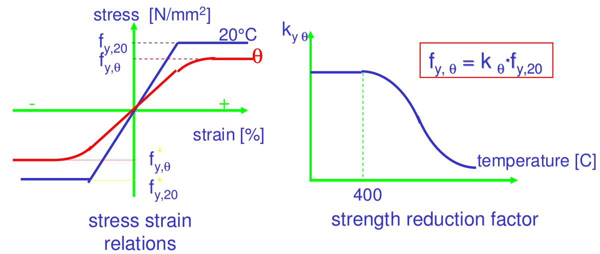
Mechanical response
Basics

- Theory of Applied Mechanics
  - Bernouilli
  - $\varepsilon_{tot} = \varepsilon_{therm} + \varepsilon_{\sigma}$
    ⇒ coefficient of thermal elongation (α_{therm})
    ⇒ constitutive relationships steel, concrete, …
  - yield models
  - deformation capacity
  - …
- Reduced strength & stiffness at elevated temperature

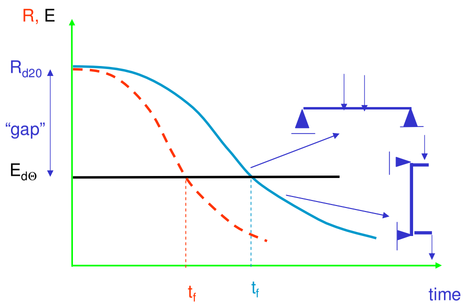
Emphasis on ultimate state analysis

Mechanical properties of steel at elevated temperatures (qualitative)



Notes: - unlimited deformation capacity
- " + " = "-"

Mechanical response
Principle



failure at t_f for:

$R_t < E_{d\Theta}$

with:

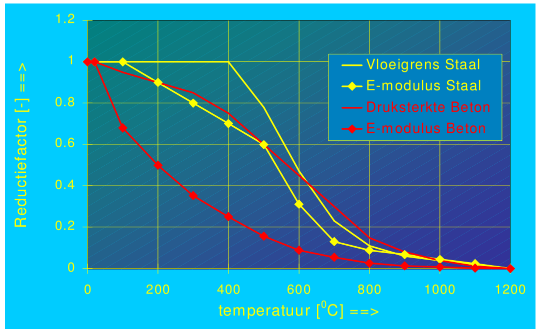
R_{Θ} : resistance at t_m

$E_{d\Theta}$: action effect at t_m

t_f : resistance to fire

note: t_f depends a.o. on the "gap" between R_{d20} and $E_{d\Theta}$

Reduction of strength & stiffness at elevated temperatures



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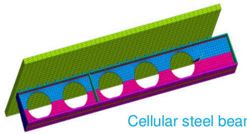
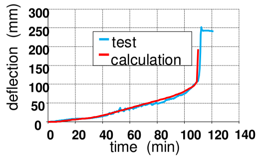
Fire Design Steel Structures
Potential of EC3-1.2

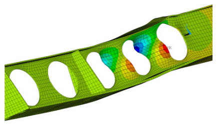


Cellular steel beam

Failure mode in test



Calculation vs test



Simulated failure mode

Source:Efectis France (CTICM)

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EUROCODES Background and Applications **Fire Design Steel Structures – *Design***

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Structural fire design procedures
Type of models

- Simple calculation models
  - beams
  - compression members
    - N only
    - N & M
  - tension members
- Advanced calculation models
- Tests

for individual members only!

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EUROCODES Background and Applications **Fire Design Steel Structures – *Design***

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Simple calculation models
Concepts

- “Resistance” concept
- “Critical temperature” concept

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EUROCODES Background and Applications **Fire Design Steel Structures – *Design***

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Simple calculation models
“Resistance” concept

- “Compression members” (N, N & M):
  procedure *different* from room temperature procedures
- “Beams” and “tension members”:
  procedure *similar* to room temperature procedures

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"Resistance" concept
Illustration for the buckling resistance $N_{b,fi,\Theta,Rd}$

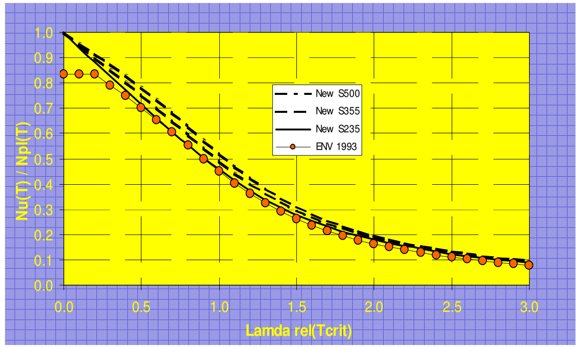
- $N_{b,fi,Rd} = \chi_{fi} A k_{y,\Theta} f_y$ ... (1)

with

- buckling coefficient $\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{\varphi_\theta^2 - \bar{\lambda}_\theta^2}}$ ... (a)
- imperfection coeff. $\varphi_\theta = \frac{1}{2}[1 + \alpha \bar{\lambda}_\theta + \bar{\lambda}_\theta^2]$ ... (b)
- rel. slenderness ratio $\bar{\lambda}_\theta = \bar{\lambda} [k_{y,\theta} / k_{E,\theta}]^{0,5}$ ... (c)

Note: - φ_Θ depends on steel grade and λ_Θ
- λ_Θ depends on temperature

Buckling curves at elevated temperature



Buckling curves
Design aid

$\chi_{(\Theta,crit)}$ for S235

λ(20°C)	400°C	500°C	600°C	700°C	800°C
0.0	1.000	1.000	1.000	1.000	1.000
0.1	0.927	0.931	0.924	0.917	0.934
0.2	0.860	0.869	0.853	0.836	0.875
0.3	0.794	0.810	0.784	0.757	0.820
0.4	0.728	0.750	0.715	0.679	0.764
0.5	0.663	0.690	0.646	0.603	0.708
0.6	0.598	0.629	0.579	0.531	0.651
0.7	0.535	0.569	0.515	0.466	0.593
0.8	0.476	0.511	0.456	0.408	0.535
0.9	0.422	0.456	0.403	0.357	0.481
1.0	0.374	0.406	0.356	0.314	0.430
1.1	0.332	0.362	0.316	0.277	0.384
1.2	0.296	0.323	0.280	0.245	0.343
1.3	0.264	0.289	0.250	0.218	0.307
1.4	0.237	0.259	0.224	0.195	0.275
1.5	0.213	0.233	0.201	0.175	0.248
1.6	0.192	0.211	0.182	0.158	0.224
1.7	0.175	0.191	0.165	0.143	0.204
1.8	0.159	0.174	0.150	0.130	0.185
1.9	0.145	0.159	0.137	0.119	0.169
2.0	0.133	0.146	0.126	0.109	0.155

"Resistance" concept
Illustration for moment capacity $M_{fi,\Theta,Rd}$

- Uniform temperature distribution:

$M_{fi,\Theta,Rd} = k_{y,\Theta} M_{Rd}$ ... (1)

- Non uniform temperature distribution*):

$M_{fi,\Theta,Rd} = k_{y,\Theta} M_{Rd} / \kappa_1 \kappa_2$ ... (2)

with:
$k_{y,\Theta}$ = strength reduction factor
A = steel area
κ_1, κ_2 = adaptation factors for non uniform temperature distribution

*) Only for class 1, 2 cross sections; an "exact" calculation is also allowed

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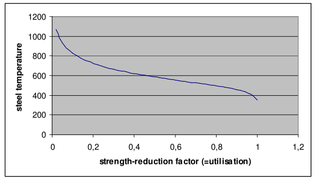
"Critical temperature" concept
Basics

- Utilisation factor μ_Θ in temperature domain:

$$E_{fi,d} / R_{fi,d,\Theta} = f_{y,\Theta}/f_y = k_{y,\Theta} \ (= \mu_\Theta)$$

- Strength reduction factor as function steel temperature

with:
Θ = steel temperature
$k_{y,\Theta}$ = strength reduction factor
μ_Θ = utilisation factor



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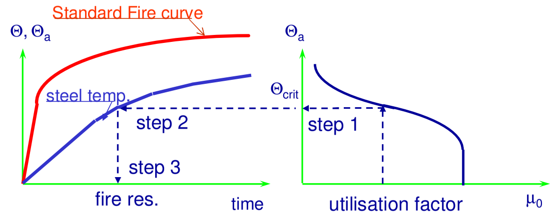
"Critical temperature" concept
Design procedure



step 1: determine mechanical response $\mu_a \Rightarrow \Theta_{crit}$
step 2: determine thermal response $\Rightarrow \Theta_a$
step 3: determine fire resistance $\Rightarrow$ fire res.

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Thermal response steel element
Uniform temperature distribution

$$\frac{\partial(\rho\, c\, \theta)}{\partial t} + \frac{\partial(\lambda \frac{\partial\Theta}{\partial x})}{\partial x} = 0$$

boundary & initial conditions

$$\Rightarrow \quad d\,\Theta_a = k_{sh} \frac{A_m/V}{c_a \rho_a} \dot{h}_{net,d}\, dt$$

"shadow" factor is new in EN version

with
A_m is exposed surface area member [m²/m]
V is volume member [m³/m]
K_{sh} is "shadow" factor
…
…

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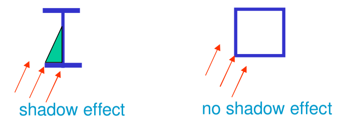
Shadow effect
Effect shape steel profile

- Shadow effect caused by local shielding of irradiative heat transfer, due to *shape* of steel profile, e.g.:



- Hence:
  - ⌶ -profiles, shadow effect: yes
  - ☐ -profiles, shadow effect: no

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Shadow effect
Bare vs. insulated steel profiles

- Without thermal radiation, no shadow effect, hence:
  - bare profiles, shadow effect: yes
  - insulated profiles, shadow effect: no

Shadow effect
Summary

- Unprotected profiles:
  - ⌶-profiles: $k_{shadow} = 0.9\ [A_m/V]_{box}/[A_m/V]$
  - ☐-profiles: $k_{shadow} = 1$
- Insulated profiles:
  - "all" profiles: $k_{shadow} = 1$

with:
$[A_m/V]$ is section factor
$[A_m/V]_{box}$ is box value of section factor

Simple calculation models
General design considerations

- Connections
- Classification cross-sections

Fire design connections
Deemed to satisfy conditions

- Fire protection not smaller than member
- Utilization less than member

Note: for calculation method refer to Annex D

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Classification of cross-sections
Old rule (→ENV)

- Border line values for b/t:
  $(b/t)_{border,\Theta} = \varepsilon_\Theta \, (b/t)_{border,20}$
  with:
  $\varepsilon_\Theta = [(235/f_y)(k_{E,\theta}/k_{y,\theta})]^{0.5}$ *) } temperature dependent
- Consequences??

*) follows directly from room temperature rules

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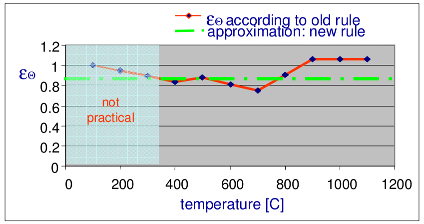
Classification of cross sections
Consequences "old" rule

- Temperature dependency



- Hence
  - classification "unstable"
  - analysis complicated

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Classification of cross sections
New rule (→EN)

- Border line values for b/t:
  $(b/t)_{border,\Theta} = \varepsilon \, (b/t)_{border,20}$
  with:
  $\varepsilon = 0{,}85 \, [(235/f_y)]^{0.5}$ } temperature *independent*
- Consequences
  - for 350 – 850 ºC: ≈ o.k.
  - for 850 – 1200 ºC: conservative

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Annexes

- **A. Strain-hardening*)**
- **B. Heat transfer external steel work*)**
- **C. Stainless steel**
- **D. Joints**
- **E. Class 4 Cross-Sections**

*) normative

[shaded box] : new compared to EN version; *informative only*

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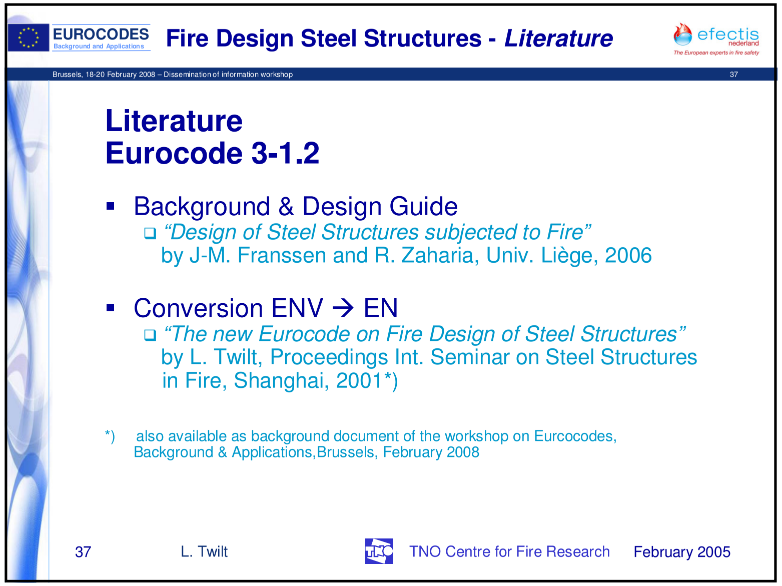
EUROCODES
Background and Applications
Fire Design Steel Structures - Literature
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The European experts in fire safety
Brussels, 18-20 February 2008 – Dissemination of information workshop
37
Literature
Eurocode 3-1.2
▪ Background & Design Guide
❑ "Design of Steel Structures subjected to Fire"
by J-M. Franssen and R. Zaharia, Univ. Liège, 2006
▪ Conversion ENV → EN
❑ "The new Eurocode on Fire Design of Steel Structures"
by L. Twilt, Proceedings Int. Seminar on Steel Structures
in Fire, Shanghai, 2001*)
*) also available as background document of the workshop on Eurcocodes,
Background & Applications,Brussels, February 2008
37
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TNO Centre for Fire Research
February 2005

EUROCODE 5 - 1.2 TIMBER STRUCTURES

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Structural fire design Eurocode 5-1.2 Timber structures

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Structural fire design – timber - sections

7 Chapters :

1. General
2. Basis of design
3. Material properties
4. Design procedure for mechanical properties
5. Design procedure for wall and floor assemblies
6. Connections
7. Detailing

Structural fire design – timber - annexes

6 Annexes :

A : (informative) Parametric fire exposure
B : (informative) Advanced calculation models
C : (informative) Load-bearing floor joists and wall studs in assemblies whose cavities are completely filled with insulation
D : (informative) Charring of members in wall and floor assemblies with void cavities
E : (informative) Analysis of the separating function of wall and floor assemblies
F : (informative) Guidance for users of this Eurocoe Part

Structural fire design – timber - verification

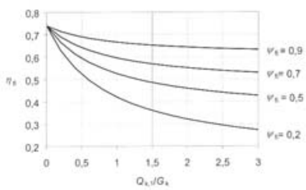
2.4 Verification methods

2.4.1 General

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

2.4.2 Member analysis

$$E_{d,fi} = \eta_{fi} E_d \qquad \eta_{fi} = f(G_k, Q_k, \gamma, \psi)$$



Structural fire design – timber – R&D

Some research work has been carried out:

Such as in the fields of

- Material properties and resistances
- Some Design procedures for mechanical resistance
- and others which will be subject to the following paper

Still more R&D has to be done

This will partially be covered by the following project:

Structural fire design - FireInTimber

WoodWisdom-Net project

FireInTimber – Fire resistance of Innovative Timber structures

December 2007

FireInTimber – Partners and countries:

SP Trätek – Sweden	VTT – Finnland
TUM, DGfH – Germany	BPU, CSTB France
TreSenteret – Norway	BRE – UK
HFA, UIBK, TUW – Austria	ETH Zuerich – Switzerland
Resand – Estonia	

European industry: CEI-Bois / BWW

Expected results:

- Analytical design concepts for load-bearing timber structures under fire conditions
- New models for load-bearing solid wood cross laminated panel and light weight structures during fire exposure
- Performance principles of connections at fire exposure
- Guidance on joints between wall and ceiling elements and on fire stops within structures

Expected results:

- Critically reviewed novel innovative products and summary of new knowledge for product development
- The first European wide guideline on the fire safe use of wood in buildings.

FireInTimber :

- a new project within the European WoodWisdom-Net framework
- with 14 participants from 9 countries
- the project has started in November 2007 and will be finalised by the end of 2009
- It is supported by industry through the European initiative BWW and public funding organisations.

Eurocode 5, part 1 . 2 :

In the following paper today's status as well as up to date findings will be presented by Jochen Fornather.

Thank you very much for your attention!

Structural fire design Eurocode 5-1.2 Timber structures

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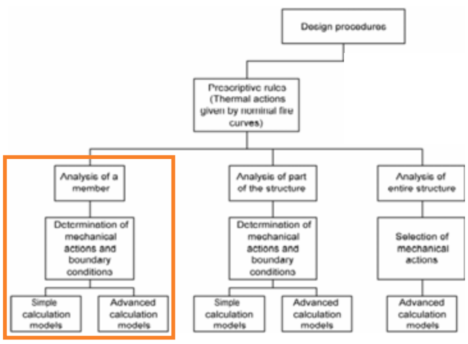
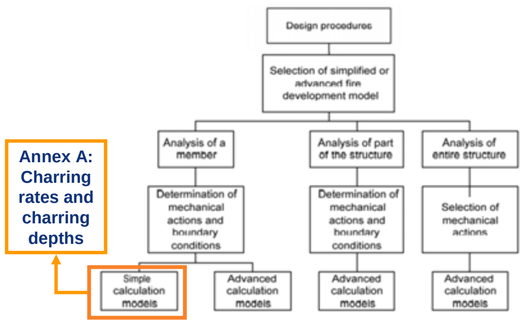
Scope of EN 1995-1-2

EN 1995-1-2
- shows the design of timber structures for the accidental situation of fire exposure
- to be used in conjunction with EN 1995-1-1 and EN 1991-1-2.
- only identifies differences from, or supplements normal temperature design.
- deals only with passive methods of fire protection
- applies to building structures with load-bearing function and/or separating function

Design procedure (1)



Design procedure (2)



Basis of design (1)

Basic requirements
- mechanical resistance
- fire compartmentation
- deformation criteria

Requirements (R, E, I) concerning
- nominal fire exposure
- parametric fire exposure

→same as EN 1991-1-2

Actions

→see EN 1991-1-2
- emissivity coefficient of wood surfaces: e = 0,8

Basis of design (2)

Design values of material properties and resistances

$$f_{d,fi} = k_{mod,fi} \frac{f_{20}}{\gamma_{M,fi}} \qquad f_{20} = k_{fi}\, f_k$$

$$S_{d,fi} = k_{mod,fi} \frac{S_{20}}{\gamma_{M,fi}} \qquad S_{20} = k_{fi}\, S_{05}$$

	k_{fi}
Solid timber	1,25
Glued-laminated timber	1,15
Wood-based panels	1,15
LVL	1,1
Connections with fasteners in shear with side members of wood and wood-based panels	1,15
Connections with fasteners in shear with side members of steel	1,05
Connections with axially loaded fasteners	1,05

$f_{d,fi}$ is the design strength in fire;

$S_{d,fi}$ is the design stiffness property (modulus of elasticity $E_{d,fi}$ or shear modulus $G_{d,fi}$) in fire;

f_{20} is the 20 % fractile of a strength property at normal temperature;

S_{20} is the 20 % fractile of a stiffness property (modulus of elasticity or shear modulus) at normal temperature;

$k_{mod,fi}$ is the modification factor for fire;

$\gamma_{M,fi}$ is the partial safety factor for timber in fire.

Basis of design (2)

Design values of material properties and resistances

$$R_{d,t,fi} = \eta \frac{R_{20}}{\gamma_{M,fi}}$$

$R_{d,t,fi}$ is the design value of a mechanical resistance in the fire situation at time t;

R_{20} is the 20 % fractile value of a mechanical resistance at normal temperature without the effect of load duration and moisture (k_{mod} = 1);

η is a conversion factor;

$\gamma_{M,fi}$ is the partial safety factor for timber in fire.

Basis of design (3)

Verification methods

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

$E_{d,fi}$ is the design effect of actions for the fire situation, determined in accordance with EN 1991-1-2:2002, including effects of thermal expansions and deformations;

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

$$E_{d,fi} = \eta_{fi} E_d \qquad \eta_{fi} = \frac{G_k + \psi_{fi} Q_{k,1}}{\gamma_G G_k + \gamma_{Q,1} Q_{k,1}}$$

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

G_k is the characteristic value of the permanent action;

γ_G is the partial factor for permanent actions;

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

ψ_{fi} is the combination factor for frequent values of variable actions in the fire situation, given either by $\psi_{1,1}$ or $\psi_{2,1}$, see EN 1991-1-2:2002;

ξ is a reduction factor for unfavourable permanent actions G.

Material properties

Mechanical properties

- simplified methods for cross section and timber frame members in wall and floor assemblies completely filled with insulation
- advanced calculation methods.

Thermal properties

Charring (depth)

- for all surfaces of wood and wood-based panels directly exposed to fire,
- for surfaces initially protected from exposure and charring occurs during the relevant time of fire exposure.

Material properties: Charring (1)

Surfaces unprotected throughout the time of fire exposure

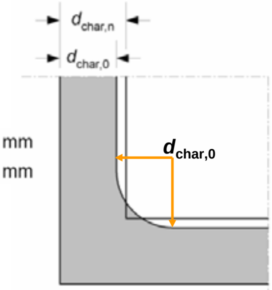
- one-dimensional charring

$$d_{char,0} = \beta_0 \, t$$

$$b_{min} = \begin{cases} 2\, d_{char,0} + 80 & \text{for } d_{char,0} \ge 13 \text{ mm} \\ 8{,}15\, d_{char,0} & \text{for } d_{char,0} < 13 \text{ mm} \end{cases}$$

- notional charring

$$d_{char,n} = \beta_n \, t$$



Material properties: Charring (2)

	β_0 mm/min	β_n mm/min
a) Softwood and beech		
Glued laminated timber with a characteristic density of ≥ 290 kg/m³	0,65	0,7
Solid timber with a characteristic density of ≥ 290 kg/m³	0,65	0,8
b) Hardwood		
Solid or glued laminated hardwood with a characteristic density of 290 kg/m³	0,65	0,7
Solid or glued laminated hardwood with a characteristic density of ≥ 450 kg/m³	0,50	0,55
c) LVL		
with a characteristic density of ≥ 480 kg/m³	0,65	0,7
d) Panels		
Wood panelling	0,9[a]	–
Plywood	1,0[a]	–
Wood-based panels other than plywood	0,9[a]	–

[a] The values apply to a characteristic density of 450 kg/m³ and a panel thickness of 20 mm; see 3.4.2(9) for other thicknesses and densities.

Material properties: Charring (3)

Charring for panels with other densities than ρ = 450 kg/m³ and smaller thickness h_p = 20 mm

$$\beta_{0,\rho,t} = \beta_0 \, k_\rho \, k_h$$

$$k_\rho = \sqrt{\frac{450}{\rho_k}}$$

$$k_h = \sqrt{\frac{20}{h_p}}$$

Example:
OSB – panel: ρ_k = 700 kg/m³
h_p = 20 mm → $\beta_{0,\rho,t}$ = 0,72 mm/min
h_p = 12 mm → $\beta_{0,\rho,t}$ = 0,93 mm/min

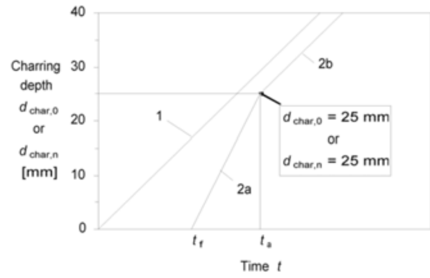
Material properties: Charring (4)

Surfaces of beams and columns initially protected from fire exposure

- the start of charring is delayed until time t_{ch};
- charring may commence prior to failure of the fire protection, but at a lower rate than the described charring rates until failure time t_f of the fire protection;
- after failure time t_f of the fire protection, the charring rate is increased above the shown values until the time t_a described below;
- at the time t_a when the charring depth equals either the charring depth of the same member without fire protection or 25 mm whichever is the lesser, the charring rate reverts to the described value.

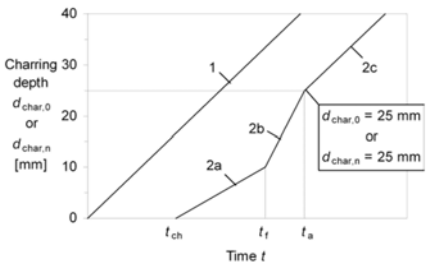
Material properties: Charring (5)

Surfaces of beams and columns initially protected from fire exposure



Material properties: Charring (6)

Surfaces of beams and columns initially protected from fire exposure



Design procedures for mechanical resistance

Simplified rules for determining cross-sectional properties - Reduced cross-section method

→ $k_{mod.fi}$ = 1,0

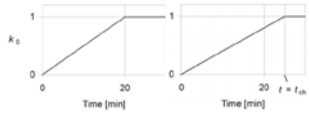
$$d_{ef} = d_{char,n} + k_0 \, d_0$$

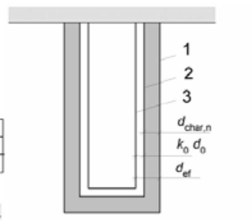
d_0 = 7 mm

k_0: unprotected surface

	k_0
t < 20 minutes	t/20
t ≥ 20 minutes	1,0

k_0: intial protected surface



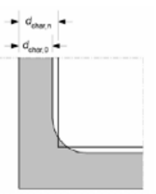


Key
1 Initial surface of member
2 Border of residual cross-section
3 Border of effective cross-section

Design procedures for mechanical resistance

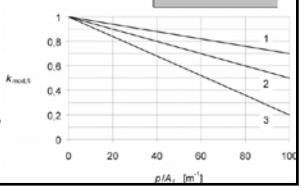
Simplified rules for determining cross-sectional properties - Reduced properties method

→ $k_{mod,fi}$ = f (p/A_r and strength, stiffness)



- apply only to rectangular cross-sections of softwood exposed to fire on three or four sides and
- round cross-sections exposed along their whole perimeter.

$k_{mod,fi}$ (t equal or greater 20 min):



1 Tensile strength, Modulus of elasticity
2 Bending strength
3 Compressive strength

Design procedures for mechanical resistance

Simplified rules for analysis of structural members and components

General

- Compression perpendicular to the grain may be disregarded.
- Shear may be disregarded in rectangular and circular cross-sections.

Beams, columns

- bracing fails should be considered

Mechanically jointed members

- reduction in slip moduli in the fire situation shall be taken into account

Bracings

Design procedures for mechanical resistance

Advanced calculation methods

- for determination of the mechanical resistance and the separating function shall provide a realistic analysis of structures exposed to fire,
- based on fundamental physical behaviour to lead to a reliable approximation of the expected behaviour of the relevant structural component under fire conditions.

Design procedures for wall and floor assemblies

Analysis of load-bearing function

- shall be designed for fire exposure on both sides at the same time.

Analysis of separating function

- take into account the contributions of different material components and their position in the assembly.

Connections (1)

•applies to connections between members under standard fire exposure, for fire resistances not exceeding 60 min.

Connections with side members of wood
Simplified rules - unprotected connections

	Time of fire resistance $t_{d,fi}$ min	Provisions[a]
Nails	15	$d \geq 2{,}8$ mm
Screws	15	$d \geq 3{,}5$ mm
Bolts	15	$t_1 \geq 45$ mm
Dowels	20	$t_1 \geq 45$ mm
Connectors according to EN 912	15	$t_1 \geq 45$ mm

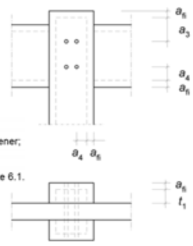
[a] d is the diameter of the fastener and t_1 is the thickness of the side member

Connections (2)

Connections with side members of wood
Simplified rules - unprotected connections

•greater t_{dfi} is possible (not more than 30 min) by increasing the following dimensions by a_{fi}:

- –the thickness of side members,
- –the width of the side members,
- –the end and edge distance to fasteners.



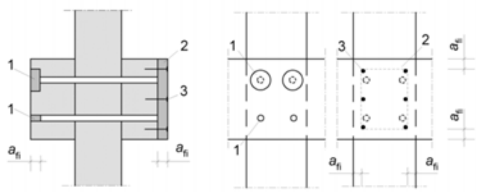
$$a_{fi} = \beta_n \, k_{flux} \, (t_{req} - t_{d,fi})$$

β_n is the charring rate according to table 3.1;
k_{flux} is a coefficient taking into account increased heat flux through the fastener;
t_{req} is the required standard fire resistance period;
$t_{d,fi}$ is the fire resistance period of the unprotected connection given in table 6.1.

•k_{flux} = 1,5

Connections (3)

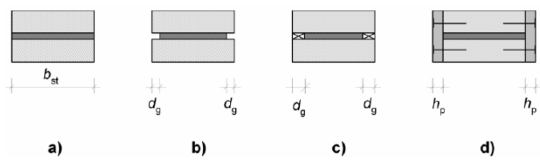
Connections with side members of wood
Simplified rules - protected connections



1 Glued-in plugs
2 Additional protection using panels
3 Fastener fixing panels providing additional protection

Connections (4)

Connections with side members of wood
Additional rules for connections with internal steel plates



Connections (5)

Connections with side members of wood
Reduced load method
Unprotected wood

$$F_{v,Rk,fi} = \eta \, F_{v,Rk}$$

$$\eta = e^{-k \, t_{d,fi}} \qquad t_{d,fi} = -\frac{1}{k} \ln \frac{\eta_{fi} \, \gamma_{M,fi}}{\gamma_M \, k_{fi}}$$

Connection with	k	Maximum period of validity for parameter *k* in an unprotected connection min
Nails and screws	0,08	20
Bolts wood-to-wood with $d \geq 12$ mm	0,065	30
Bolts steel-to-wood with $d \geq 12$ mm	0,085	30
Dowels wood-to-wood[a] with $d \geq 12$ mm	0,04	40
Dowels steel-to-wood[a] with $d \geq 12$ mm	0,085	30
Connectors in accordance with EN 912	0,065	30

[a] The values for dowels are dependent on the presence of one bolt for every four dowels

$F_{v,Rk}$ is the characteristic lateral load-carrying capacity of the connection with fasteners in shear at normal temperature, see EN 1995-1-1 section 8;

η is a conversion factor;

k is a parameter given in table 6.3;

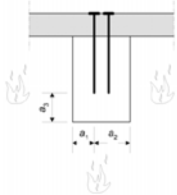
$t_{d,fi}$ is the design fire resistance of the unprotected connection, in minutes.

Protected wood

Connections (6)

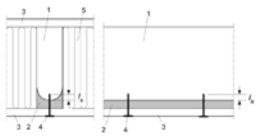
Connections with external steel plates
- unprotected
- protected

Simplified rules for axially loaded screws
- design resistance of the screws
- conversion factor η



Detailing

Walls and floors
- **Dimensions and spacings**
- **Detailing of panel connections**
- **Insulation**
- **Other elements**



1 Unburnt timber
2 Char layer
3 Panel
4 Fastener
5 Insulation

Thank you very much for your attention!

Contact:
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EUROCODE 9 - ALUMINIUM ALLOYS STRUCTURES

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Structural Fire Design of Aluminium Structures according to Eurocode 9 Part 1-2

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Secretary CEN TC 250 / SC 9 1992-2007
and member of the ENV PT for structural fire design of aluminium structures

Acknowledgements:

- Leen Twilt (Convenor), the Netherlands
- Steinar Lundberg (Technical Secretary), Norway

As main contributors in preparing EC9 – 1.2

Aluminium structures and fire:

- Most aluminium alloys have lost about 50% of their original strength at about 180 - 250°C
- Aluminium alloys melt at about 580 - 660°C
- Aluminium alloy structures with a fire resistance requirement will have to be insulated
- The insulation represents a main part of the fire resistance concept
- Aluminium structures can also be used unprotected when appropriate in a fire safety strategy, e.g. checked for radiation from a flare boom

Fire rated aluminium structures:

- Well known in the off-shore industry, e.g. living quarters with R60/REI60 – H120 structures/partitions
- Less common in the building market, however housing structures with R15 – R30 protected aluminium structural elements have been conceived
- Unprotected aluminium structures are set to R0

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EC9 – 1.2 : Aluminium structures - fire

Brussels, 18-20 February 2008 – Dissemination of information workshop 5

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EC 9 Part 1.2 provide

- **Mechanical and thermal properties for aluminium alloys at elevated temperatures**
- **Methodology for structural fire design in line with EC3 Part 1.2, differing from this however in that**
  - EC 9 give strength data for a variety of alloys
  - Non-linear stress strain relationships are not given
  - E.g. design procedure less comprehensive compared to what is possible for steel structures

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Comments received after ENV-period

- **Respondents: 2 countries only, Finland and Sweden**
- **Total number 32, editorial 7, technical 25**
- **Treated by PT in the conversion period**
- **Further improvements/updating introduced by the PT (Twilt/Lundberg)**
- **Editorial changes introduced by the editing panel in the final stage**

MATERIAL PROPERTIES - MECHANICAL

For thermal exposure up to 2 hours, the 0,2 % proof strength at elevated temperature of the aluminum alloys follows from:

$f_{o,\theta} = k_{o,\theta} \cdot f_o$

where

$f_{o,\theta}$ *is 0,2 proof strength at elevated temperature*

f_o *is 0,2 proof strength at room temperature according to EN 1999-1-1.*

Ratios $k_{o,\theta}$ 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-3004	H34	1,00	1,00	0,98	0,57	0,31	0,19	0,13	0
EN AW-5005	O	1,00	1,00	1,00	1,00	0,82	0,58	0,39	0
EN AW-5005	H14[1)]	1,00	0,93	0,87	0,66	0,37	0,19	0,10	0
EN AW-5052	H34[2)]	1,00	1,00	0,92	0,52	0,29	0,20	0,12	0
EN AW-5083	O	1,00	1,00	0,98	0,90	0,75	0,40	0,22	0
EN AW-5083	H12[3)]	1,00	1,00	0,80	0,60	0,31	0,16	0,10	0
EN AW-5454	O	1,00	1,00	0,96	0,88	0,50	0,32	0,21	0
EN AW-5454	H34	1,00	1,00	0,85	0,58	0,34	0,24	0,15	0
EN AW-6061	T6	1,00	0,95	0,91	0,79	0,55	0,31	0,10	0
EN AW-6063	T5	1,00	0,92	0,87	0,76	0,49	0,29	0,14	0
EN AW-6063	T6[4)]	1,00	0,91	0,84	0,71	0,38	0,19	0,09	0
EN AW-6082	T4[5)]	1,00	1,00	0,84	0,77	0,77	0,34	0,19	0
EN AW-6082	T6	1,00	0,90	0,79	0,65	0,38	0,20	0,11	0

1)The values may be applied also for temper H24/H34/H12/H32
2)The values may be applied also for temper H12/H22/H32
3)The values may be applied also for temper H22/H32
4)The values may be applied also for EN AW-6060 T6 and T66
5)The values do not include an increase in strength due to aging effects. It is recommended to ignore such effects.

Lower limits of the 0,2% proof strength ratios $k_{o,\theta}$ for aluminium alloys at elevated temperature for up to 2 hours thermal exposure period

	Aluminium alloy temperature C							
	20	100	150	200	250	300	350	550
Lower limit values	1,00	0,90	0,75	0,50	0,23	0,11	0,06	0

Modulus of elasticity of aluminium alloys at elevated temperature for a two hour thermal exposure period, $E_{al,\theta}$

Aluminium alloy temperature, θ (°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

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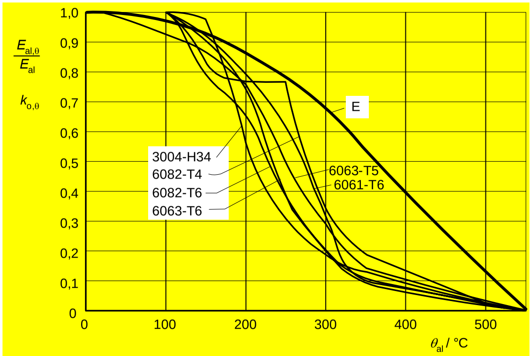
EC9 – 1.2 : Aluminium structures - fire

Brussels, 18-20 February 2008 – Dissemination of information workshop 13



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CEN/TC 250/SC 9/PT Fire
Design of aluminium structures.
Structural fire design.

Doc. no: CEN/TC 250/SC 9/PT Fire/N-27
Date: 26.08.03
Page: 1 of 4

Background document:

Mechanical properties at elevated temperature for aluminium alloys.

by Steinar Lundberg

- The N27 document is available at this work shop
- Refers international test data
- Summarizes the main background for the strength data given in EC 9 Part 1.2

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OBSERVE THAT

- Strength data are based on the 0,2 proof stress - only
- Modulus of elasticity is given the same temperature dependent reduction factor for all alloys
- No stress-strain relationships are given for the plastic range
- The modulus of elasticity in the critical temperature range is relatively less reduced compared to the strength reduction
- High temperature creep is not explicitly given

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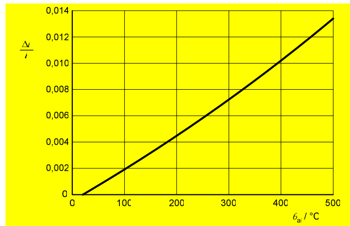
Brussels, 18-20 February 2008 – Dissemination of information workshop 16

MATERIAL PROPERTIES - THERMAL

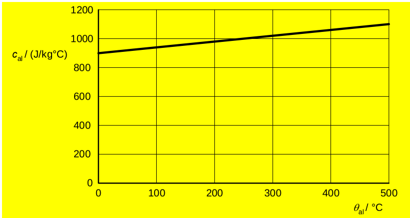
Thermal strain



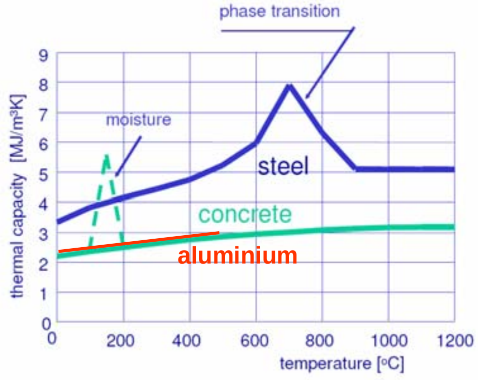
Compare:

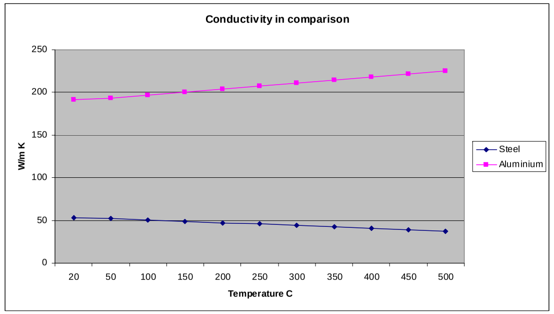
Aluminium at 200 °C: 0,0044, steel at 500 °C: 0,00675, also: Elasticity modulus less than for steel – restraint loads correspondingly less

Specific heat



Thermal capacity – in comparison…..



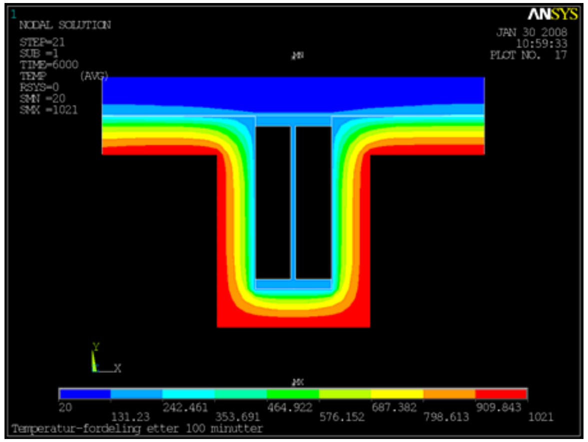


OBSERVE THAT

- Aluminium has a conductivity significantly higher than that of steel – beneficial wrt distribution of heat input
- The heat capacity (per m³) is somewhat lower compared to that of steel, however, looking at given structures (aluminium vs steel) with the same function, the heat capacity is about the same because deflection control often governs the design for an aluminium structure.

The non-linear transient thermal analysis

- Solution of Fourier's equation by FEM
- Thermal properties of insulation product more significant than those of aluminium (c(θ), λ (θ)) wrt results
- Example: I beam insulated with 100mm Rockwool 110kg/m3



Fire protection materials

- The properties and performance of fire protection materials used in design should be assessed as to verify that the fire protection remains coherent and cohesive to its support throughout the relevant fire exposure.
- The verification of the properties of protection materials is generally performed by tests. Presently there are no European standard for testing of such materials in connection with aluminium structures. An illustration of such test applicable to fire protected steel structures is given in ENV 13381-4.

Observe

For fire protected structures the integrity of the insulation system is theoretically less challenged as long as the strain levels are kept at a moderate level (as for aluminium, provided that high temperature creep does not become significant) throughout the fire exposure

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Structural fire design

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

- **Tension members and beams: "Straigth forward"**
- **Columns: Reduction factor 1,2 to take account of high temperature creep**

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Classification of cross-sections

- In a fire design situation, cross-sections may be classified as for normal temperature design according to 6.1.4 in EN 1999-1-1.
- **This rule is based on the same relative drop in the 0,2 % proof strength and modulus of elasticity. If the actual drop in modulus of elasticity is taken into account according to Figure 2, the classification of the section changes, and a larger capacity value of the section can be calculated. The National Annex may give provisions to take this into account.**
- **Confer Background document N26**

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RESISTANCE

Tension members

$N_{fi,t,Rd} = \sum A_i k_{o,\theta,i} f_o / \gamma_{M,fi}$ or $N_{fi,\theta,Rd} = k_{o,\theta} N_{Rd} (\gamma_{Mx} / \gamma_{M,fi})$

Beams

$M_{fi,t,Rd} = \sum A_i z_i k_{o,\theta,i} f_o / \gamma_{M,fi}$ or $M_{fi,t,Rd} = k_{o,\theta max} M_{Rd} (\gamma_{Mx} / \gamma_{M,fi})$

(accordingly for torsional bending and shear)

Columns

$N_{b,fi,t,Rd} = k_{o,\theta,max} N_{b,Rd} (\gamma_{M1} / 1{,}2\ \gamma_{M,fi})$ **Factor 1,2; Creep**

Note also possible to reduce buckling length, as in EC 3 Part 1.2, the same method is given

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Furthermore:

- **Lumped mass method for temperature calculation as for steel, for unprotected (moderate radiation) and protected (verified test data needed) aluminium structures, (now FEM is more suited, competitive)**
- **Advanced calculation methods only mentioned by principle, must be based on comprehensive studies and verified material models**
- **Heat transfer to external structural aluminium members: Material independent (ex emissivity) steady-state model as for steel**

Summary

- EC9 Part 1.2 offers a pragmatic and practical approach to design for fire resistance of aluminium structures
- The protection system represents a main part of the fire resistance concept
- Approved and verified thermal data c(θ), λ (θ) for use with FEM are needed from the fire insulation industry
- Integrity of protection systems can be verified only through reference to tests

Refer also
http://www.eaa.net/eaa/education/TALAT/lectures/2502.pdf,

THANK YOU FOR YOUR ATTENTION