“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
### Structural fire design

*Roi Baudoin room*

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<td>N. Forsén (Multiconsult)</td>
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All workshop material will be available at [http://eurocodes.jrc.ec.europa.eu](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"

ESSENTIAL REQUIREMENTS

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

HARMONISATION of ASSESSMENT METHODS

To prove compliance with Essential Requirements:
- Tests + extended applications of results
- calculation and/or design methods
- combination of tests and calculations

EUROCODES for STRUCTURAL FIRE DESIGN

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

CEN TC 250 – Sub-Committees involved in Fire Safety

TC 250 Structural Eurocodes

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.

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.

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.
2.4 Temperature Analysis

- (1) 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.

2.5 Mechanical Analysis

- (1) 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 \( t \)
- \( \Theta_d \): design value of material temperature
- \( \Theta_{cr,d} \): design value of the critical material temperature
2.1.1 General (cont'd)

- (3) 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.

Example from EC2-1.2

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 shall 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.

Example from EC2-1.2

Material Properties

2.3 Design values of material properties

- (1)P Design values of mechanical (strength and deformation) material properties \( X_{d,fi} \) are defined as follows:
  \[ X_{d,fi} = k \frac{X_k}{M,fi} \]
  - \( X_k \): characteristic value of a strength or deformation property
  - \( k \): reduction factor for a strength or deformation property dependent on temperature
  - \( M,fi \): partial safety factor for the relevant material property, for the fire situation

- (2) Design values of thermal material properties \( X_{d,fi} \) are defined as follows:
  \[ X_{d,fi} = X_{d,\text{ave}} / M,fi \]
  - \( X_{d,\text{ave}} \): value of a material property in fire design
  - \( M,fi \): partial safety factor for the relevant material property, for the fire situation.

Note 1: The value of \( X_{d,\text{ave}} \) for use in a Country may be found in its National Annex. The recommended value is \( X_{d,\text{ave}} = 1.0 \).

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

Example from EC2-1.2

Verification method: BASIC PRINCIPLE

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

\[ E_{d,fi} \leq R_{d,fi} \]

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

Example from EC2-1.2

Schematisation of the structure

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

(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.

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

Fire protection to:
- ENV 13381-3: concrete members
- ENV 13381-4: 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

Prescriptive Regulation
(Thermal Actions given by a Nominal Fire)

Performance-Based Code
(Physically Based Thermal Actions)

Member analysis
Mechanical actions at boundaries
Selection of mechanical actions
Tabulated data
Simple calculation models
Advanced calculation models

Prescriptive Regulation
(Thermal Actions given by a Nominal Fire)

Analysis of part of the structure
Mechanical actions at boundaries
Selection of mechanical actions

Analysis of the entire structure
Mechanical actions at boundaries
Simple calculation models
Advanced calculation models

Possible Design Procedures (cont’d)

ISO Concept vs FSE* Approach

Model    ISO – concept                  FSE* Approach
fire model
structural model
heat transfer model
mechanical model

Tank you for your attention
EUROCODE 1 - 1.2 ACTION IN CASE OF FIRE

T. Lennon
BRE
Background and Applications

EUROCODES

Tom Lennon
Principal Consultant, BRE, UK

Introduction to structural fire engineering design

Why structural fire engineering?
What is structural fire engineering design?
How do we do it?

Existing body of data
Tried and tested solutions
Accepted levels of safety and reliability
Tabulated data generally conservative

Structural fire engineering design – Do we need it?

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

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 – Do we need it? – YES!

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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

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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Background and Applications

Structural fire engineering design – what is it?

- **FLASHOVER**
- Natural fire curve
- Standard fire curve

- **Ignition - Smouldering**
- **Heating**
- **Cooling**
- **Life safety**

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

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Background and Applications

- **Performance-Based Code**
  (Physically based Thermal Actions)
- **Prescriptive Rules**
  (Thermal Actions by Nominal Fire)
- **Calculation of Mechanical Actions at Boundaries**
- **Member Analysis**
- **Project Design**
- **Selection of Simple or Advanced Fire Development Models**
- **Analysis of Part of the Structure**
- **Analysis of Entire Structure**
- **Calculation of Mechanical Actions at Boundaries**
- **Selection of Mechanical Actions**
- **Advanced Calculation Models**
- **Simple Calculation Models**

If available

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Background and Applications

- **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.

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Background and Applications

- **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.

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Background and Applications

- **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.

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Background and Applications

- **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.
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.

Thermal actions are given by the net heat flux:

\[ \dot{h}_{\text{net}} = \dot{h}_{\text{netc}} + \dot{h}_{\text{netr}} \]

Convective heat flux
Radiative heat flux

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
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.

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.

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.

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.

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:

$$Q_{j} = \sum_{j=1}^{n} (\psi_{j}o_{j}r_{j}Q_{j})$$

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

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

$$E_{f,d,t} = E_{f,d} = \eta_{f}E_{d}$$

Where

$$\eta_{f} = \frac{E_{f,d,t}}{R_{d}}$$

Changes in behaviour may be set by the National Annex.
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 \( \Gamma = \frac{(O/b)^2}{(0.04/1160)^2} \)

\( O \) is the opening factor

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

Where \( \rho \) = density (kg/m³)

\( c \) = specific heat (J/kgK)

\( \lambda \) = thermal conductivity (W/mK)

**Scope of Equation**

- \(-0.02 \leq O \leq 0.2\) (m½) (lower limit of 0.01 in UK NA)
- \(-100 \leq b \leq 2000\) (J/m² s½ °K)
- \(-A_f \leq 500m²\) (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)

**EC1 Parametric exposure**

Cooling phase

\[ G_1 = \theta_{max} - \frac{625(t^*-t_{max,x})}{t_{max}} \] for \( t_{max} \leq 0.5 \)

\[ G_2 = \theta_{max} - 250(3-t_{max})(t^*-t_{max,x}) \] for \( t_{max} < 2 \)

\[ G_3 = \theta_{max} - 250(t^*-t_{max,x}) \] for \( t_{max} \geq 2 \)

Where \( t_{max} = (0.2 \times 10^{-3} \cdot q_{cf}/O) \Gamma \)

And \( t_{max} \) = maximum of \((0.2 \times 10^{-3} \cdot q_{cf}/O)\) 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
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: \( t_e = q_f \cdot c \cdot w \)
Law: \( t_e = kL/\sqrt{(A_v A_t)} \)
Pettersson: \( t_e = 0.067 q_f (A_v \cdot h/A_t)^{0.5} \)
EC1: \( t_{e,d} = q_{f,d} \cdot k_b \cdot w_f \)

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

<table>
<thead>
<tr>
<th>Element</th>
<th>Area (m²)</th>
<th>Height of compartment (m)</th>
<th>Height of ventilation opening (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>36</td>
<td>7.2 (3.6m wide by 2m high)</td>
<td>3.6</td>
</tr>
<tr>
<td>Floor</td>
<td>36</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Walls</td>
<td>76.8</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

Time equivalent – thermal properties

<table>
<thead>
<tr>
<th>Element</th>
<th>Material</th>
<th>Thermal inertia (b value – J/m²s½K) (m²)</th>
<th>Area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>Concrete</td>
<td>2280</td>
<td>36</td>
</tr>
<tr>
<td>Floor</td>
<td>Plasterboard</td>
<td>520</td>
<td>36</td>
</tr>
<tr>
<td>Walls</td>
<td>Plasterboard</td>
<td>520</td>
<td>76.8</td>
</tr>
</tbody>
</table>

Time equivalent worked example

\[ t_{e,d} = (q_{f,d} \cdot k_b \cdot w_f) \cdot k_s \]

Where \( q_{f,d} = \) design fire load density (MJ/m²)
\( k_b = \) a factor dependent on thermal properties of the lining materials
\( w_f = \) a ventilation factor given by:

\[ w_f = (6/H)^{0.3} \cdot [0.62 + 90(0.4 - \alpha_v)] \]

Where \( H = \) the height of the compartment (m) and \( \alpha_v = A_v/A_t \)

\( k_s = \) factor dependent on material – 1.0 for protected steel

Time equivalent worked example

<table>
<thead>
<tr>
<th>Occupancy</th>
<th>Characteristic fire load density (MJ/m²) 80% fractile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dwelling</td>
<td>948 (400)</td>
</tr>
<tr>
<td>Hospital</td>
<td>280 (350)</td>
</tr>
<tr>
<td>Hotel</td>
<td>377 (400)</td>
</tr>
<tr>
<td>Office</td>
<td>511 (570)</td>
</tr>
<tr>
<td>School classroom</td>
<td>347 (360)</td>
</tr>
</tbody>
</table>
Time equivalent worked example

\[ q_{ef} = 570 \text{ MJ/m}^2 \]

\[ w_f = 0.863 (\alpha_v - 0.2) \]

\[ k_b = 0.07 (b = 945 (\sum (b_j A_j/A_j)) \]

\[ k_c = 1.0 \text{ (protected steel beam)} \]

\[ t_{ed} = 570 \times 0.863 \times 0.07 = 34 \text{ minutes therefore 60 minutes fire protection would be appropriate} \]

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
convener of Project Teams
- ENV 1992-1-2
- EN 1992-1-2

• 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
- Dr. Yngve Anderberg, Fire Safety Design AB, Sweden
- Dr. Ing. Nils Erik Forsén, Multiconsult AS, Norway
- Mr. Tauno Hietanen, Concrete Industry Association, Finland
- Mr. José Maria Izquierdo, INTEMAC, Spain
- Dr.-Ing. Ekkehard Richter, TU Braunschweig, Germany
- Mr. Robin T. Whittle, Ove Arup & Partners, United Kingdom

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. Dorette (B), L. Krampf (D), J. Mathez (F)
  - including material properties harmonized between EC 2, 3 and 4
- Project Team started the revision 1999 and prEN was approved for Formal Vote 2002

Scope of EN 1992-1-2

(5) 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) 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

<table>
<thead>
<tr>
<th>Member analysis</th>
<th>Tabulated data</th>
<th>Simplified calculation methods</th>
<th>Advanced calculation methods</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>YES</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Analysis of part of the structure</td>
<td>NO</td>
<td>Temperature profiles given for Standard fire only</td>
<td>Only the principles are given</td>
</tr>
<tr>
<td>Global structural analysis</td>
<td>NO</td>
<td>NO</td>
<td></td>
</tr>
</tbody>
</table>
Resistance to Fire CE-marking

National fire regulations:
- Required class - or fire resistance time

Parametric fire:
- European REI (M) classification

Nominal fire:
- Fire resistance time

Fire parts of Eurocodes:
- Tabulated data
- Simplified calculation
- Advanced calculation

EN 13501-2
Classification standard

EN 1363, EN 1365
Fire tests

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

\[ f_{c1,0} = 1.0 \text{ in fire design} \]

\[ \frac{3 \cdot f_{c1}}{\varepsilon_{c1,0}} \]

Mathematical model and parameters \( f_{c1,0}, \varepsilon_{c1,0} \) and \( \varepsilon_{c1,0} \)

\( \alpha_{CC} = 1.0 \) in fire design

Concrete: Stress-strain relationship

Strength reduction of concrete

- The same strength reduction values are given for simplified calculation methods in Section 4
  1. Siliceous concrete
  2. Calcareous concrete
Reinforcing and prestressing steel: Stress-strain relationship

- Mathematical model and parameters $f_{sp}$, $f_{sy}$, $\varepsilon_{sp}$, $\varepsilon_{sy}$, and $E_s$

Reinforcing steel strength

- 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 $\varepsilon_{s,fi} < 2\%$

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 of reinforcing steel at elevated temperatures are determined by applying standard SFS-EN 10002-5.
  - Requirements for 0.2 % proof strength $R_{p0.2}$ are given in Table 3.2-FI, where $f_{yk}$ is nominal yield strength or 0.2 % proof stress of the reinforcing steel at room temperature.

Table 3.2-FI: Strength requirements of reinforcing steel at elevated temperatures

Temperature (°C) | $R_{p0.2}$ (% of $f_{yk}$) |
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>100</td>
</tr>
<tr>
<td>400</td>
<td>80</td>
</tr>
<tr>
<td>500</td>
<td>60</td>
</tr>
<tr>
<td>650</td>
<td>45</td>
</tr>
</tbody>
</table>

Reference curve for Tabulated data in Section 5

1. Reinforcing steel $f_{yk} = 550$ ºC
   - 0.6 stress level
2. Prestressing bars $8r = 400$ ºC
   - 0.55 stress level
3. Prestressing wires and strands $8r = 350$ ºC
   - 0.55 stress level
Strength reduction is given by $f_{p,y} \left( \beta f_{p,k} \right)$ and $f_{p,y} \left( \beta f_{p,k} \right)$, where $\beta$ is NDP.

- Class A: $\beta = 0.9$
- Class B: $\beta = 0.9$

Common new proposal from the University of Liège and CERIB for the general and simplified models for the mechanical properties of prestressing steel (wires and strands) at elevated temperatures, September 12th 2003.

Strength reduction for simplified calculation methods in Section 4.

- Specific heat of concrete, $u$ is moisture % by weight
- Thermal conductivity of concrete, NDP between upper and lower limit
- 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 8.3.
• 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

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

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

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

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

Annex E
Simplified method to calculate bending capacity for predominantly uniformly distributed loads
This is some kind of extension of Tabulated data
\[
M_{\text{calc}} = \left( \frac{f_0}{f_{0,x}} \right) \times f_0(\theta) \times M_{\text{calc}} \left( A_{\text{proxi}} / A_{\text{calc}} \right)
\]
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 $\theta_p$ 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

<table>
<thead>
<tr>
<th>Calculation methods</th>
<th>Tabulated data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Define exposure class</td>
<td>Explosive spalling is covered by minimum requirements. No further checks needed.</td>
</tr>
<tr>
<td>Moisture content ≤ 3%</td>
<td>No, or yes but &gt; 3%</td>
</tr>
<tr>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>More accurate assessment</td>
<td>A more accurate assessment of surface reinforcement, type of aggregates, permeability of concrete, heating rate.</td>
</tr>
<tr>
<td>OK</td>
<td>OK</td>
</tr>
<tr>
<td>False behaviour been checked by tests.</td>
<td>False behaviour been checked by tests.</td>
</tr>
<tr>
<td>OK</td>
<td>OK</td>
</tr>
</tbody>
</table>

Falling off of normal strength concrete

<table>
<thead>
<tr>
<th>Shall be minimised or taken into account</th>
<th>No -&gt; OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c \geq 70$ mm</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tests to show that falling of does not occur</th>
<th>Yes</th>
<th>OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>Provide surface reinforcement</td>
<td></td>
</tr>
</tbody>
</table>

EN 1992-1-2

- 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 calciumous 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 torsional capacity and anchorage details.

4. When using tabulated data no further checks are required concerning spalling, except for surface reinforcement.
Europes
Background and Applications

Tabulated data are based on a reference load level \( \eta = 0.7 \), 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 \( \eta = 0.7 \) may not be valid. In such circumstances the value of \( \eta \) for use in a Country may be found in its National Annex.

For walls and columns load level \( \eta \) or degree of utilisation \( \mu \) is included in the tables

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

---

### Load level and degree of utilisation

**Actions**

- ACTIONS

**Resistances**

- RESISTANCES

\[
E_d \times \eta = E_{d,\text{fi}} \quad \text{Rd}
\]

\( \eta \) = load level

\( \mu = E_{d,\text{fi}} / \text{Rd} \) = degree of utilisation

takes into account 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 (\( \theta_{cr} = 500^\circ C \)), to be increased for prestressing steel (bars 10 mm, strands and wires 15 mm)

\( \theta_{cr} = 500^\circ C \) is derived from load level 0.7 divided by partial factor for reinforcement \( \gamma_s = 1.15 \)

For prestressing strands and wires \( \theta_{cr} = 350^\circ C \) and \( \sigma_s,fi / f_{p0,1k} = 0.55 \)

\( E_d = 0.7 E_d f_{cd} / f_{yd} = 0.9, \eta_s = 1.15 \)

---

### Parameters 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 \( \leq 3 \) m and first order eccentricity \( \leq 0.15h \) (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 \( \leq 0.25h \) and \( \lambda_{fi} \leq 30 \)
  - 9 pages of tables in Annex C

---

### Tabulated data for columns

- Method A degree of utilisation:
  \( \mu = N_{d,\text{fi}} / N_{d,\text{pd}} \)

- Method B load level is defined as:
  \( n = N_{d,\text{fi}} / (0.7(A_s f_{yd} + A_t f_{pt})) \)

---

### 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

\[
\sigma_s = E_d / f_{cd} x f_{cd} (20^\circ C) / A_{se} x A_{p0,1k} / A_{se}
\]

For beams and slabs:

\( E_d = 0.7 E_d f_{cd} / f_{yd} = 0.9, \eta_s = 1.15 \)

---

### Tabulated data in EN 1992-1-2

- Eccentricity
- Slenderness, \( \lambda_{cr} \)
  - upper floor 0.7 \( l \)
  - intermediate floor 0.5 \( l \)
Method A for columns

- Beams, slabs, tensile members
- Walls

### Table: Standard fire resistance

<table>
<thead>
<tr>
<th>Column width ( b_{min}/\text{axis distance} a ) of the main bars ( \text{mm} )</th>
<th>Minimum dimensions (mm)</th>
<th>( \phi_A/\psi )</th>
</tr>
</thead>
<tbody>
<tr>
<td>300 x 300</td>
<td>( a = 35 )</td>
<td>( \eta, \varphi = 0.5 )</td>
</tr>
<tr>
<td>( \eta, \varphi = 0.3 ) &gt; 4 bars</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( \eta, \varphi = 0.5 ) &gt; 4 bars</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Beam data:**
- \( \phi_A/\psi = 1,2 \) for normal temperature conditions
- \( \phi_A/\psi = 1,0 \) for fire conditions
- \( \psi = 0.5 \) for fire conditions

**Equations:**
- \( R = 120 \left( R_p + R_s + R_c + R_f / 120 \right)^{0.6} \)
- \( R_p = 1,0 \left( a - 10 \right) \)
- \( R_s = 0,9 \left( 5 - \psi \right) \)
- \( R_c = \left( 200 - a \right) / 200 \) for \( a > 200 \)
- \( R_f = \phi_A \cdot (a/\psi) \) for circular cross-sections
- \( a = \text{axis distance to the longitudinal steel bars (mm); } 25 \text{ mm} \leq a \leq 80 \text{ mm} \)
- \( b' = \text{effective length of the column under fire conditions; } 2 \text{ m} \leq b' \leq 6 \text{ m} \)
- \( \omega = \beta / (a/\psi) \text{ for rectangular cross-sections (mm)} \)
- \( \omega = \text{mechanical reinforcement ratio at normal temperature conditions} \)
- \( \omega_a = \text{coefficient for compressive strength (see EN 1992-1-1)} \)

**Walls:**
- 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

**Beams, slabs, tensile members:**
- 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 (for more conservative direction)
**EN 1992-1-2**

- 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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- Section 6 High strength concrete

**Strength reduction of high strength concrete**

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

**HSC strength reduction is NDP**

**HSC Tabulated data**

<table>
<thead>
<tr>
<th>Increase of minimum cross section by factor</th>
<th>Class 1</th>
<th>Class 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls and slabs exposed on one side</td>
<td>1,1</td>
<td>1,3</td>
</tr>
<tr>
<td>Other structural members</td>
<td>1,2</td>
<td>1,6</td>
</tr>
</tbody>
</table>

**HSC simplified calculation**

<table>
<thead>
<tr>
<th>Moment capacity reduction factors for beams and slabs</th>
<th>$M_{red}$</th>
<th>$N_{red}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beams</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>Slabs exposed to fire in the compression zone</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>Slabs exposed to fire in the tension side, $h_t \geq 120$ mm</td>
<td>0.98</td>
<td>0.95</td>
</tr>
<tr>
<td>Slabs exposed to fire in the tension side, $h_t = 50$ mm</td>
<td>0.95</td>
<td>0.85</td>
</tr>
</tbody>
</table>

**Spalling of HSC**

- 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 $\geq 2$ mm with a pitch $\leq 50 \times 50$ mm. The nominal cover to the main reinforcement should be $\geq 40$ 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/m$^3$ 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

L. Twilt
TNO Centre for Fire Research
The Netherlands
**Fire Design Structures - History**

**Conversion from ENV → EN**
- CEN MS's involved
- Comments received
  - editorial
  - technical
  - legal
- total:

**Comments per main issue**

**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

**Resistance to fire - Chain of events**

1: Ignition
2: Thermal action
3: Mechanical actions
4: Thermal response
5: Mechanical response
6: Possible collapse

---

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TNO Centre for Fire Research  
The Netherlands
Thermal response Basics

Thermal conduction (= λ)
Thermal capacity (= ρc_p)

DV: (shown for 1 direction only)

\[ \frac{\partial (\rho_c \Theta)}{\partial t} + \frac{\partial (\lambda \frac{\partial \Theta}{\partial x})}{\partial x} = 0 \]

Boundary condition: incoming/outgoing flux at surface: \( h_{\text{net,tot}} \)
Initial condition: room temperature

Heat balance:

\[ \Delta q \Theta / \Delta x + (\Delta (\rho_c \Theta) / \Delta t) = 0 \]

Fouier’s law:

\[ q = \lambda \frac{\Delta \Theta}{\Delta x} \]

Thermal conductivity Steel vs. concrete

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Thermal Conductivity [W/mK]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>400</td>
<td>30</td>
</tr>
<tr>
<td>600</td>
<td>40</td>
</tr>
<tr>
<td>800</td>
<td>50</td>
</tr>
<tr>
<td>1000</td>
<td>60</td>
</tr>
</tbody>
</table>

Thermal capacity Steel vs. concrete

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Thermal Capacity [MJ/m^3K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>200</td>
<td>2</td>
</tr>
<tr>
<td>400</td>
<td>3</td>
</tr>
<tr>
<td>600</td>
<td>4</td>
</tr>
<tr>
<td>800</td>
<td>5</td>
</tr>
</tbody>
</table>

Thermal response Steel beam/concrete slab (2D)

<table>
<thead>
<tr>
<th>Temperature [°C]</th>
<th>Time [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>60</td>
</tr>
<tr>
<td>0</td>
<td>120</td>
</tr>
</tbody>
</table>
**Mechanical response Basics**

- Theory of Applied Mechanics
  - Bernoulli
  - $E_{\text{tot}} = E_{\text{therm}} + E_{\sigma}$
  - $E_{\text{tot}}$ coefficient of thermal elongation ($\alpha_{\text{therm}}$)
  - Constitutive relationships steel, concrete, …
- Yield models
- Deformation capacity

- Reduced strength & stiffness at elevated temperature

**Mechanical properties of steel at elevated temperatures (qualitative)**

- $f_y = k_f f_{y,20}$

**Reduction of strength & stiffness at elevated temperatures**

- Failure at $t_f$ for:
  - $R_t < E_{\text{gap}}$
  - $R_t$ resistance at $t_m$
  - $E_{\text{gap}}$ action effect at $t_m$
  - $t_f$ resistance to fire

Note: $t_f$ depends a.o. on the "gap" between $R_{t,m}$ and $E_{\text{gap}}$.
Fire Design Steel Structures – Main route

Potential of EC3-1.2

Calculation vs test

Source: Efectis France (CTICM)

L. Twilt
TNO Centre for Fire Research
February 2005

Fire Design Steel Structures – Design

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!

Simple calculation models

Concepts

- “Resistance” concept
- “Critical temperature” 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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February 2005
“Resistance” concept
Illustration for the buckling resistance $N_{b,\phi,Rd}$

- $N_{b,\phi,Rd} = \varphi A k,_{\phi} f_{y}$  \(\text{... (1)}\)
  
  with
  - buckling coefficient $\varphi$
  - imperfection coeff. $k,_{\phi}$
  - rel. slenderness ratio $\lambda$

Note: $\varphi$ depends on steel grade and $\lambda$
$\lambda$ depends on temperature

Buckling curves at elevated temperature

Buckling curves Design aid

Uniform temperature distribution:

$n_{b,\phi,Rd} = k,_{\phi} \cdot M_{k,\phi}$  \(\text{... (1)}\)

Non uniform temperature distribution*):

$n_{b,\phi,Rd} = k,_{\phi} \cdot M_{k,\phi} / k,_{1} k,_{2}$  \(\text{... (2)}\)

Note: $k,_{1}$ = strength reduction factor
$A$ = steel area
$\kappa,_{1}, \kappa,_{2}$ = adaptation factors for non uniform temperature distribution

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

Basics

- Utilisation factor $\mu_\Theta$ in temperature domain:
  $E_{\text{str}} / R_{\text{str}} = f_{\text{y},\Theta} / f_{\text{y}} = k_{\text{y},\Theta} = (\mu_\Theta)

- Strength reduction factor as function steel temperature

with:
- $\Theta$ = steel temperature
- $k_{\text{y},\Theta}$ = strength reduction factor
- $\mu_\Theta$ = utilisation factor

"Critical temperature" concept

Design procedure

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

Thermal response steel element

Uniform temperature distribution

$\frac{\partial (\rho c \Theta)}{\partial t} + \frac{\partial}{\partial x} \left( \rho c \Theta \frac{\partial \Theta}{\partial x} \right) = 0$

with:
- $A_e$ is exposed surface area member [m$^2$/m]
- $V$ is volume member [m$^3$/m]
- $K_{sh}$ is "shadow" factor

"shadow" factor is new in EN version

Shadow effect

Effect shape steel profile

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

- Hence:
  - $\square$ -profiles, shadow effect: yes
  - $\Box$ -profiles, shadow effect: no
Shadow effect
Bare vs. insulated steel profiles

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

Summary
Unprotected profiles:
- profiles: \( k_{\text{shadow}} = 0.9 \frac{A_m}{V_{\text{box}}} \)
- \( \square \) profiles: \( k_{\text{shadow}} = 1 \)

Insulated profiles:
- “all” profiles: \( k_{\text{shadow}} = 1 \)

with:
- \( A_m \) is section factor
- \( \frac{A_m}{V_{\text{box}}} \) 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
Classification of cross-sections

Old rule (ENV)

- Border line values for b/t:
  \[ \left( \frac{b}{t} \right)_{\text{border}} = \varepsilon \left( \frac{b}{t} \right)_{\text{border,20}} \]
  with:
  \[ \varepsilon = \left( \frac{235}{f_y} \right) \left( k_{\text{rel}} k_{\text{res}} \right)^{0.5} \]

- Consequences ??

*) follows directly from room temperature rules

Temperature dependency

Hence
- classification "unstable"
- analysis complicated

Classification of cross-sections “old” rule

- Temperature dependency

Annexes

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

*) normative

for 350 – 850 °C: = o.k.
for 850 – 1200 °C: conservative

New rule (EN)

- Border line values for b/t:
  \[ \left( \frac{b}{t} \right)_{\text{border}} = \varepsilon \left( \frac{b}{t} \right)_{\text{border,20}} \]
  with:
  \[ \varepsilon = 0.85 \left( \frac{235}{f_y} \right)^{0.5} \]

- Consequences
  - for 350 – 850 °C: = o.k.
  - for 850 – 1200 °C: conservative

*) new compared to EN version; informative only
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 Eurocodes,
Background & Applications, Brussels, February 2008
EUROCODE 5 - 1.2 TIMBER STRUCTURES

H. Hartl
University Innsbruck

J. Fornather
Austrian Standards Institute
Structural fire design
Eurocode 5-1.2
Timber structures

Hans Hartl
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Hans.Hartl@uibk.ac.at

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

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 Eurocode Part

2.4 Verification methods

2.4.1 General

\[ E_{d,n} \leq R_{d,t,n} \]

2.4.2 Member analysis

\[ E_{d,n} = \eta_n E_d \]

\[ \eta_n = f(G_k, Q_k, \gamma, \psi) \]

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:

FireInTimber – Partners and countries:
SP Trätek – Sweden  VTT – Finland
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

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

Jochen Fornather
Austrian Standards Institute
jochen.fornather@on-norm.at

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

Scope of EN 1995-1-2
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- shows the design of timber structures for the accidental situation of fire exposure
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- 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)

Annex A: Charring rates and charring depths

Basis of design (1)

Basis of design (2)

Design values of material properties and resistances

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
**Design values of material properties and resistances**

\[ R_{d,t}, f = R_{d,B} / \gamma_{M,B} \]

- \( R_{d,B} \) is the design value of a mechanical resistance in the fire situation at time \( t \).
- \( R_{d,B} \) is the 20% fractile value of a mechanical resistance at normal temperature without the effect of load duration and moisture (\( \gamma_{M,B} = 1 \)).
- \( \gamma_{M,B} \) is a conversion factor.
- \( \gamma_{M,B} \) is the partial safety factor for timber in fire.

**Verification methods**

\[ E_{d,t}, f = \frac{E_d}{\gamma_b} \]

- \( E_d \) 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.
- \( E_b \) is the corresponding design resistance in the fire situation.
- \( \gamma_b \) is the partial safety factor for permanent actions.
- \( \gamma_{b,1} \) is the partial factor for variable action 1.
- \( \gamma_{b,2} \) is the combination factor for frequent values of variable actions in the fire situation, given either by \( \gamma_{b,1} \) or \( \gamma_{b,2} \). See EN 1991-1-2:2002.
- \( \delta \) is a reduction factor for unfavourable permanent actions.

**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.

**Surfaces unprotected throughout the time of fire exposure**

- one-dimensional charring
  \[ d_{\text{char}}, 0 = \beta_0 \cdot t \]
  \[ n_{\text{char}} = \begin{cases} 2 \cdot d_{\text{char}}, 0 & \text{for } d_{\text{char}}, 0 \geq 13 \text{ mm} \\ 8,15 \cdot d_{\text{char}}, 0 & \text{for } d_{\text{char}}, 0 < 13 \text{ mm} \end{cases} \]
- notional charring
  \[ d_{\text{char}}, n = \beta_n \cdot t \]

**Charring for panels with other densities than \( \rho = 450 \text{ kg/m}^3 \) and smaller thickness \( h_p = 20 \text{ mm} \)**

\[ \beta_{0,10} = \beta_0 \cdot K_p \cdot K_h \]

\[ K_p = \frac{450}{\sqrt{\rho}} \]

\[ K_h = \frac{20}{\sqrt{h_p}} \]

**Example**

- OSB – panel: \( \rho = 700 \text{ kg/m}^3 \)
  - \( h_p = 20 \text{ mm} \rightarrow \beta_{0,10} = 0.72 \text{ mm/min} \)
  - \( h_p = 12 \text{ mm} \rightarrow \beta_{0,10} = 0.93 \text{ mm/min} \)
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.

---

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

$\bar{A}_f = d_{ch,r} + k_0 d_0$

- $k_0$: unprotected surface
- $k_0$: initial protected surface

- 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

---

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
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.

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

<table>
<thead>
<tr>
<th>Time of fire resistance $t_{fa}$ min</th>
<th>Provisions*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nails</td>
<td>15</td>
</tr>
<tr>
<td>screws</td>
<td>15</td>
</tr>
<tr>
<td>bolts</td>
<td>15</td>
</tr>
<tr>
<td>dowels</td>
<td>20</td>
</tr>
<tr>
<td>Connections according to EN 912</td>
<td>15</td>
</tr>
</tbody>
</table>

* $d_f$ is the diameter of the fastener and $t_s$ is the thickness of the side member.

Connections (2)
- greater $t_{fa}$ is possible (not more than 30 min) by increasing the following dimensions by $a_i$:
  - the thickness of side members,
  - the width of the side members,
  - the end and edge distance to fasteners.

$$a_i = \beta_x \cdot F_{flux} \cdot (t_{fa} - t_{fa})$$

$\beta_x$ is the sharing rate according to table 5.1;
$F_{flux}$ is a coefficient taking into account increased heat flux through the fastener;
$t_{fa}$ is the requested standard fire resistance period;
$t_{fa}$ is the fire resistance period of the unprotected connection given in table 6.1.

$F_{flux} = 1.5$

Connections (3)
- applies to connections between members under standard fire exposure, for fire resistances exceeding 60 min.

Connections with side members of wood
Simplified rules - protected connections

Connections (4)
- applies to connections between members under standard fire exposure, for fire resistances exceeding 60 min.

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

1. Glue-in plugs
2. Additional protection using panels
3. Fastener fixing panels providing additional protection
Connections (5)

Connections with side members of wood
Reduced load method
Unprotected wood

\[ F_{v,Rk,li} = \eta F_{v,Rk} \]

\[ \eta = e^{-k \frac{\tau_{li}}{H}} \]

\[ \tau_{li} = \frac{V_0}{\gamma_{Mk}} \delta_{fl} \]

- \( F_{v,Rk,li} \) is the characteristic lateral load-carrying capacity of the connection with fasteners in shear at normal temperature. See EN 1995-1-1 section 8.
- \( \eta \) is a conversion factor.
- \( \delta_{fl} \) is a parameter given in Table 6.3.
- \( \tau_{li} \) 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 \( \eta \)

Detailing

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

Thank you very much for your attention!

Contact:
jochen.fornather@on-norm.at
Structural Fire Design of Aluminium Structures according to Eurocode 9 Part 1-2

Nils E. FORSÉN
Multiconsult AS, Norway
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
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

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
For thermal exposure up to 2 hours, the 0.2 % proof strength at elevated temperature of the aluminum alloys follows from:

\[ f_{o, \theta} = k_{o, \theta} \cdot f_0 \]

where

- \( f_{o, \theta} \) is 0.2 proof strength at elevated temperature
- \( f_0 \) 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

| Alloys | Temper | \( k_{o, \theta} \) ratio for EN AW-6060 T6
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EN AW-6060</td>
<td>O</td>
<td>0.09</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>H24</td>
<td>0.11</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>H34</td>
<td>0.19</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>H12</td>
<td>0.23</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>H22</td>
<td>0.38</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>H32</td>
<td>0.40</td>
</tr>
</tbody>
</table>

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where

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- \( f_0 \) is 0.2 proof strength at room temperature according to EN 1999-1-1.

Lower limits of the 0.2% proof strength ratios \( k_{o, \theta} \) for aluminum alloys at elevated temperature for up to 2 hours thermal exposure period

| Alloys | Temper | Lower limit ratios
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>EN AW-6060</td>
<td>T6</td>
<td>1.00</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>T3</td>
<td>0.89</td>
</tr>
<tr>
<td>EN AW-6060</td>
<td>T5</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Modulus of elasticity of aluminum alloys at elevated temperature for a two hour thermal exposure period, \( E_{\theta} \)

| Aluminum alloy temperature, \( \theta \) (°C) | Modulus of elasticity, \( E_{\theta} \) (N/mm²)
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>70 600</td>
</tr>
<tr>
<td>50</td>
<td>63 000</td>
</tr>
<tr>
<td>100</td>
<td>59 900</td>
</tr>
<tr>
<td>150</td>
<td>56 300</td>
</tr>
<tr>
<td>200</td>
<td>52 300</td>
</tr>
<tr>
<td>250</td>
<td>48 100</td>
</tr>
<tr>
<td>300</td>
<td>44 000</td>
</tr>
<tr>
<td>350</td>
<td>40 000</td>
</tr>
<tr>
<td>400</td>
<td>36 000</td>
</tr>
<tr>
<td>450</td>
<td>32 000</td>
</tr>
<tr>
<td>500</td>
<td>28 000</td>
</tr>
</tbody>
</table>
EC9 – 1.2 : Aluminium structures - fire

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

**EUROCODES Background and Application Workshop Brussels 18-20 February 2008**

**EC9 – 1.2 : Aluminium structures - fire**

- **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

**Material Properties - Thermal**

- Compare:
  - Aluminium at 300 °C: 0,0044, steel at 500 °C: 0,00675, also: Elasticity modulus less than for steel - restraint loads correspondingly less

**EC9 – 1.2 : Aluminium structures - fire**

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

**OBSERVE THAT**

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**Background document:**

**Mechanical properties at elevated temperature for aluminium alloys.**

by Steinar Lundberg

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**Material Properties - Thermal**

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  - Aluminium at 300 °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…..

Conductivity in comparison

OBSERVE THAT

- Aluminium has a conductivity significantly higher than that of steel – beneficial wrt distribution of heat input
- The heat capacity (per m$^3$) 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 \((c(\theta), \lambda (\theta))\) 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.
**Structural fire design**

\[ E_{f,\text{d}} \leq R_{f,\text{d}} \]

- Tension members and beams: "Straight forward"
- Columns: Reduction factor 1.2 to take account of high temperature creep

**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

**Resistance**

Tension members

\[ N_{\text{t,1,Re}} = \sum A_k k_{\text{tot},i} f_{\gamma_{R,\text{d}}} \quad \text{or} \quad N_{\text{t,1,Re}} = k_{\text{tot}} N_{\text{t,Re}} \left( \gamma_{R,\text{d}} / \gamma_{R,\text{d}} \right) \]

Beams

\[ M_{\text{b,1,Re}} = \sum A z_k k_{\text{tot},i} f_{\gamma_{R,\text{d}}} \quad \text{or} \quad M_{\text{b,1,Re}} = k_{\text{tot},\text{max}} M_{\text{b,Re}} \left( \gamma_{R,\text{d}} / \gamma_{R,\text{d}} \right) \]

(accordingly for torsional bending and shear)

Columns

\[ N_{\text{b,1,Re}} = k_{\text{tot},\text{max},\text{b}} N_{\text{b,Re}} \left( \gamma_{R,\text{d}} / 1.2 \gamma_{R,\text{d}} \right) \text{ Factor 1.2; Creep} \]

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

**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 $c(\theta), \lambda(\theta)$ 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