



Structural Fire Design according to Eurocodes

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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

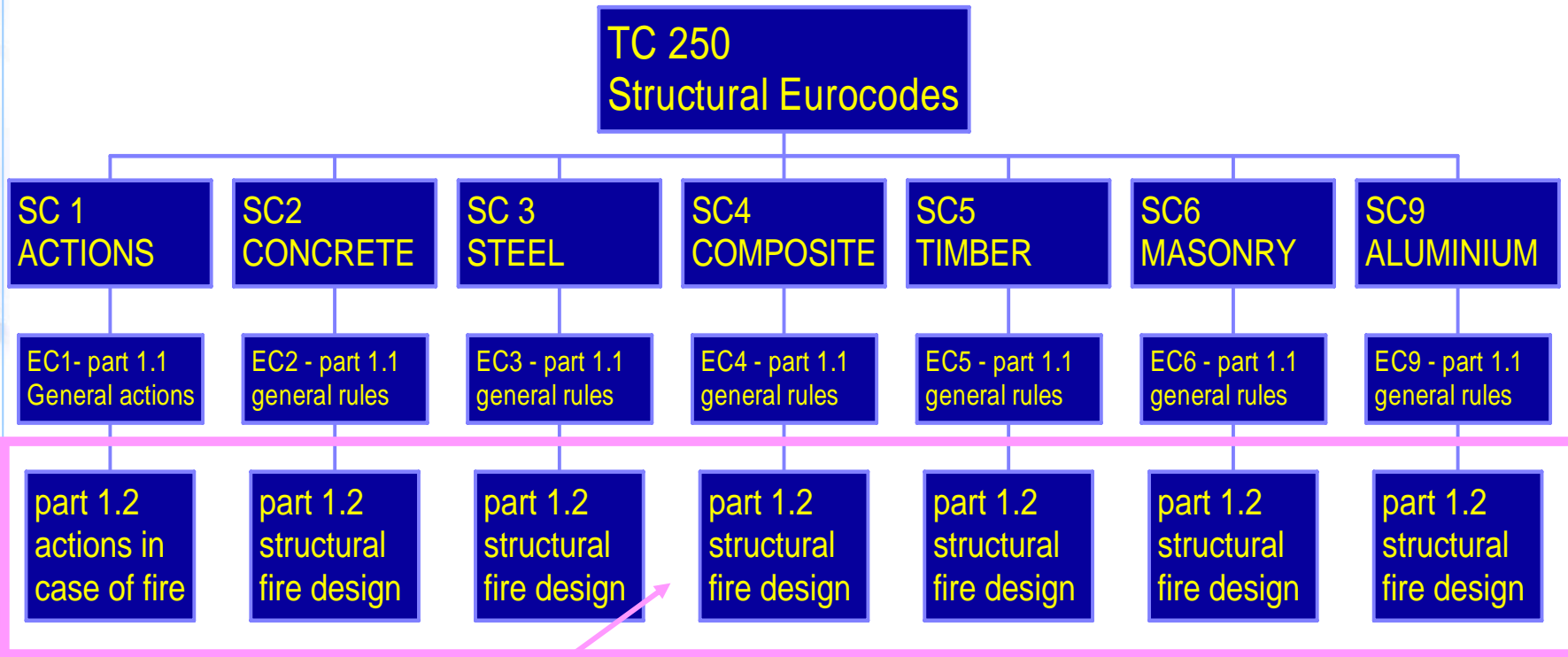
EC 6 : MASONRY

EC 9 : ALUMINIUM ALLOYS STRUCTURES



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- B. A. Haseltine (UK – Masonry)
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- J. Kruppa (F – Actions - Steel – Composite)
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HORIZONTAL GROUP "FIRE"



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 annexes on simple calculation methods



2.1 General

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

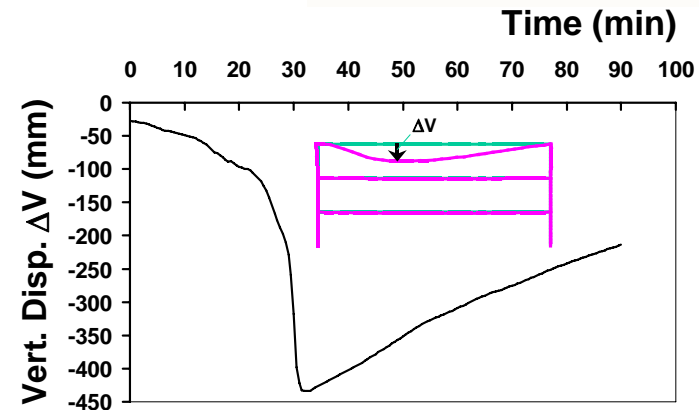
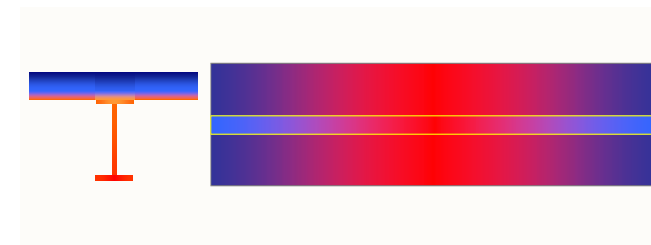
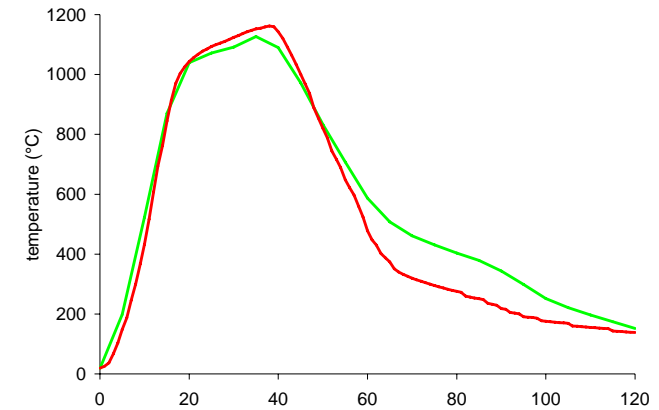
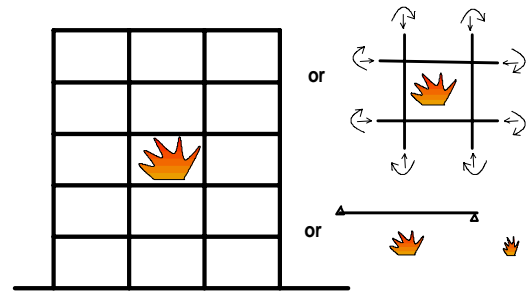
- selection of the relevant design fire scenarios,
- determination of the corresponding design fires,
- calculation of temperature evolution within the structural members,
- calculation of the mechanical behaviour of the structure exposed to fire.

Fire Development and propagation

Structural schematisation

Heat Transfer to structural elements

Mechanical behaviour at elevated temperatures



2.2 Design fire scenario

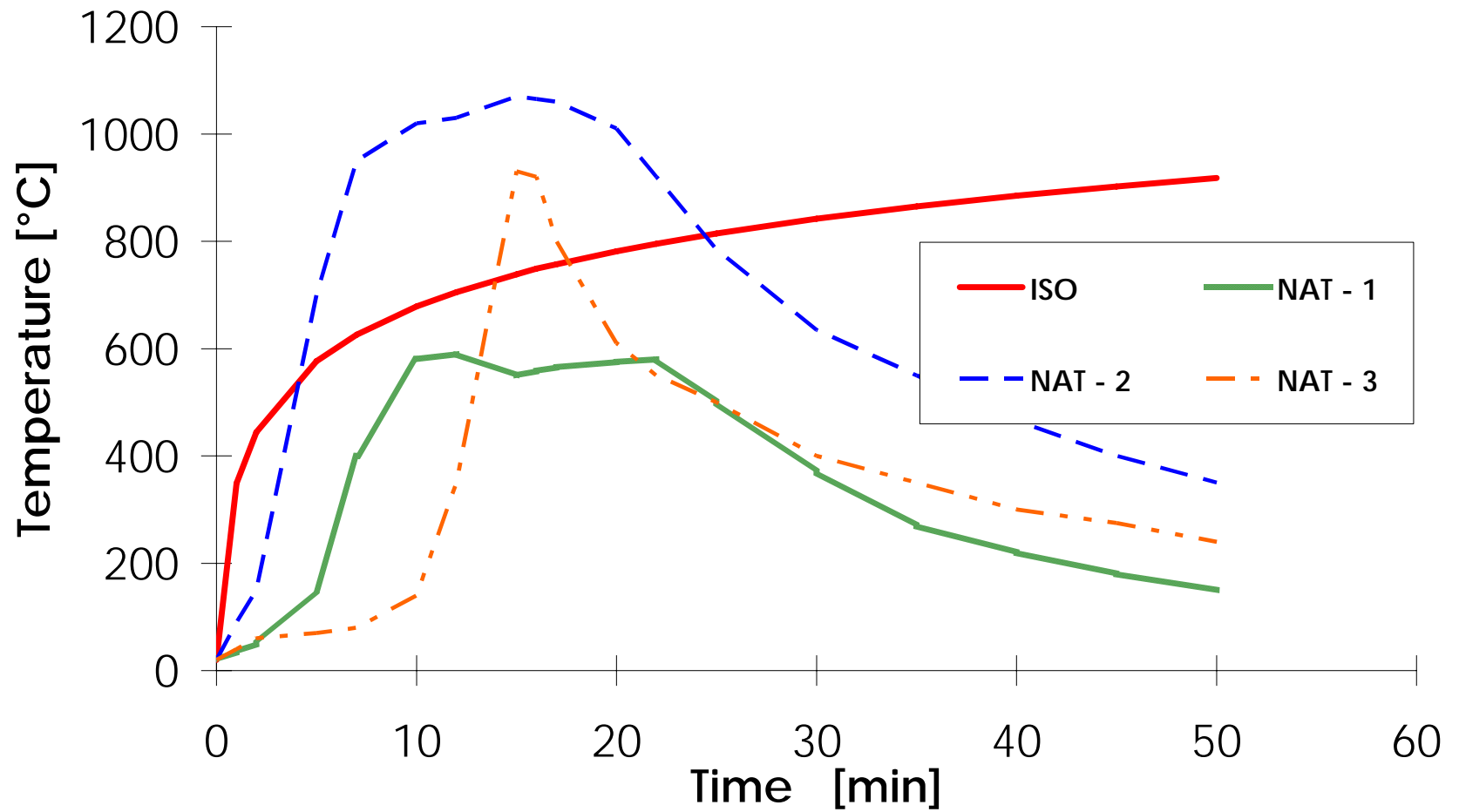
- (1) To identify the accidental design situation, the relevant design fire scenarios and the associated design fires should be determined on the basis of a **fire risk assessment**.
- (2) For structures where **particular risks of fire arise as a consequence of other accidental actions**, this risk 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.





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)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.



2.1.1 General (cont'd)

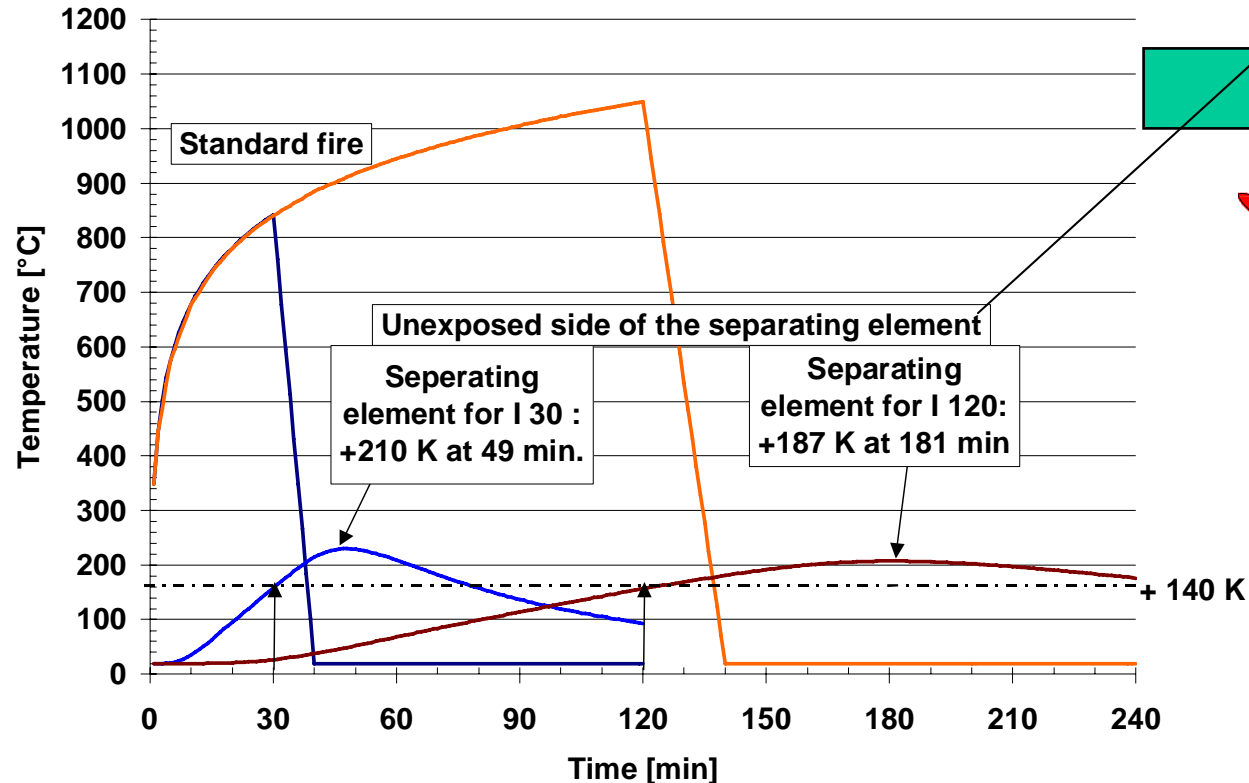
- (3)P **Deformation criteria** shall be applied where the **means of protection**, or the design criteria for **separating elements**, require consideration of the deformation of the load bearing structure.
- (4) Consideration of the deformation of the load bearing structure **is not necessary** in 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 $X_{d,fi}$ 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 $X_{d,fi}$ 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 :

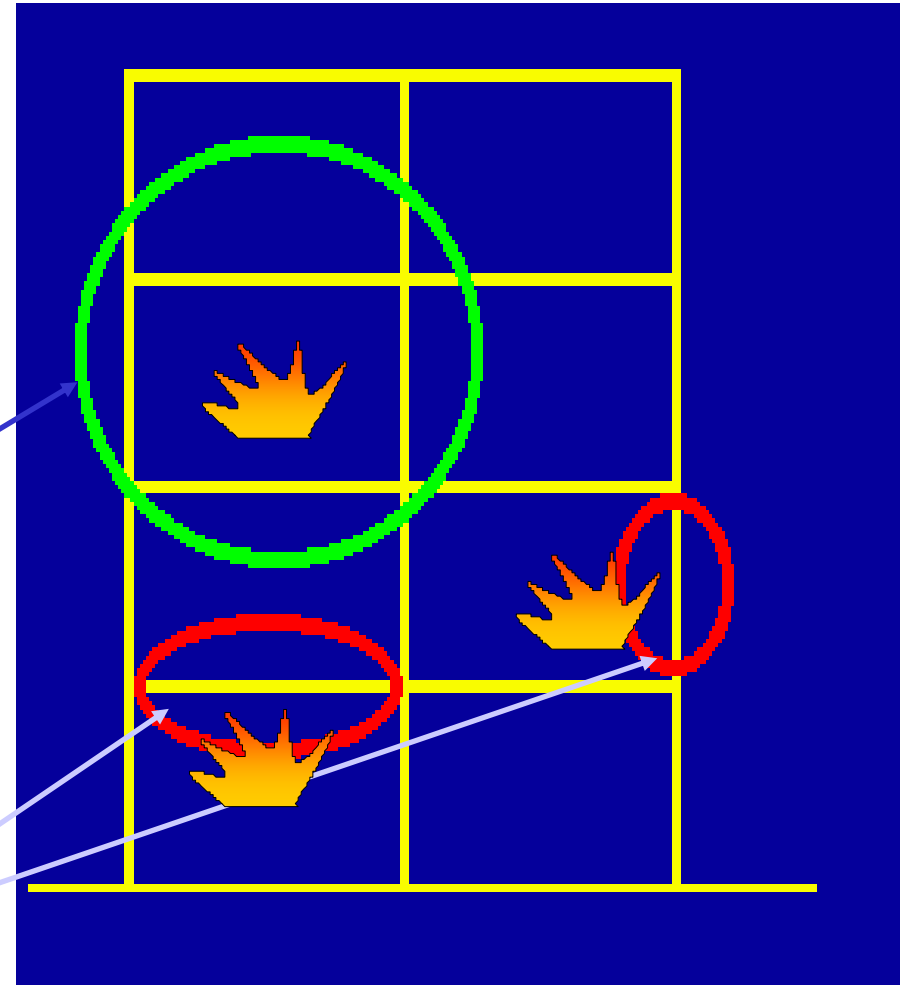
- $E_{d,t, fi}$: design effect of actions (Eurocode 1 part 1.2)
- $R_{d,t, fi}$: design resistance of the structure at time t

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)





- (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:

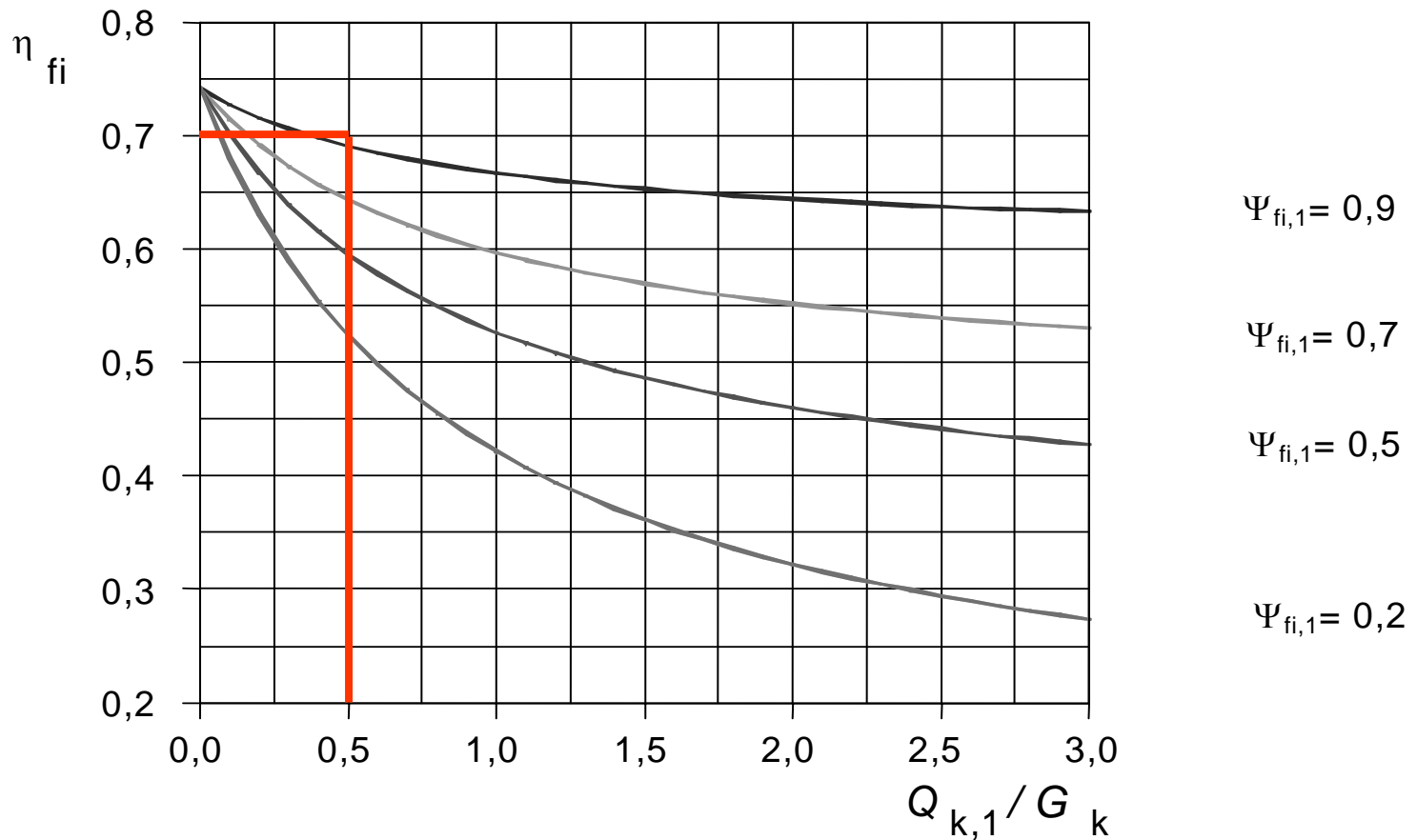
$$E_{d,fi} = \eta_{fi} E_d$$

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.

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



assumptions: $\gamma_G = 1,35$ and $\gamma_{Q,1} = 1,5$.

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

- (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.**



(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.

covering both thermal model and mechanical model

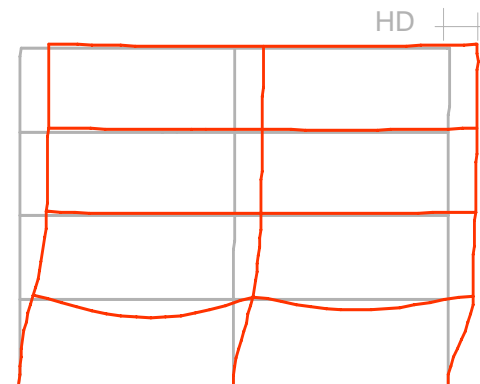
tabulated data

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	120	160	200	80
		25	15	10	10	
R 60	b _{min} a	120	160	200	300	100
		40	35	30	25	
R 90	b _{min} a	150	200	250	400	100
		55	45	40	35	
R 120	b _{min} a	200	240	300	500	120
		65	55	50	45	
R 180	b _{min} a	240	300	400	600	140
		80	70	65	60	
R 240	b _{min} a	280	250	500	500	160
		90	80	75	70	

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





Membrane protection

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

Fire protection to :

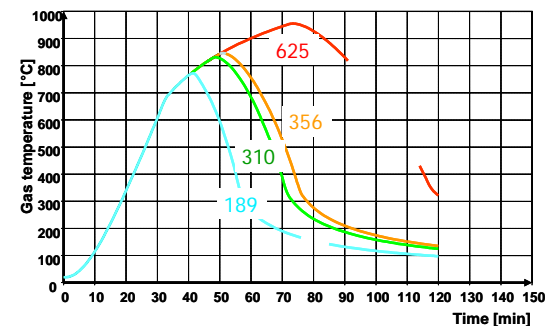
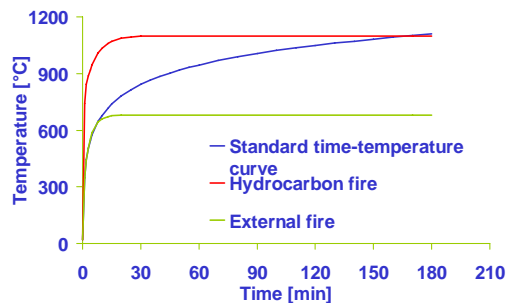
- ENV 13381 -3 : concrete members
- ENV 13381 -4 (& -8 ?) : steel members
- ENV 13381 -5 : concrete/profiled steel sheet
- ENV 13381 -6 : concrete filled hollow steel columns
- ENV 13381 -7 : timber members

(Developed by CEN TC 127)

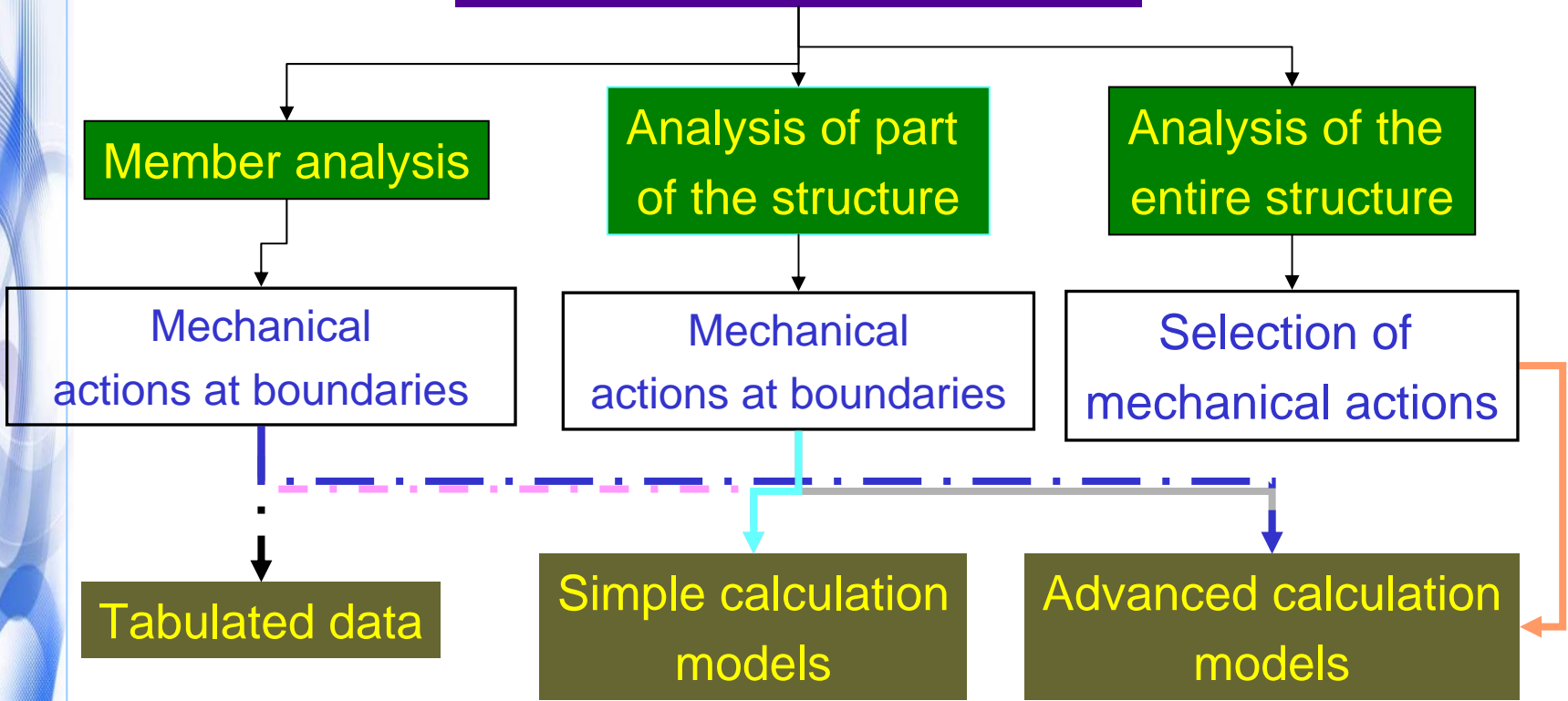
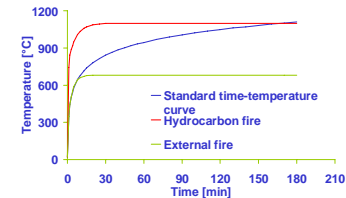
Project Design

Prescriptive Regulation
(Thermal Actions given by a Nominal Fire)

Performance-Based Code
(Physically Based Thermal Actions)

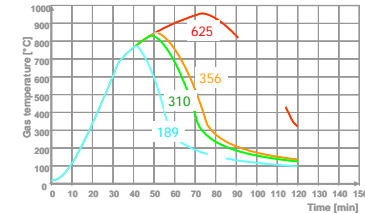


Prescriptive Regulation *(Thermal Actions given by a Nominal Fire)*



Performance-Based Code

Fire development Model



Member analysis

Analysis of part of the structure

Analysis of the entire structure

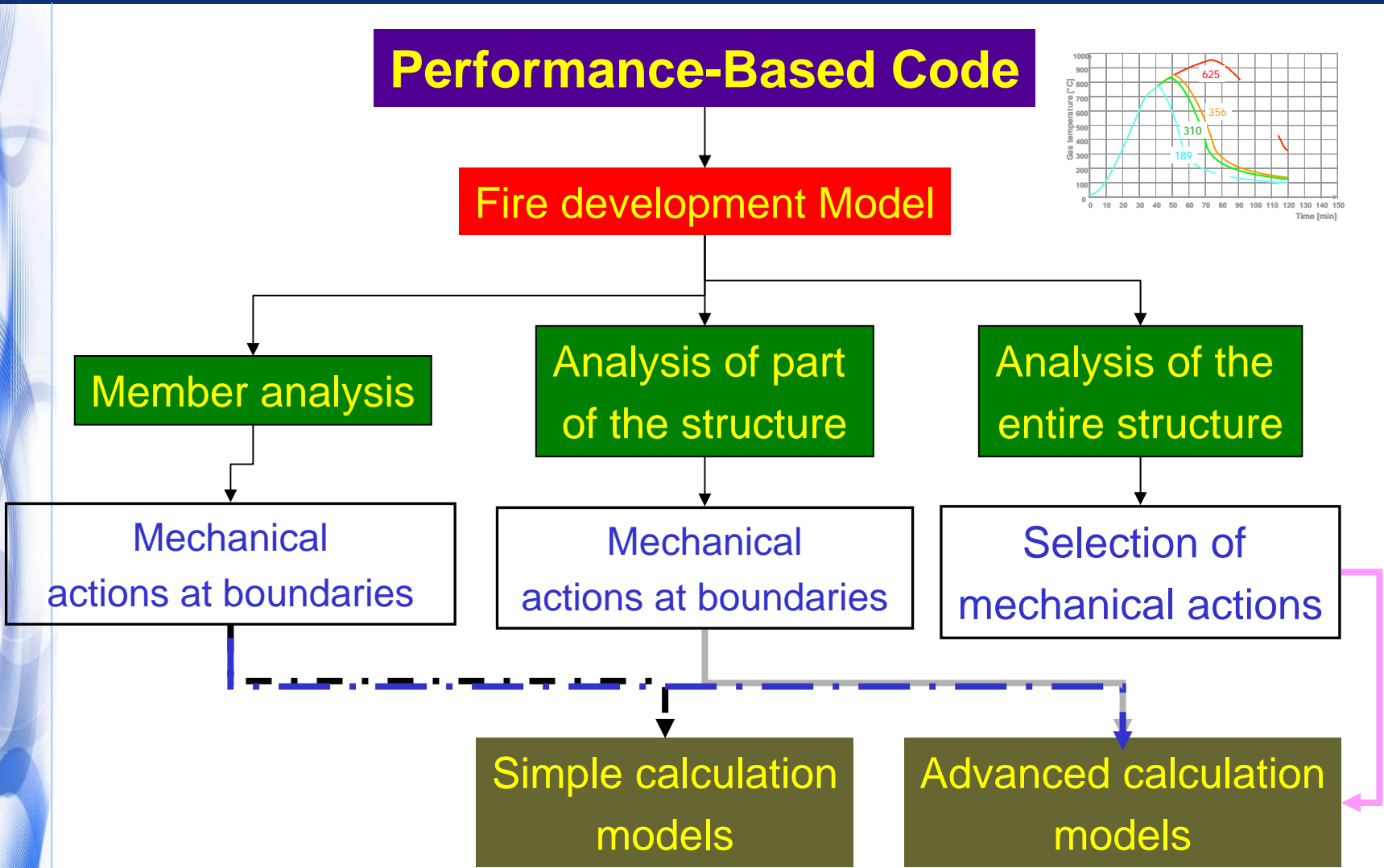
Mechanical actions at boundaries

Mechanical actions at boundaries

Selection of mechanical actions

Simple calculation models

Advanced calculation models





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



***Thank you for
your attention***