Conceptual Fire Design and assessment

Fabienne ROBERT
CERIB

Caroline MORIN
CERIB

Part I

CONCEPTUAL FIRE DESIGN

(Fabienne ROBERT)

Essential Requirements

The construction works must be designed and build in such a way, that in the event of an outbreak of fire :

- the load bearing resistance of the construction can be assumed for a specified 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

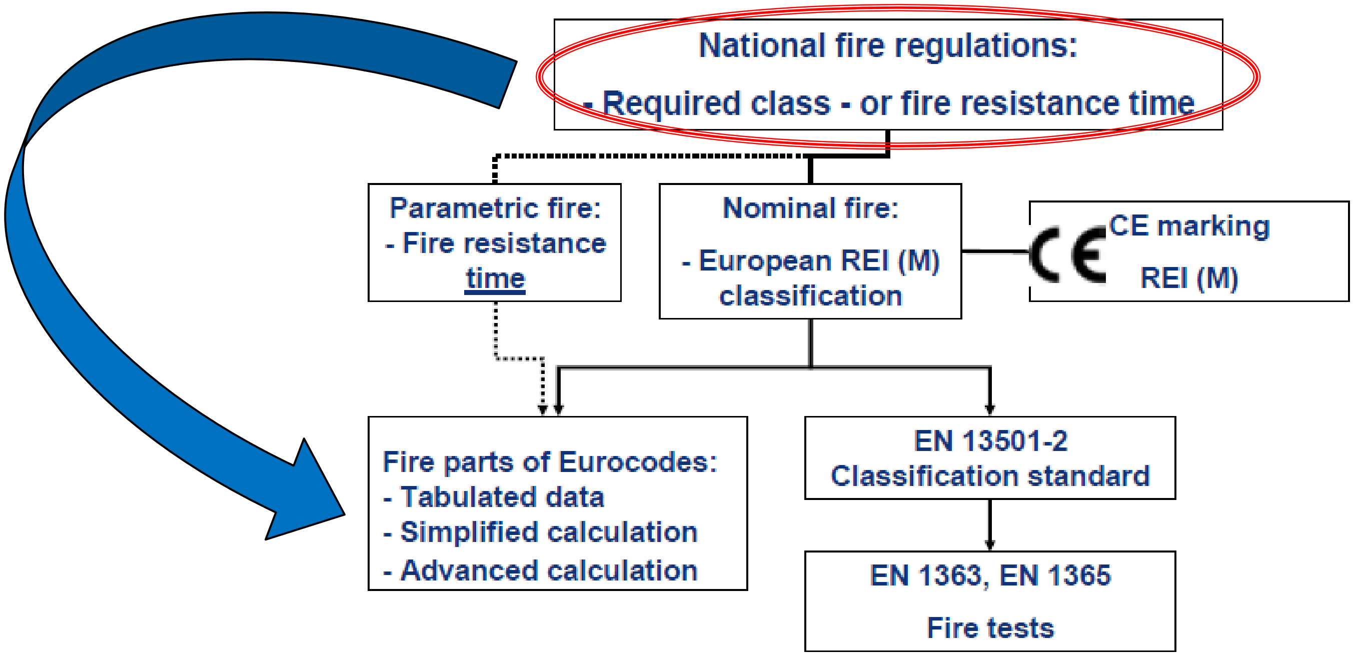
- the occupants can leave the works or can be rescued by other means

- the safety of rescue teams is taken into consideration

Essential Requirements

To prove compliance with Essential Requirements :

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

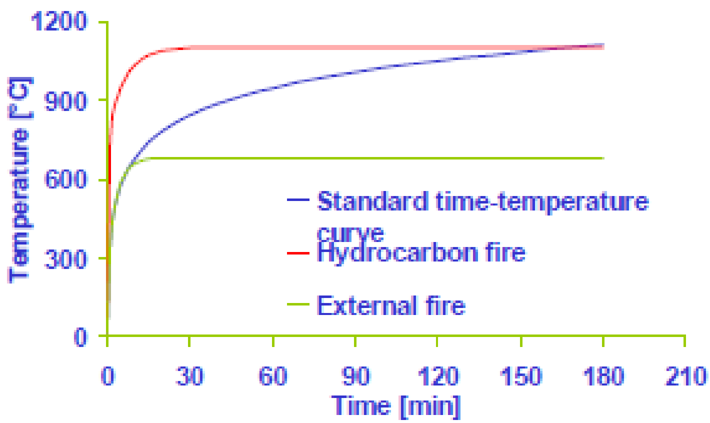


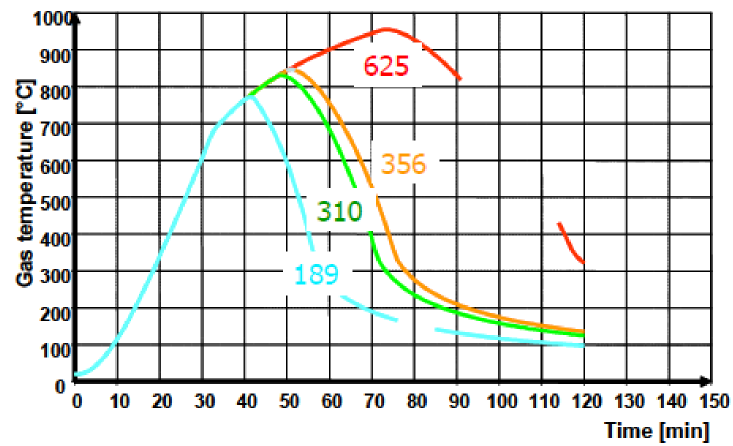
Alternative verification method

Project Design

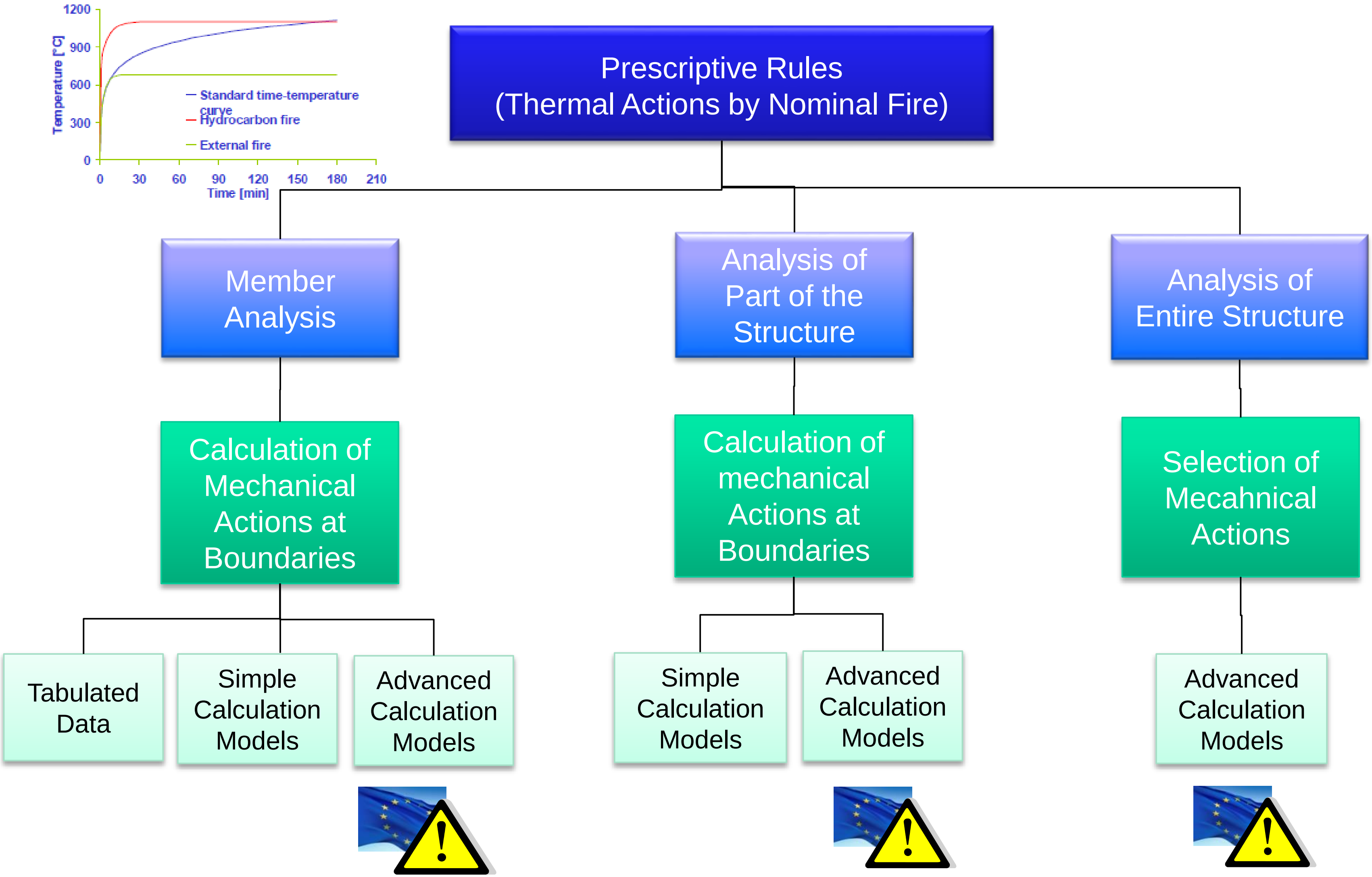
Prescriptive Regulation
(Thermal Actions given by a Nominal Fire)

Performance-Based Code
(Physical Based Thermal Actions)

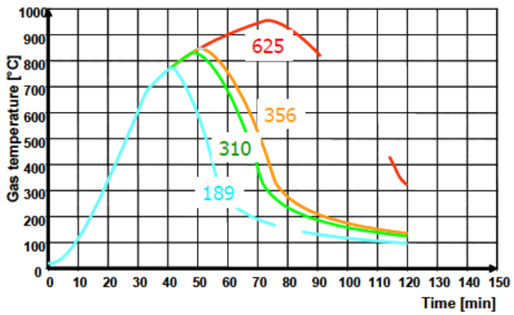




Alternative verification method



Alternative verification method



Performance-Based Code
(Physically based Thermal Actions)

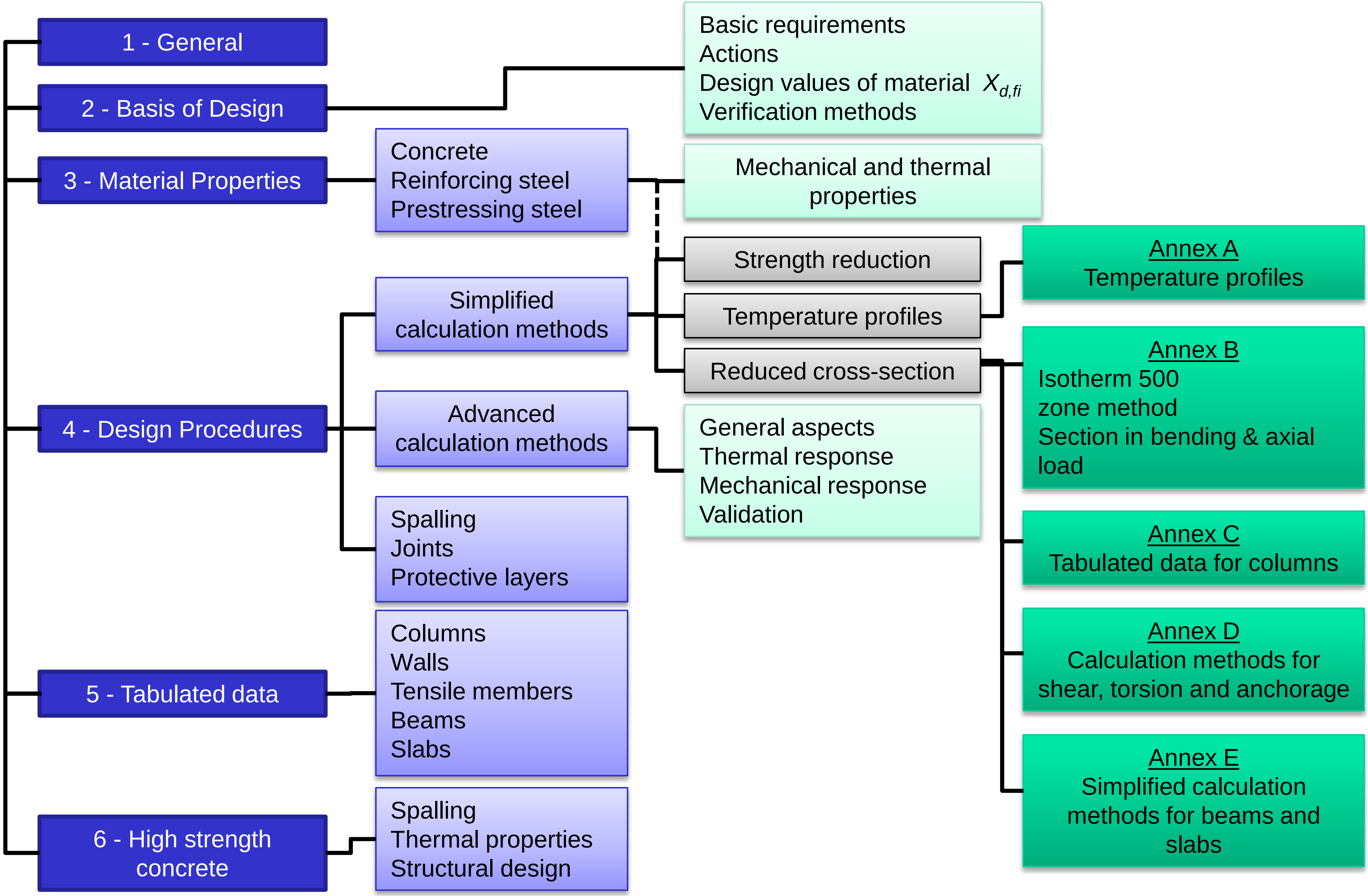
Selection of Simple or Advanced Fire Development Models

Member Analysis
- Calculation of Mechanical Actions at Boundaries
  - Simple Calculation Models (if available)
  - Advanced Calculation Models

Analysis of Part of the Structure
- Calculation of mechanical Actions et Boundaries
  - Advanced Calculation Models

Analysis of Entire Structure
- Selection of Mecahnical Actions
  - Advanced Calculation Models

Content of EN 1992-1-2



Scope

- Design of concrete structures for fire exposure in conjonction with EN 1992-1-1 and EN 1991-1-2
- Applicable to normal weight concrete up to C 90/105 and lightweight concrete up to LC 50/60

❑ Requirements

✓ **Design to maintain the load-bearing function (R) and/or**

✓ **Design and construction to maintain the separating function (E, I)**

→ **Nominal fire exposure during the required time period**

→ **Parametric fire exposure during the complete duration of fire (specific criterion for I in the decay phase)**

❑ Design values of material properties

- **Mechanical material properties**
  $X_{d,fi} = k_{\theta} \cdot X_k / \gamma_{M,fi}$
- **Thermal material properties**
  $X_{d,fi} = X_k / \gamma_{M,fi}$ **(favourable)**
  $X_{d,fi} = X_k \cdot \gamma_{M,fi}$ **(unfavourable)**

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

Verification method – 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:

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

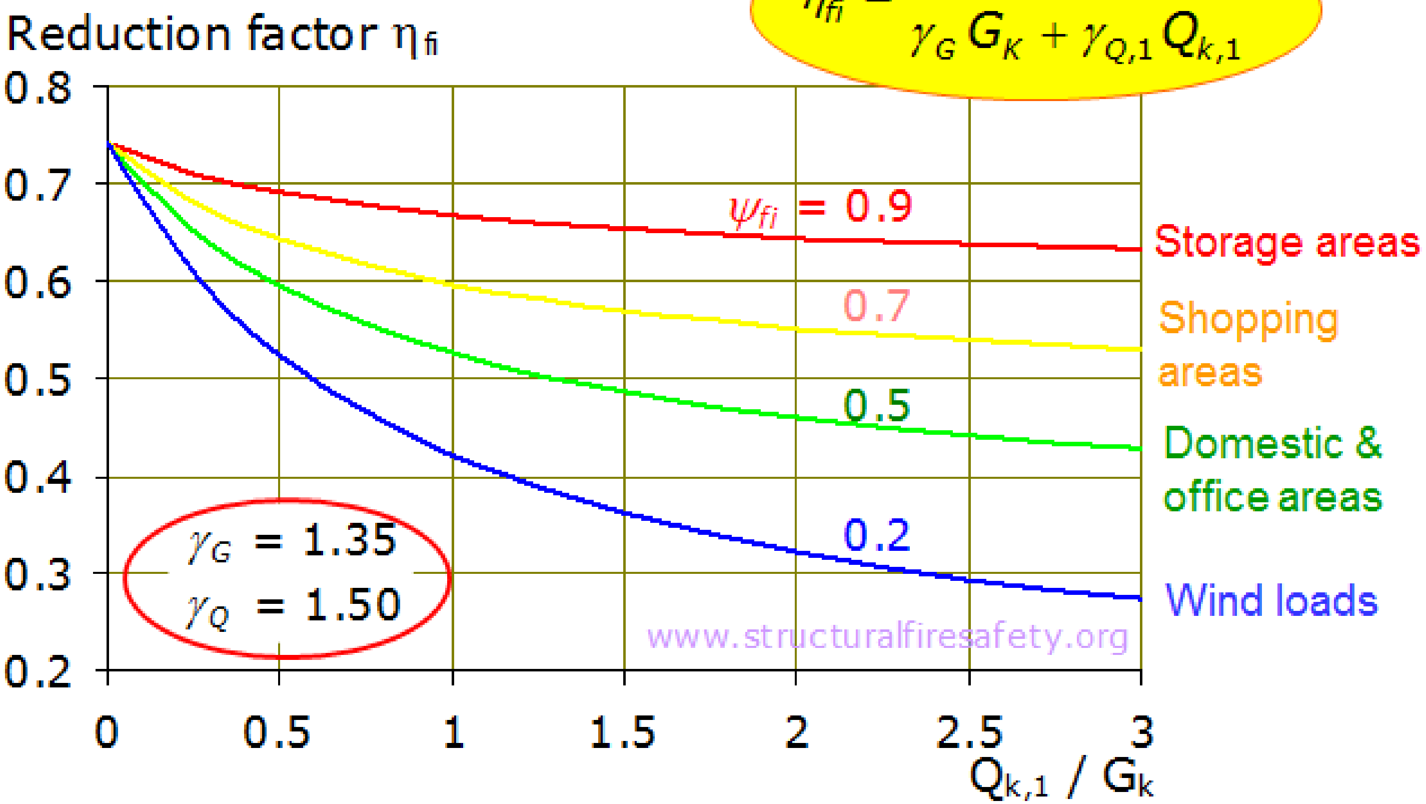
Where

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.

Example for η_{fi}

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



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

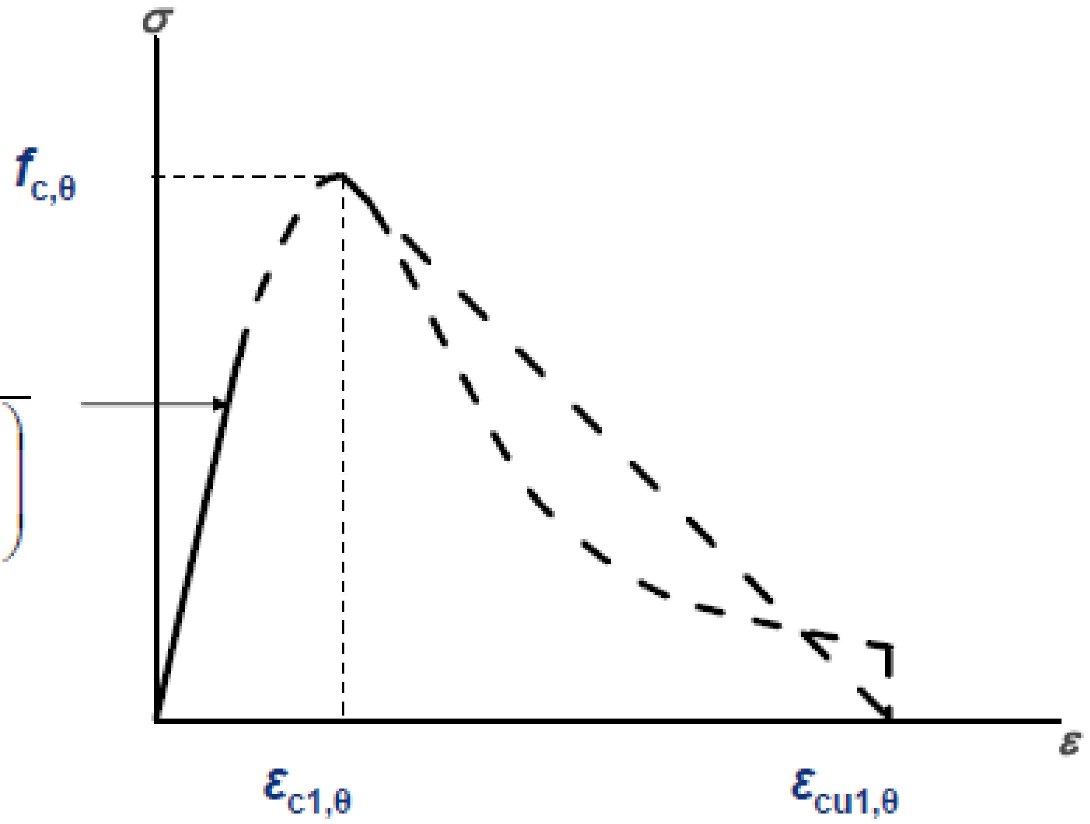
SECTION 3 - Material Properties

- 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)

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

α_{CC} = 1,0 in fire design

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

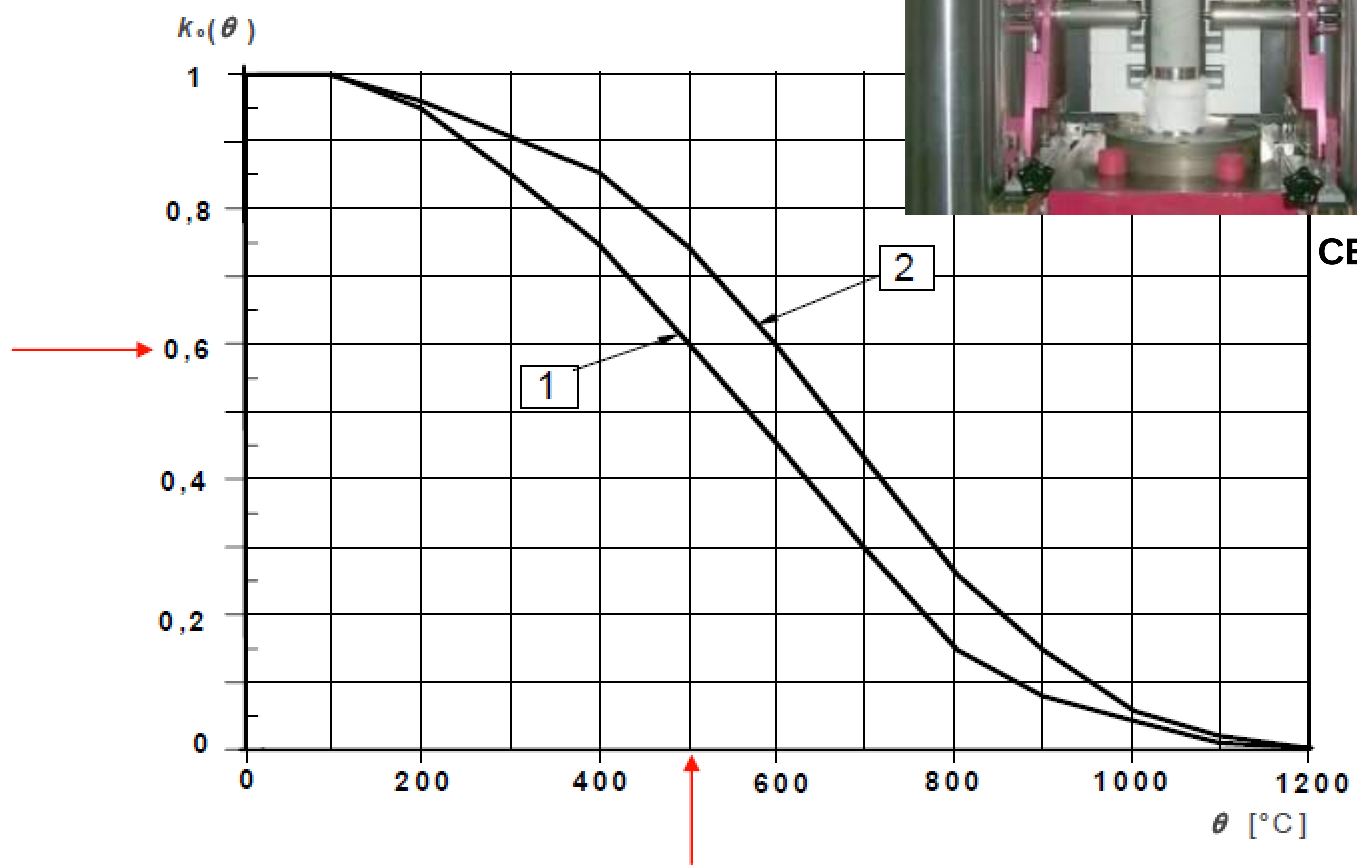


Strength reduction of concrete

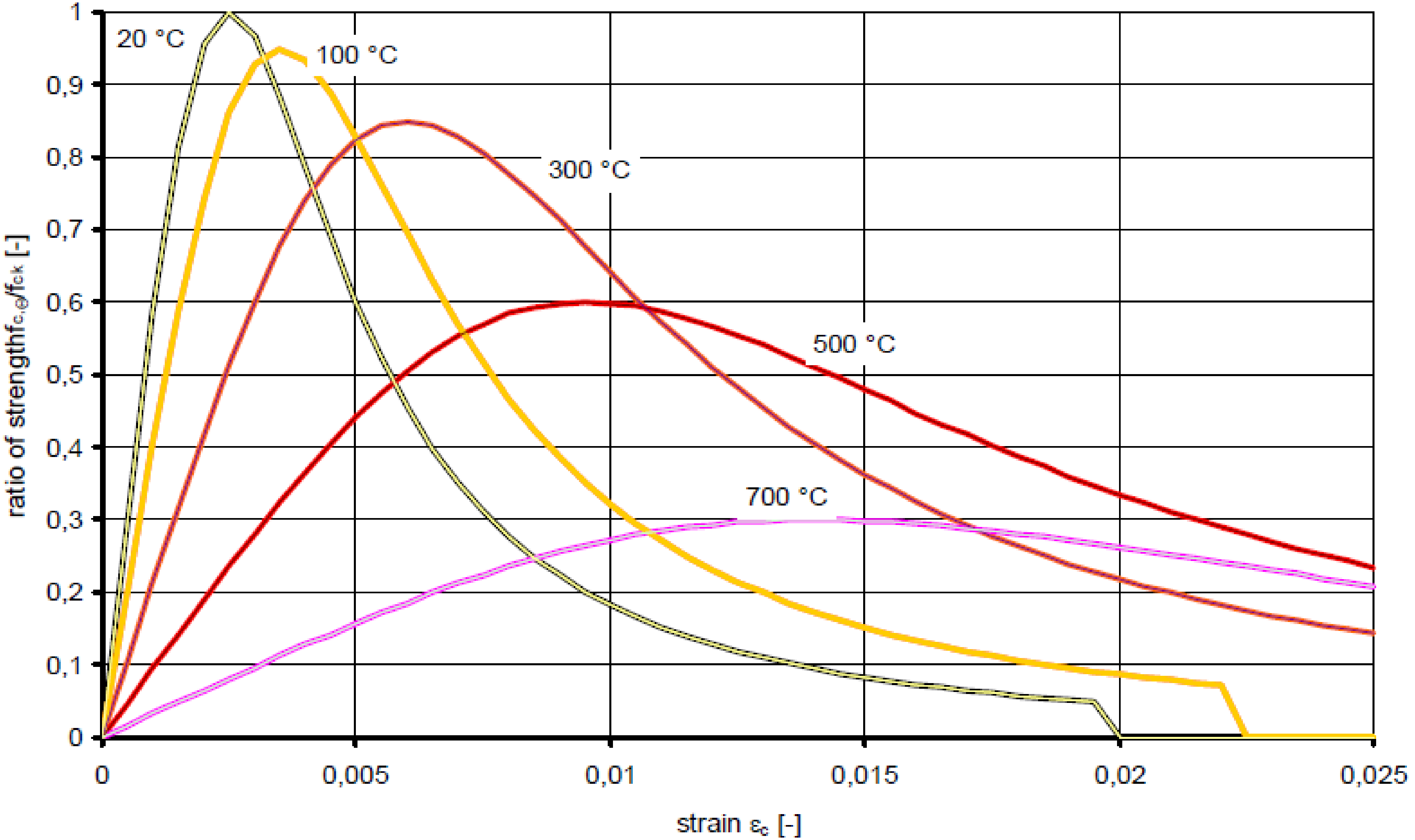
The same strength reduction values are given for simplified calculation methods in Section 4

1. Siliceous concrete
2. Calcareous concrete

CERIB



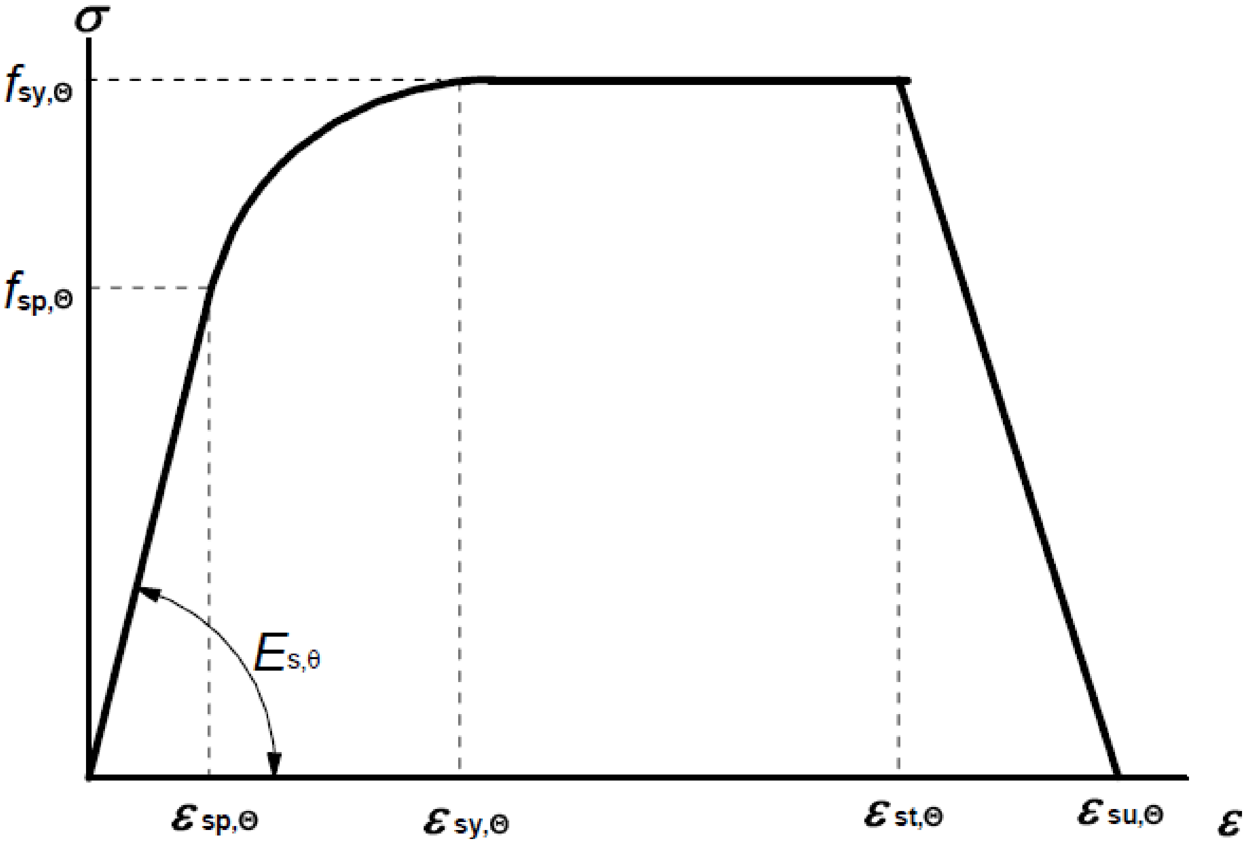
Concrete compressive strength



Reinforcing and prestressing steel : stress-strain relationship

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

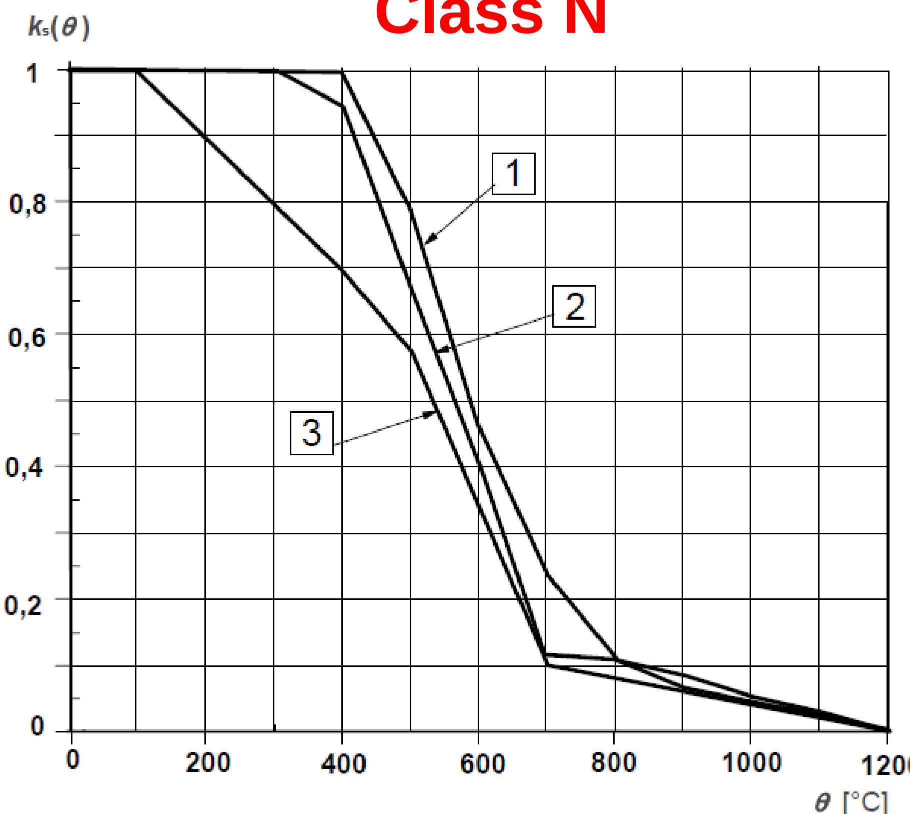
Class A reinforcement: $\varepsilon_{st,\theta} = 0{,}05$ $\varepsilon_{su,\theta} = 0{,}10$



CERIB

Strength reduction (f_{yk}) for reinforcing steel

Class N

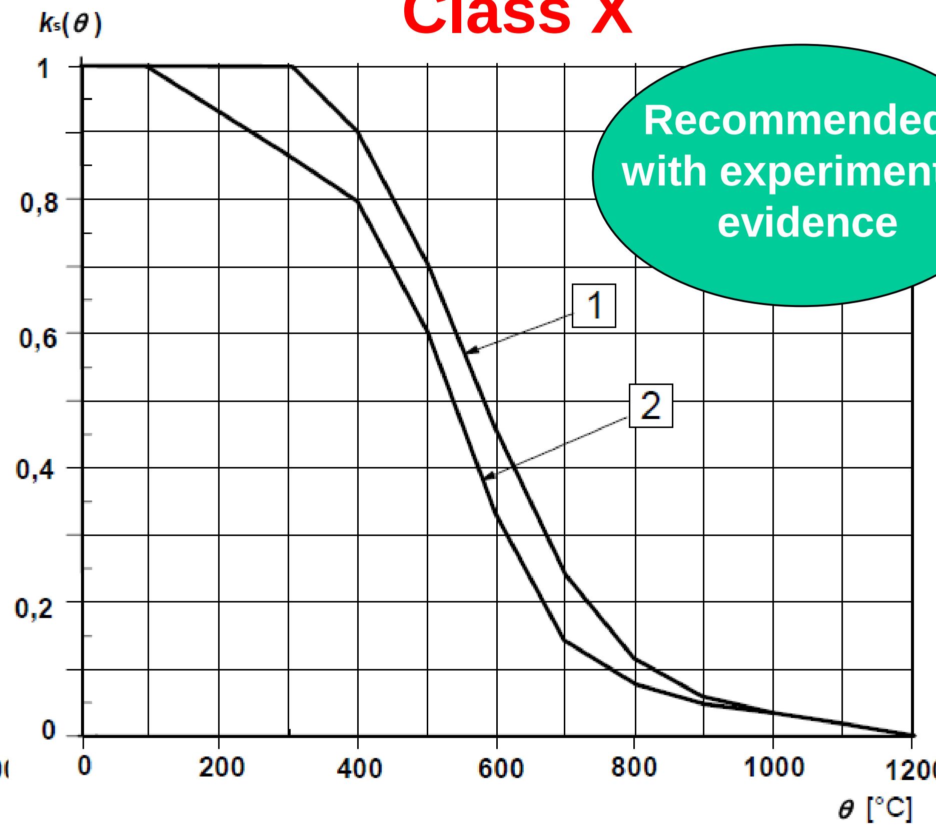


Curve 1 : Tension reinforcement (hot rolled) for strains $\varepsilon_{s,fi} \geq 2\%$

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

Curve 3 : Compression reinforcement and tension reinforcement for strains $\varepsilon_{s,fi} < 2\%$

Class X

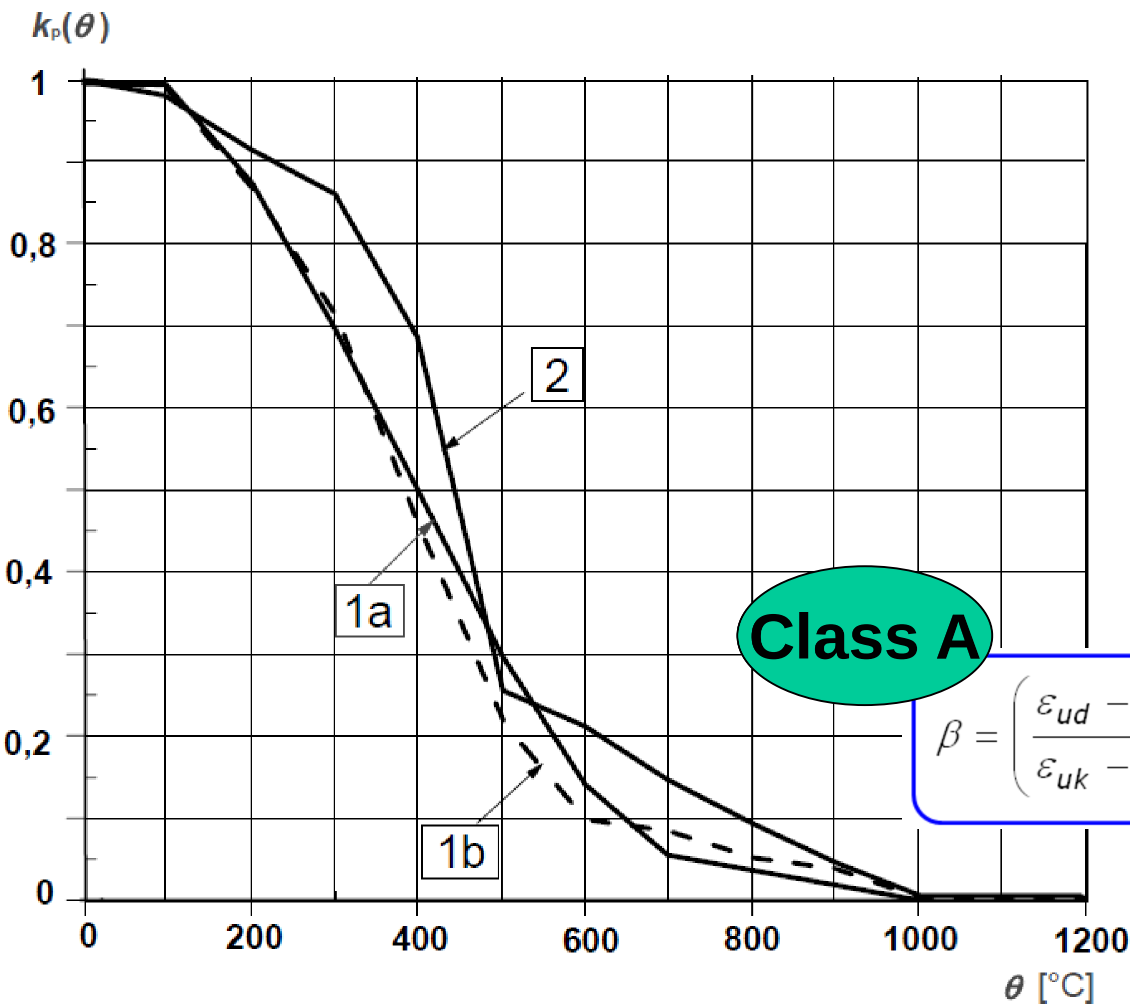


Recommended with experimental evidence

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

Strength reduction (βf_{pk}) for prestressing steel



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)

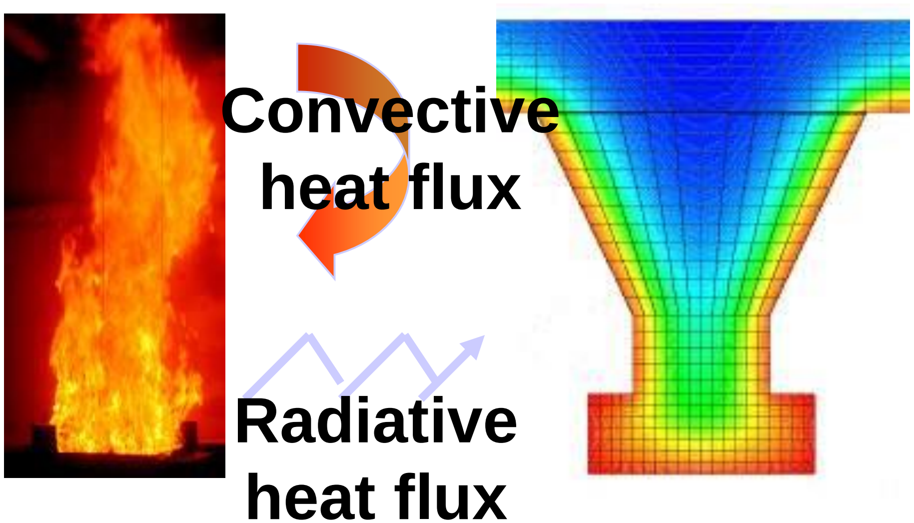
Class A

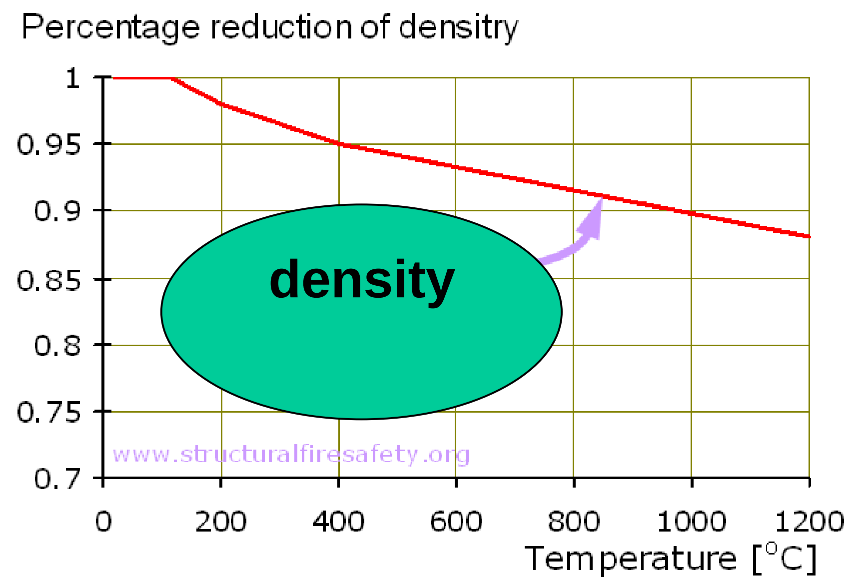
$$\beta = \left(\frac{\varepsilon_{ud} - f_{p0.1k} / E_p}{\varepsilon_{uk} - f_{p0.1k} / E_p} \right) \times \left(\frac{f_{pk} - f_{p0.1k}}{f_{pk}} \right) + \frac{f_{p0.1k}}{f_{pk}}$$

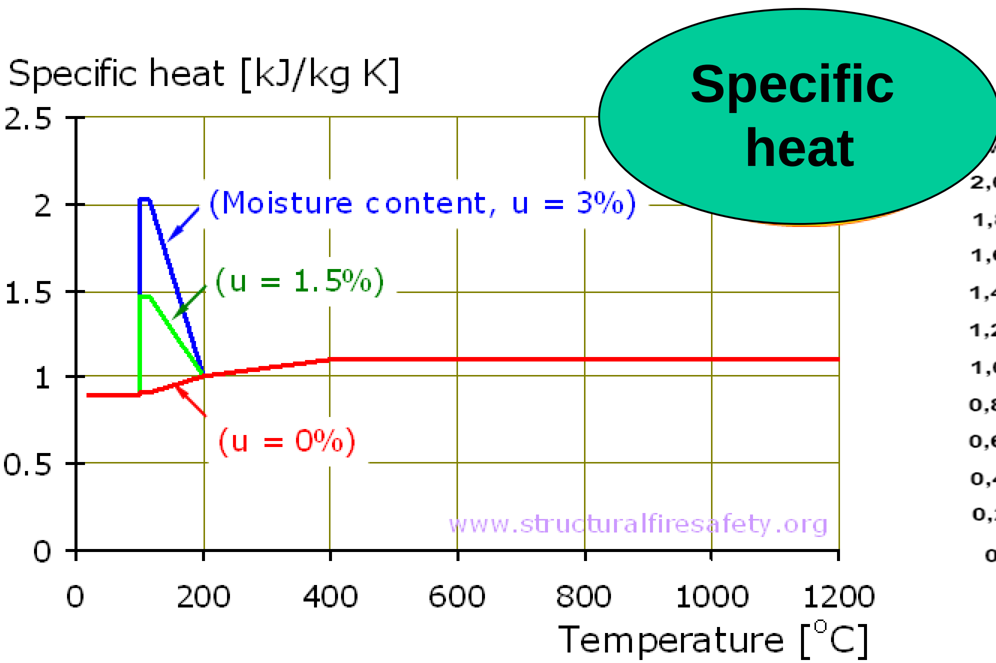
Class B

$$\beta = 0.9$$

Thermal properties







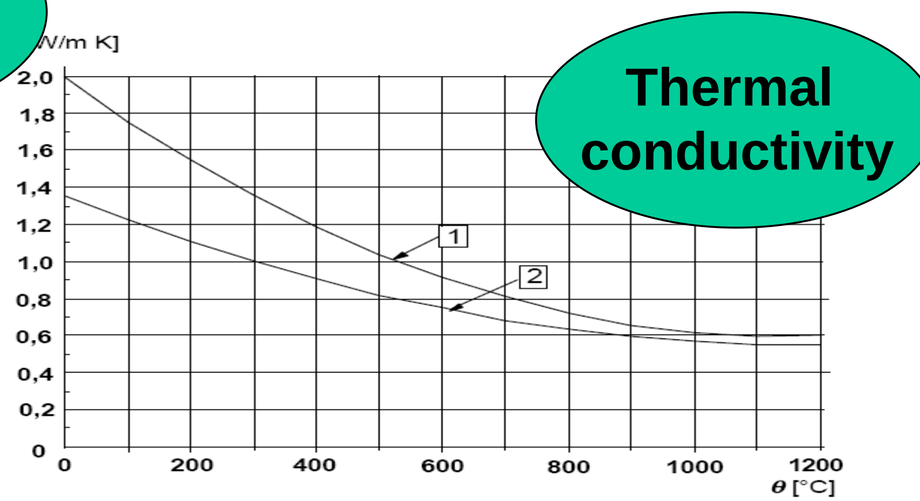
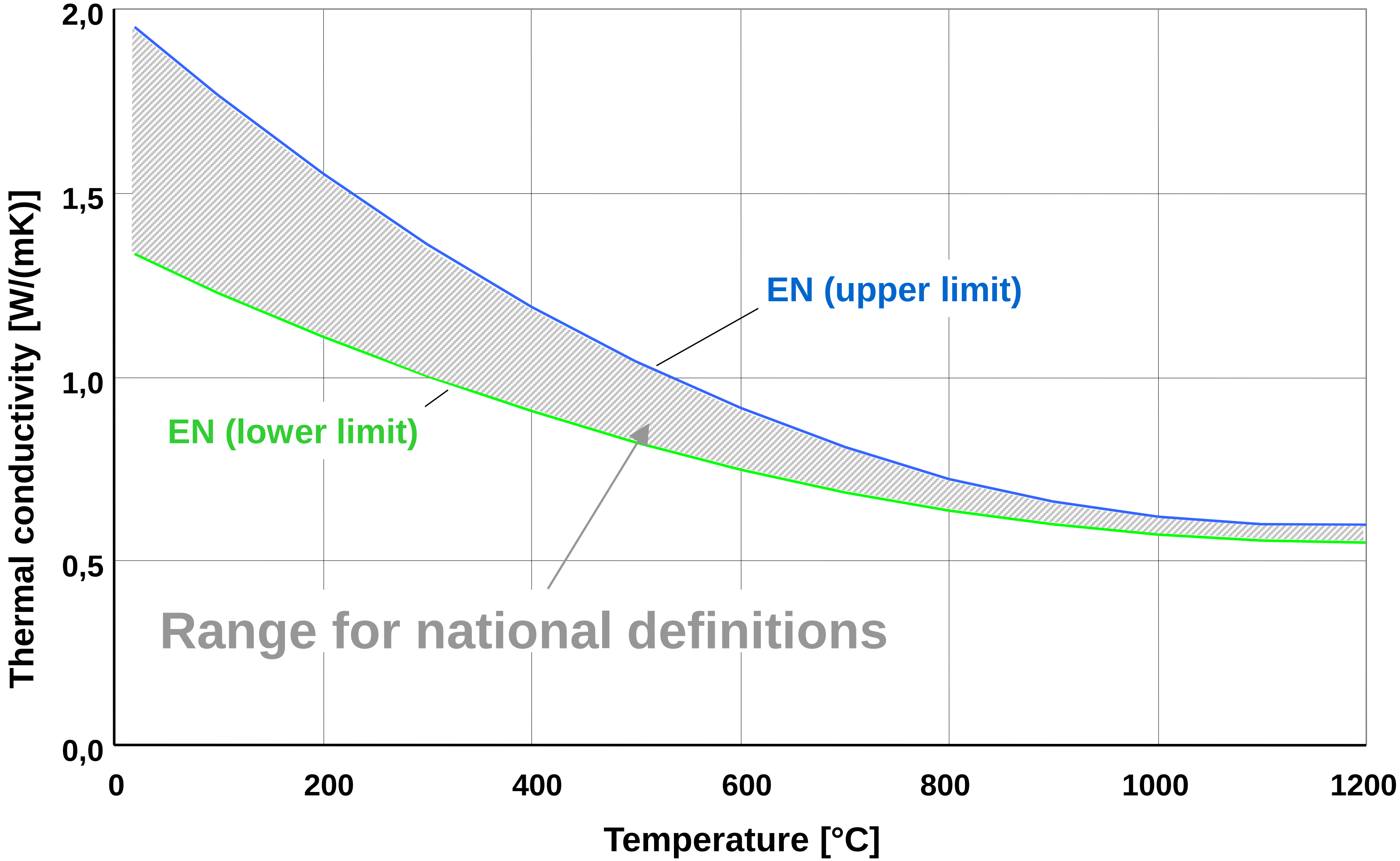
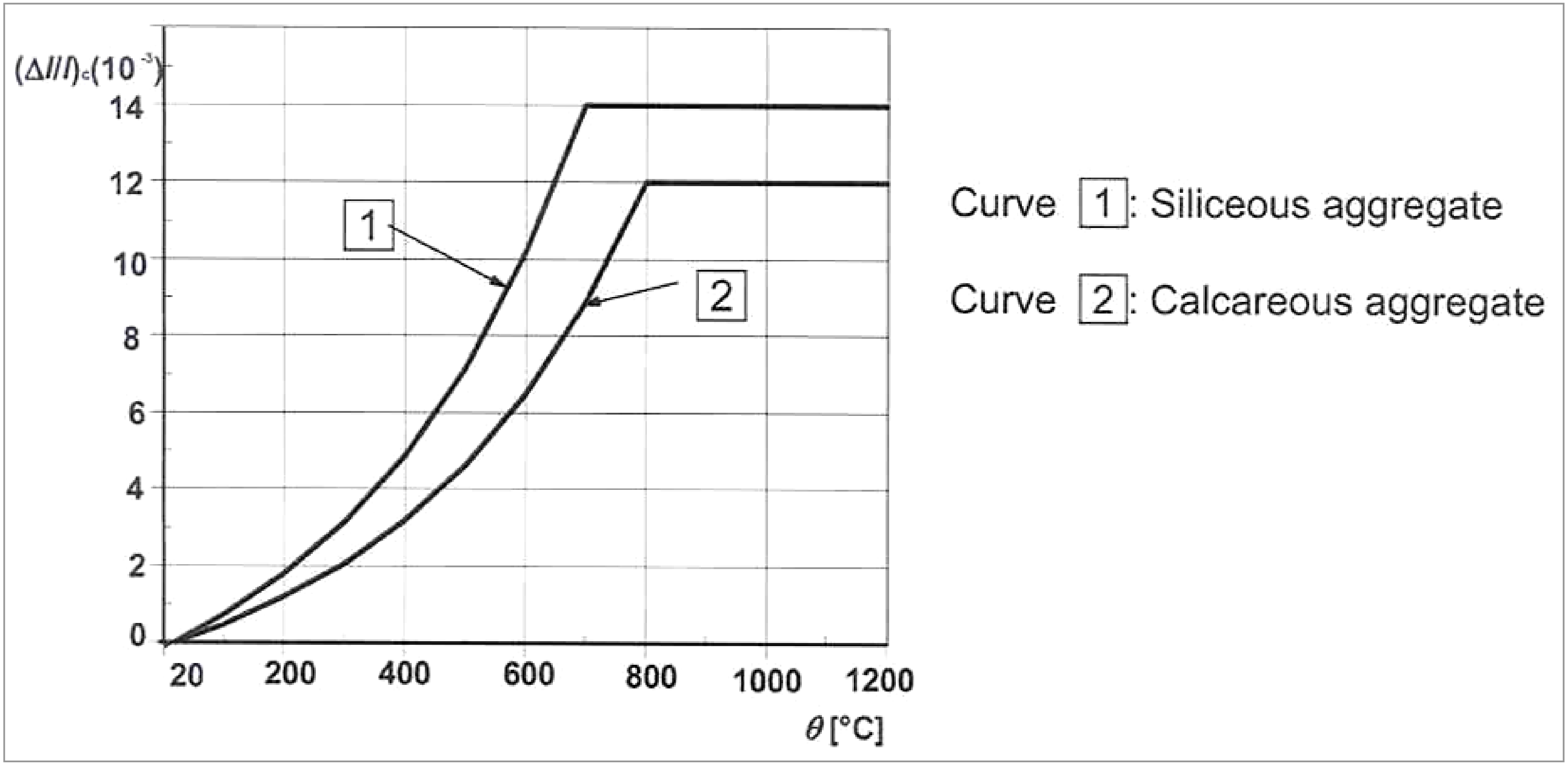


Figure 3.7 – Conductivité thermique du béton

Thermal Conductivity



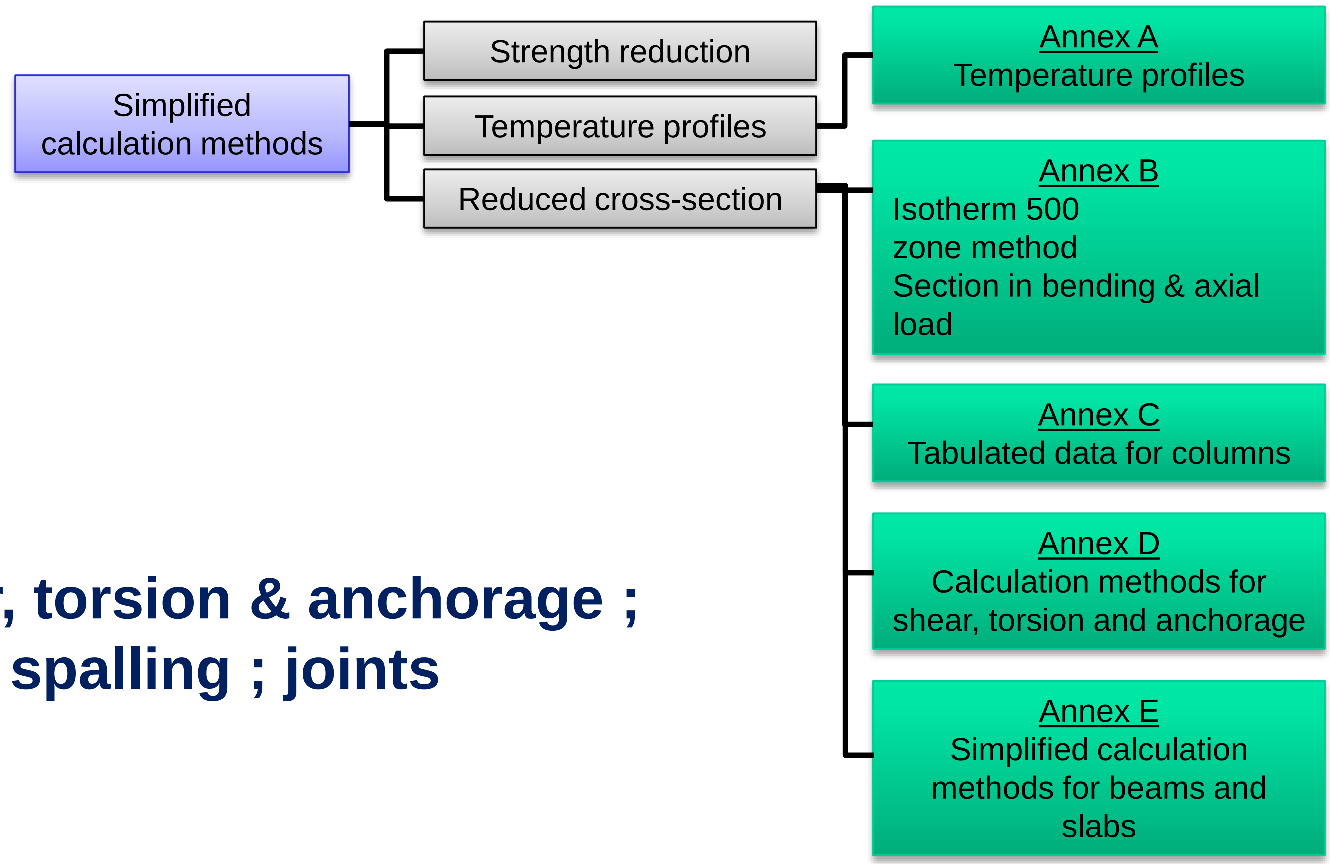
Thermal Elongation



Total thermal elongation of concrete

SECTION 4 - Design procedure

- **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**

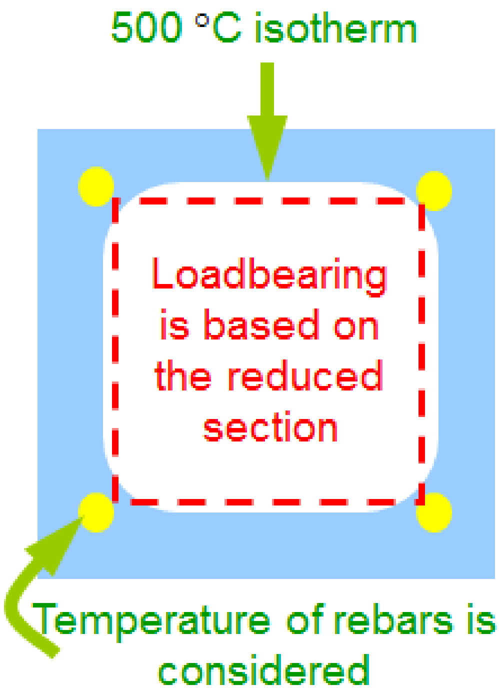


- **shear, torsion & anchorage ; spalling ; joints**

Simplified calculation methods

- **500°C isotherm method**

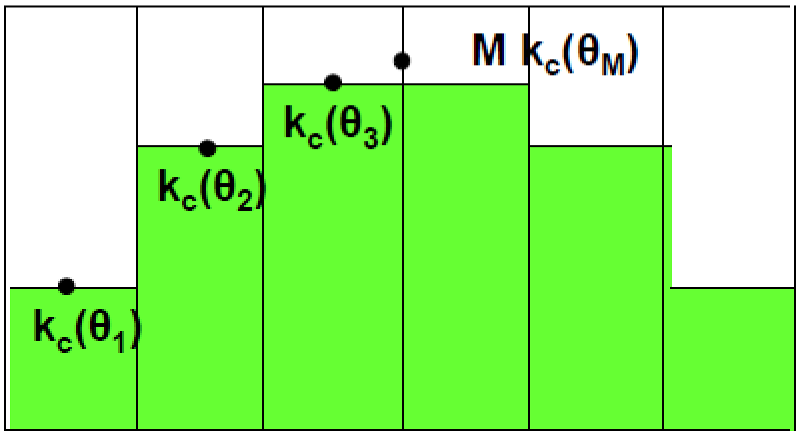
  Concrete with temperature below 500°C retains full strength and the rest is disregarded



- **Zone method**

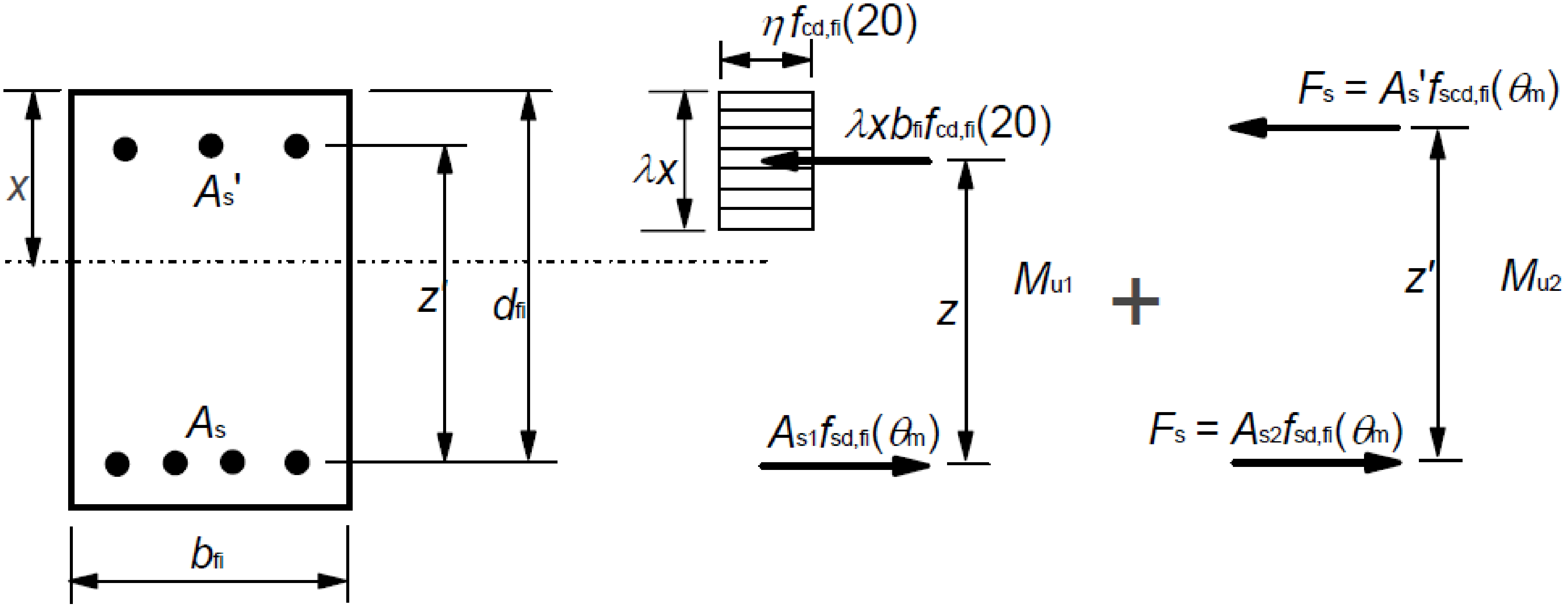
  Cross section is divided in zones. Mean temperature and corresponding strength of each zone is used

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



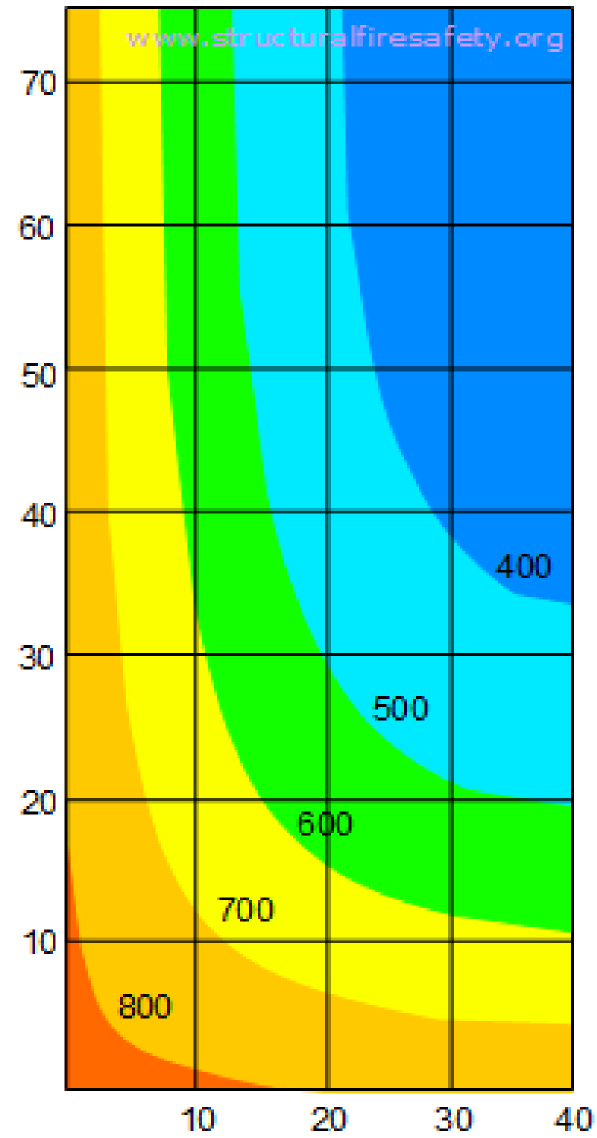
Simplified calculation methods

- **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**



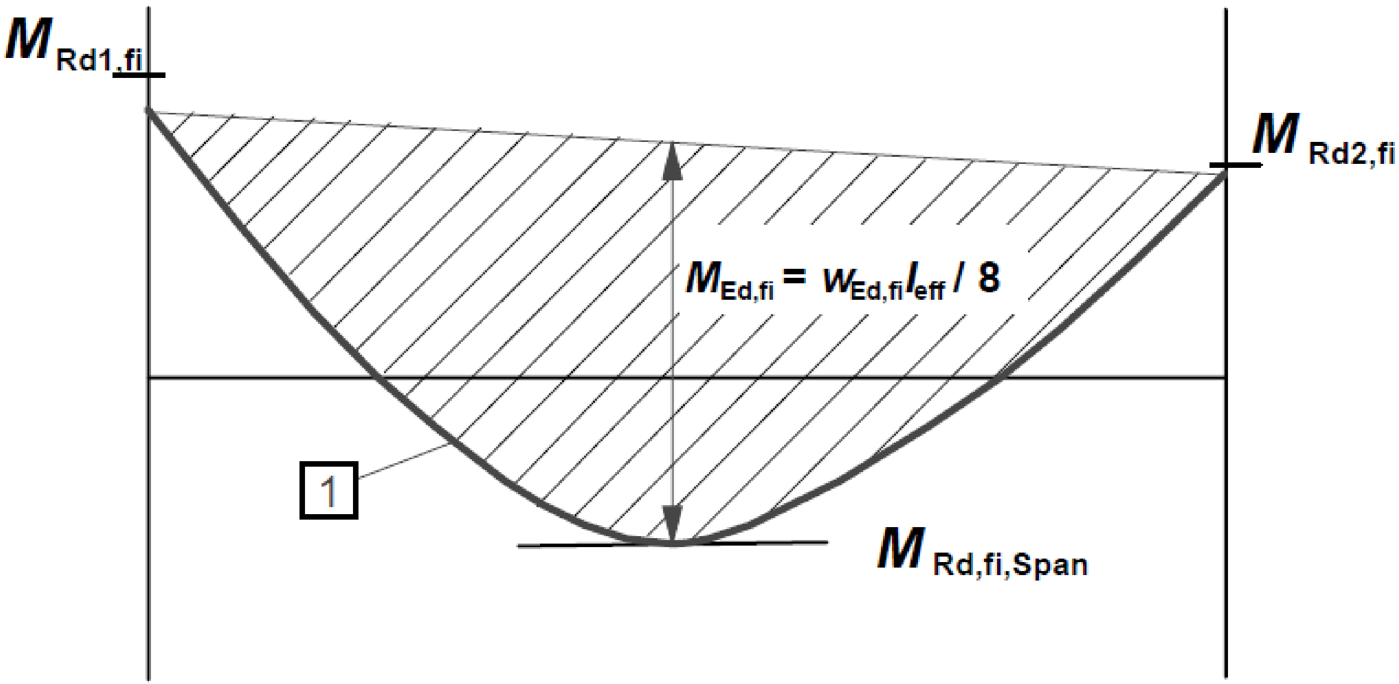
Temperature profiles

- **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 beam and slabs

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

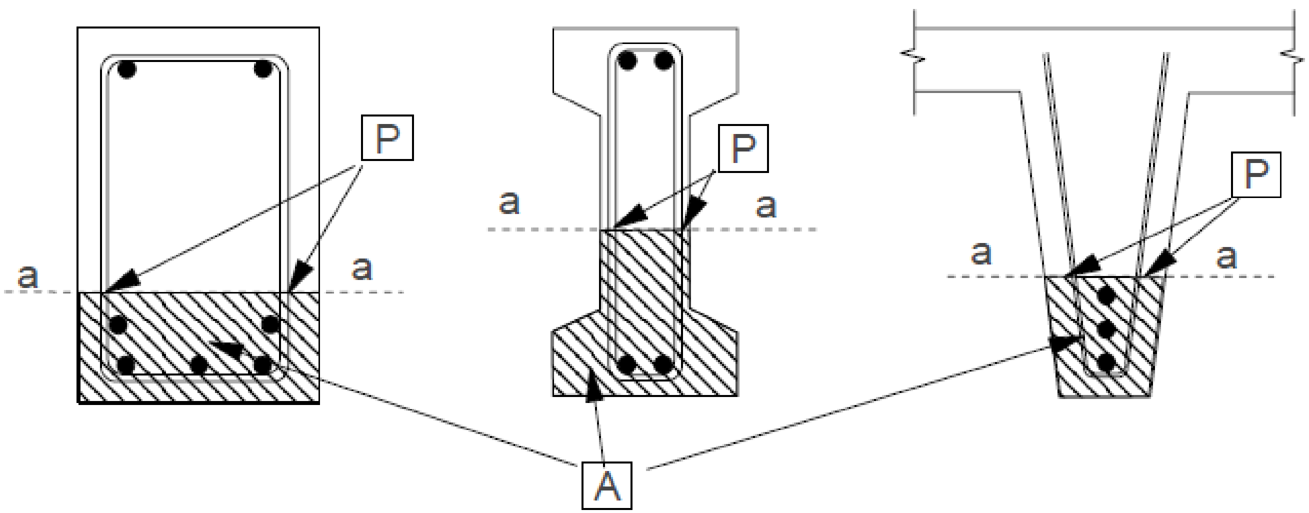


1 Free moment diagram for uniformly distributed load under fire conditions

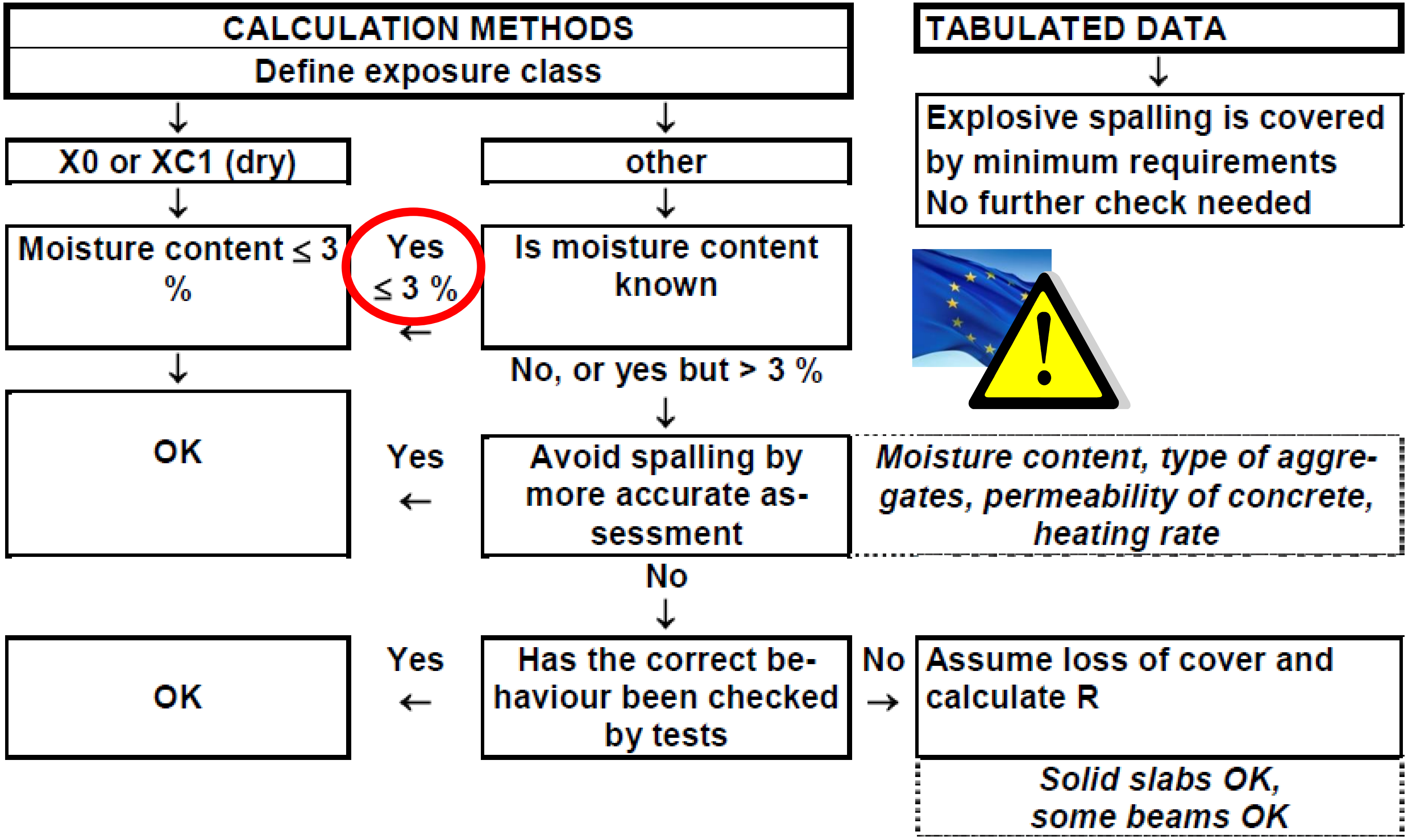
Annex D (informative)

- Shear failures due to fire are very uncommon. However, the calculation methods given in this Annex are not fully verified.

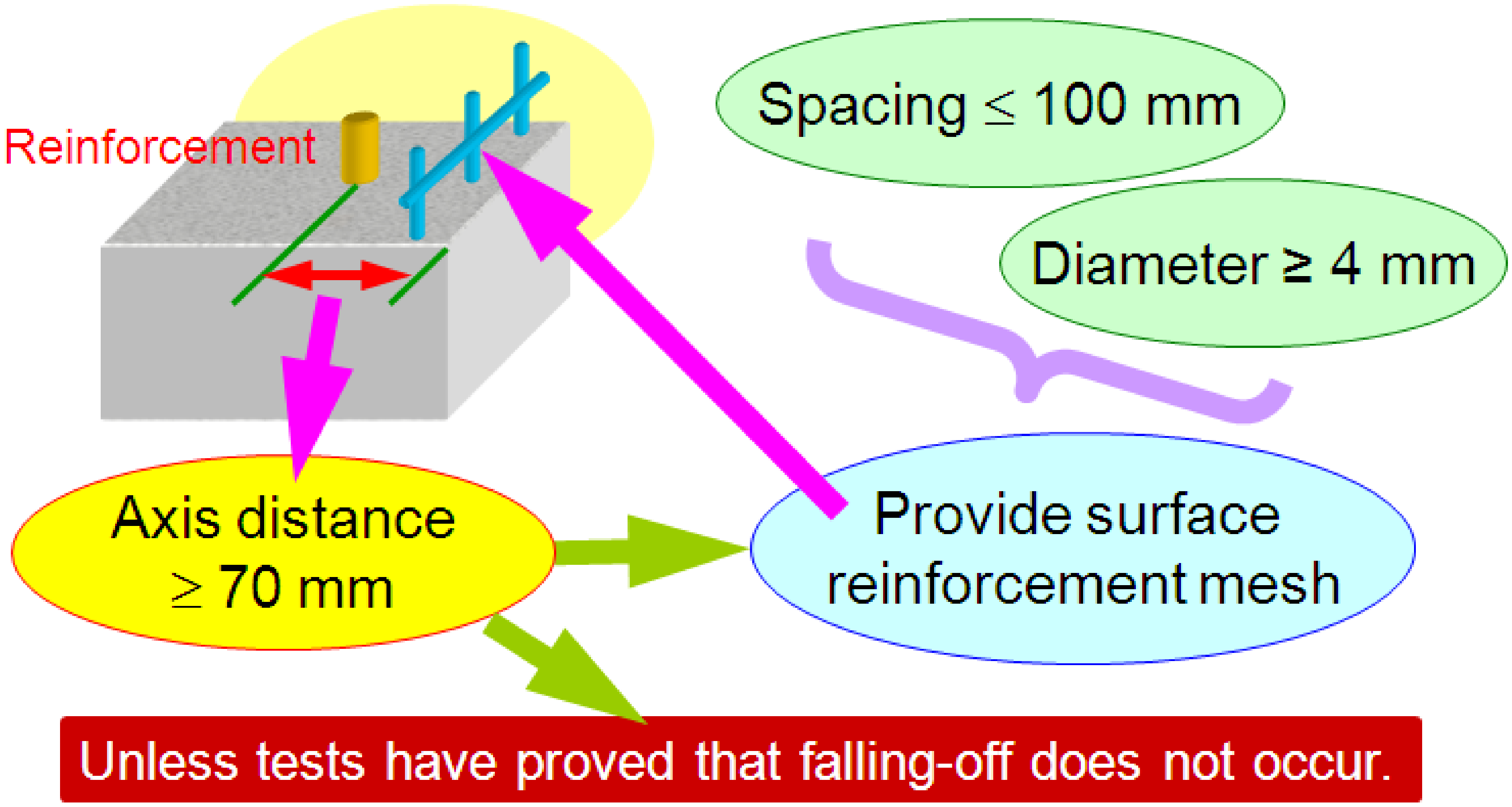
The reference temperature θ_p should be evaluated at points P along the line ‘a -a’ for the calculation of the shear resistance. The effective tension area A may be obtained from EN 1992-1 (SLS of cracking).



Spalling


CALCULATION METHODS
Define exposure class
X0 or XC1 (dry)
other
Moisture content ≤ 3 %
Yes ≤ 3 %
Is moisture content known
No, or yes but > 3 %
OK
Yes
Avoid spalling by more accurate assessment
Moisture content, type of aggregates, permeability of concrete, heating rate
No
OK
Yes
Has the correct behaviour been checked by tests
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 concrete



(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 are based on a reference load level $\eta_{fi} = 0,7$, 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 $\eta_{fi} = 0,7$ 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

TABULATED DATA FOR COLUMNS

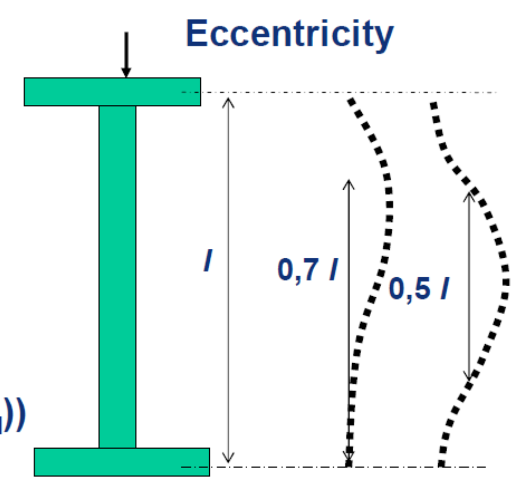
- Two optional methods are given
  - **Method A** is derived from test results, but field of application is limited to buckling length ≤ 3 m and first order eccentricity ≤ 0,15h to 0,4h (depending on the National Annex)
  - **Method B** is based on calculations, it is more conservative and many interpolations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

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

TABULATED DATA FOR COLUMNS : tables for Method B

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* 200/40:400/25*	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* 500/50:600/40 500/50:600/45
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)

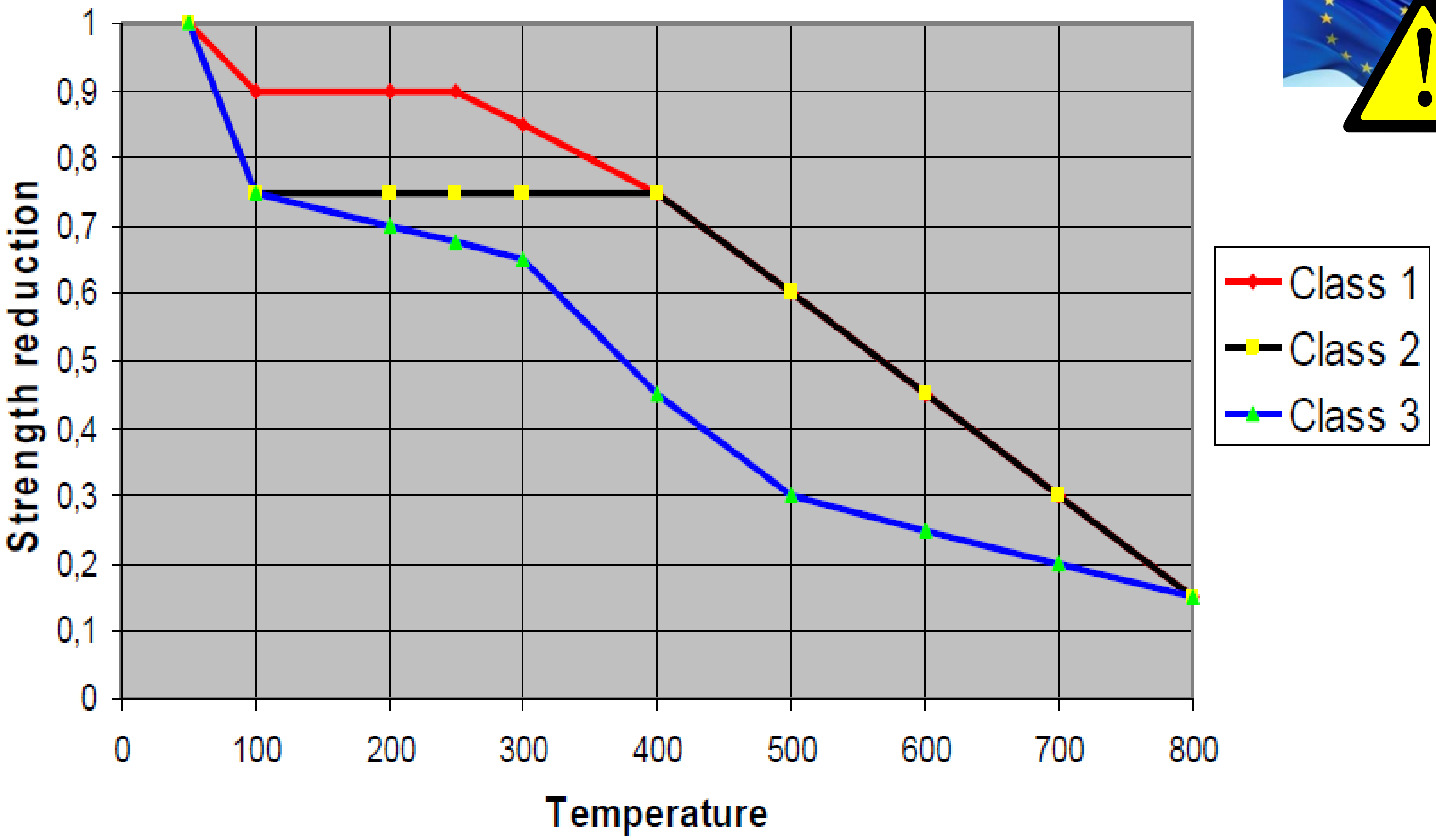
* Normally the cover required by EN 1992-1-1 will control.

(1) Requires width greater than 600 mm. Particular assessment for buckling is required.

SECTION 5 – Tabulated data

- **Tables for loadbearing and non loadbearing wall**
- **Fire walls have been added**
  - Classification M, to be used only if there are national requirements
- **Tables for simply supported and continuous beams**
- **Tables for simply supported and continuous slabs, flat slabs, ribbed slabs**

Reduction of strength at elevated temperature



Concrete C 55/67 and C 60/75 is Class 1, concrete C 70/85 and C80/95 is Class 2 and concrete C90/105 is Class 3.

Spalling

Methods for concrete grades C 55/67 to C 80/95 with higher content of silica fume than 6% by weight of cement and for concrete grades 80/95 < C ≤

Method A

Use reinforcement mesh with a nominal cover of 15 mm:
- Wire diameter ≥ 2 mm
- Pitch ≤ 50 x 50 mm
- Nominal cover to main reinforcement ≥ 40 mm

Method B

Use a type of concrete that will not spall under fire exposure – demonstrated by local experience or testing.

Method C

Use a protective layers which has been demonstrated that no spalling of concrete occurs under fire exposure.

Method D

Include in the concrete mix more than 2 kg/m^3 of monofilament propylene fibres.

- **Thermal properties (thermal conductivity)**
- **specific structural design**

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		

Moment capacity reduction factors for beams and slabs	k_m	
	Class 1	Class 2
Beams	0,98	0,95
Slabs exposed to fire in the compres-sion 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

References of the presentation

- **Dissemination of information for training workshop, 18-20 February 2008, Brussels**

- **EN 1992-1-2 : 2004, The university of Manchester, www.structuralfiresafety.org**

- **EN 1992-1-2 : 2004**

Part II

CASE STUDY (Caroline MORIN)

Objective

Apply the design methods presented in the Eurocode 2 ‘Design of concrete structures ‘ Part 1-2 ‘**Structural fire**’ on a structure exposed under fire

Methodology

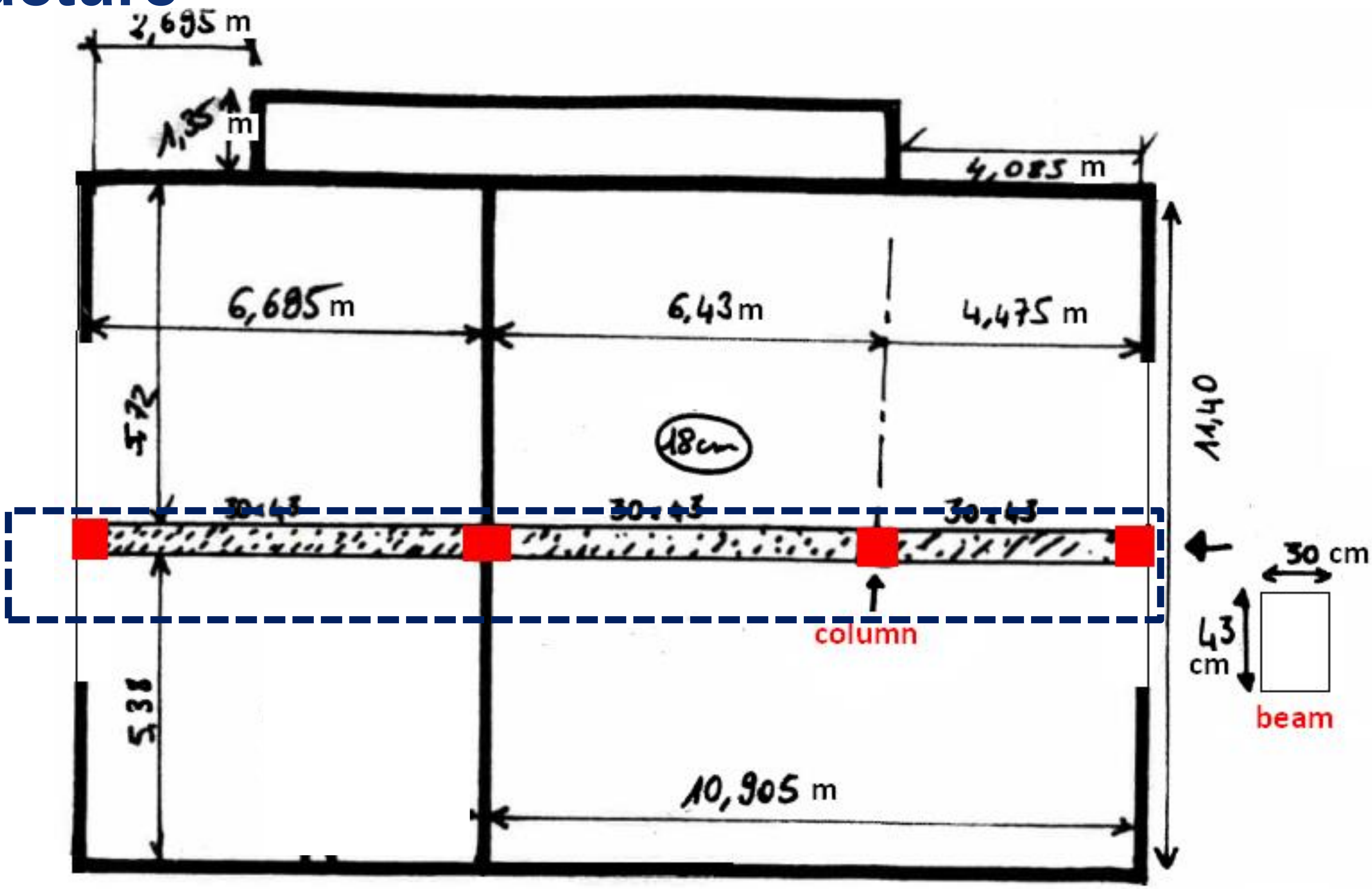
Selection of 2 elements in the selected structure

- A continuous beam
- A column

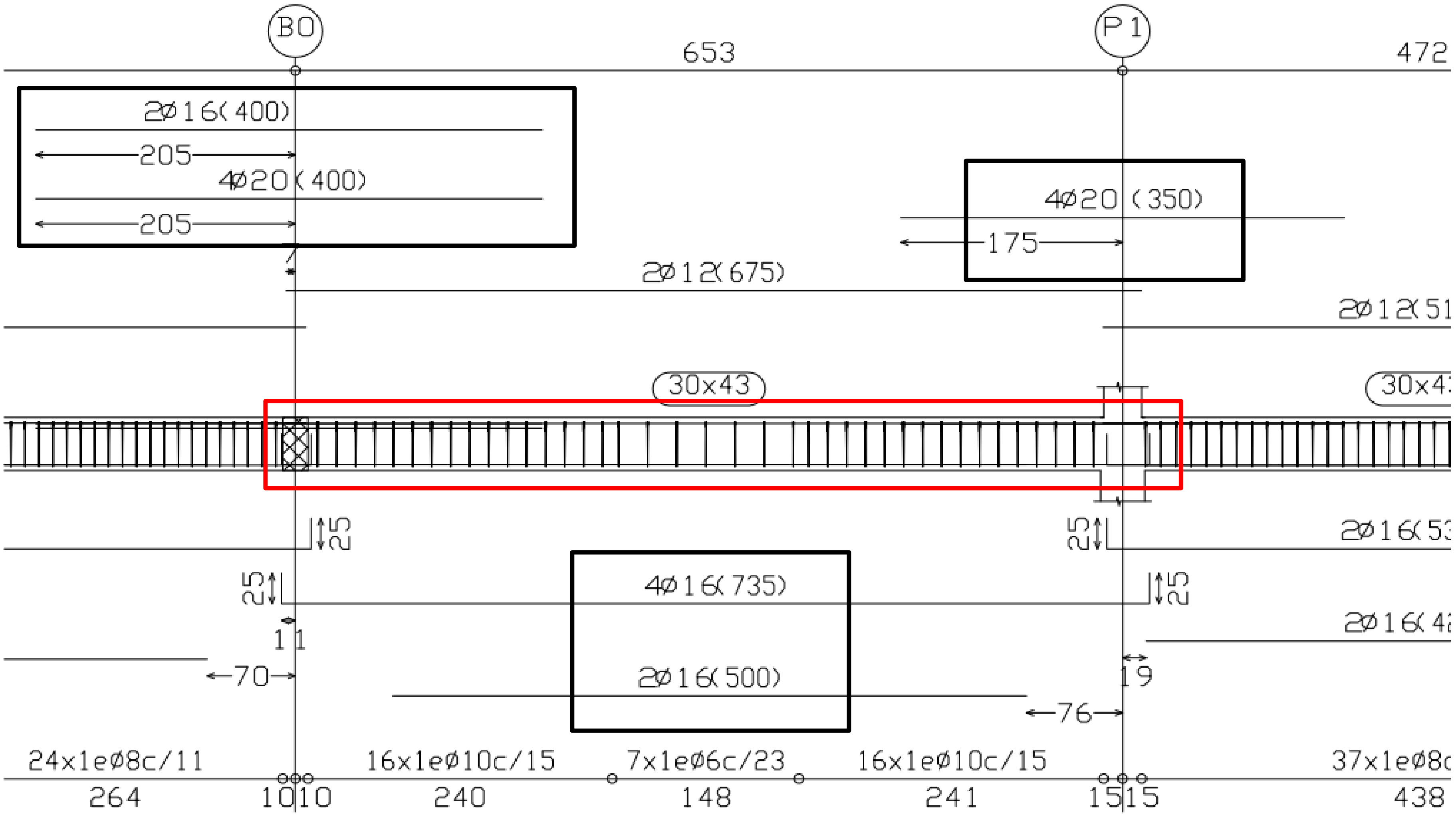
Verification of the design of the structure under a fire with:

- Tabulated data
- Simplified calculation method
- Advanced calculation method

Structure


2,695 m
1,35 m
4,085 m
6,685 m
6,43 m
4,475 m
5,72
18cm
11,40
30x43
30x43
30x43
30 cm
43 cm
column
beam
5,38
10,905 m

Reinforcing steel of the intermediate selected span



Sections

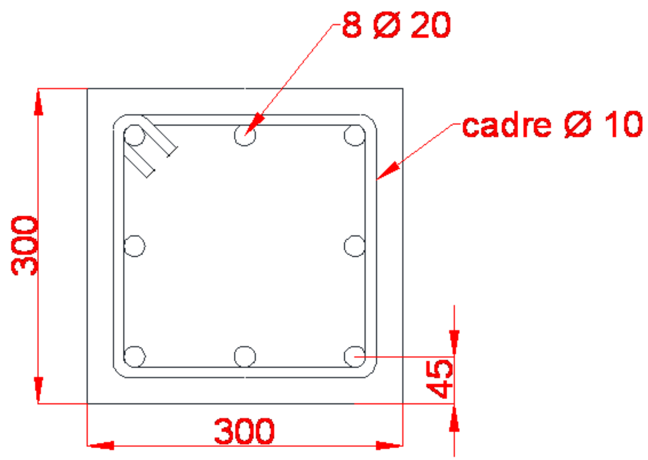
Beam

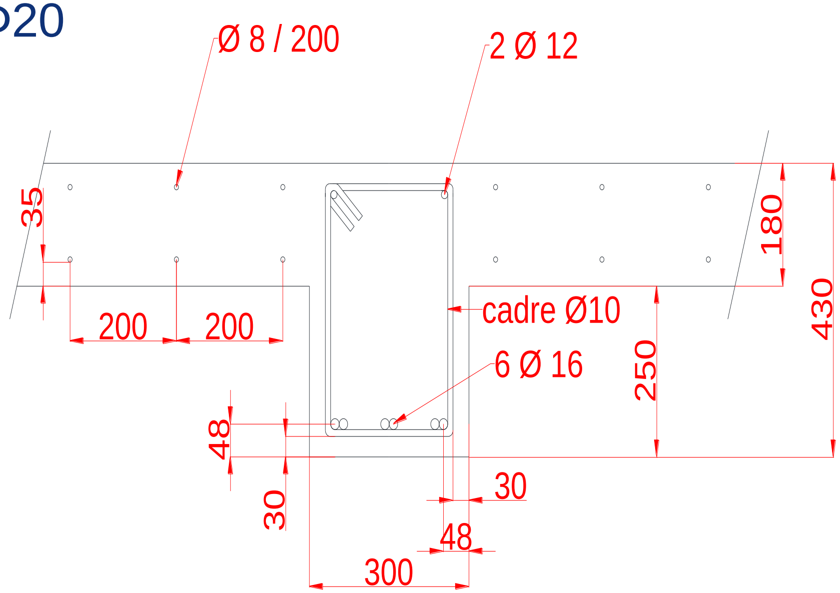
- b=0.30 m * h=0.43 m
- Bars in tension in the middle of the span: 6Φ16, a=48 mm
- Bars near the support (west side): 2Φ16 (a=68 mm) & 4Φ20 (a=50 mm)
- Bars near the support (east side): 4Φ20 (a=50 mm)

Column

- b=0.30 m, l=2.80 m, a =45 mm
- Longitudinal reinforcing steel: 8Φ20

measurements in mm



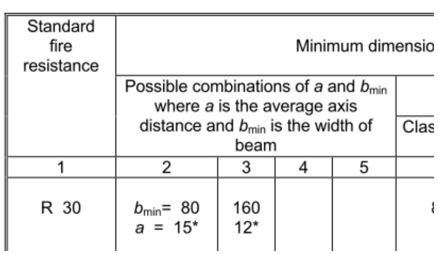


Scope (EN 1992-1-2, section 5.1 & 5.2)

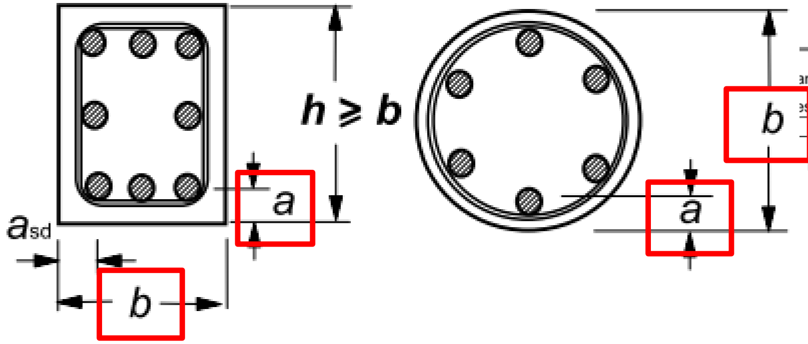
- Design solutions for the fire exposure **up to 240 minutes**
- Normal weight concrete made with **siliceous aggregates**
- No further checks are required concerning shear, torsion, anchorage
- No further checks are required concerning spalling, except for surface reinforcement

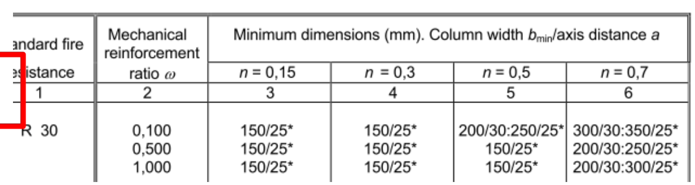
General design rules

- For load bearing function, minimum requirements concerning **section sizes** and **axis distance of steel reinforcement** are given
- Symbol used in tables



Standard fire resistance	Minimum dimensio				
	Possible combinations of a and b_{min} where a is the average axis distance and b_{min} is the width of beam				Clas
1	2	3	4	5	
R 30	b_{min} = 80 a = 15*	160 12*			





...ndard fire ...esistance	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*

Column characteristics

300/45, reinforcing steel 8Φ20, length =2.80 m
normal weight concrete made with **siliceous aggregates**
Standard fire exposure of 120 minutes, exposed on more than one side
Braced structure
G= 232.3 kN, Q= 48.31 kN et $\psi_{2,1}$=0.3 ($\psi_{1,1}$=0.5 EN 1992-1-2/NAF)

Method A (Table 5.2a)

Validity of the method:

- Effective length of the column under fire conditions: **$l_{0,fi}$=1.40 m ≤ 3 m**
- First excentricity under fire conditions: **e=0.0021 m ≤ 0.15b=0.045 m**
- Amount of reinforcement: **A_s=25,13 cm² ≤ 0.04 A_c=36 cm²**
- Reduction factor for the design level in the fire situation: **$\mu_{fi}=N_{Ed,fi}/N_{Rd}$=0.1**

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 120	250/40 350/35	450/40**	450/51**	175/35

Linear interpolation ➔300/37.5

Column characteristics

300/45, reinforcing steel 8Φ20, length =2.80 m
Normal weight concrete made siliceous aggregates
Standard fire exposure of 120 minutes, exposed on more than one side
Braced structures
G= 232.3 kN, Q= 48.31 kN

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

$$\omega = \frac{A_s f_{yd}}{A_c f_{cd}} \qquad e = M_{0Ed,fi} / (N_{0Ed,fi})$$

Method B (Table 5.2b)

Validity of the method:

- Load level at normal temperature conditions: **n=0.14**
- First excentricity under fire conditions: **e=0.0021 m, e/b=0.013 ≤ 0.25**
- Slenderness of the column under fire conditions: **$\lambda_{fi}=l_{0,fi}/i$=11.55 ≤ 30**
- Mechanical reinforcement ratio at normal temperatures conditions: **w=0.73**

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 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

OK R120 (300/45)

Beam characteristics

300/48, reinforcing steel 6Φ16

Normal weight concrete made with siliceous aggregates,

Standard fire exposure of 120 minutes, exposed to fire on three sides

G= 40.85 kN.m, Q= 8.7 kN.m

Method for continuous beam (Table 5.6)

Minimum values of axis distance **a** to the soffit and sides of continuous beams together with minimum values of length **b**

Redistribution of bending moment for normal temperature design <15 %

Area of top reinforcement should be: $A_{s,req}(x) = A_{s,req}(0) \cdot (1 - 2{,}5x/l_{eff})$

Standard fire resistance	Minimum dimensions (mm)						
	Possible combinations of a and b_{min} where a is the average axis distance and b_{min} is the width of beam				Web thickness b_w		
					Class WA	Class WB	Class WC
1	2	3	4	5	6	7	8
R 120	b_{min}= 200 a = 45	300 35	450 35	500 30	130	120	120

OK R120 (300/48)

General (section 4.2)

Simplified cross-section calculations methods may be used to determine the **ultimate load-bearing capacity** of a heated cross section and **to compare the capacity with the relevant combination**

- **Informative Annex B**: 2 alternatives methods for calculating the resistance to bending moments: **« 500°C isotherm method »** and **« Zone method »**

Standard fire exposure
Temperature profiles determined from calculation or tests
Reduced cross-section
Strength reduction of materials

Note: for shear and anchorage, when minimum dimensions given in tabulated data are followed, further checks for shear and anchorage are not required (section 4.4)

Continuous beam

Recall of data

- l=6.43 m, b=0.30 m, h=0.40 m, h_{slab}=0.18 m
- Hot rolled reinforcing steel: 6Φ16, a =48 mm
- West top reinforcement: 4Φ20 + 2Φ16, a_1 =50 mm et a_2=68 mm
- East top reinforcement: 4Φ20, a=50 mm
- Siliceous aggregates, f_{ck}=25 MPa
- G= 40.85 kN.m, Q= 8.7 kN.m et $\psi_{1,1}$=0.5

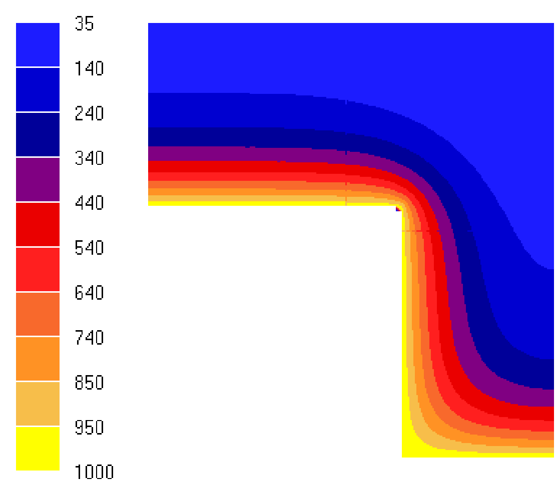
Method B1 valid with a minimum cross-section b=0.30 m > 0.16 m

Fire resistance	R 60	R 90	R120	R180	R240
Minimum width of cross-section mm	90	120	160	200	280

Temperature profiles: Fire exposure up to 120 min

Reduced cross section

- **500°C isotherm method**➔$a_{500°C}$
- **b_{fi}=0.210 m**
- **h_{fi}=0.365 m**



Continuous beam

Temperature of reinforcing bars in tension

Reduced strength of the reinforcement due to the temperature

- $k_{moy}=0.515$
- $f_{yd,fi}=k_{moy}*f_{yk}/\gamma_{s,fi}=0.515*500/1=257.37$ MPa
- $d_{fi}=d=0.390$ m
- $A_s *f_{yd,fi}= A_s *k_{moy}*f_{yk}/\gamma_{s,fi}=12.06^{E-4}*257.37=0.310$ MN

Reinforcement	x (mm)	y (mm)	T (°C)	Asi (mm²)	ksi	ks.As (mm²)	ai.ksi.Asi (mm3)
1	40	48	692	201	0,2492	50	2405
2	56	48	617	201	0,4292	86	4142
3	142	48	461	201	0,8658	174	8356
1'	260	48	692	201	0,2492	50	2405
2'	244	48	617	201	0,4292	86	4142
3'	158	48	461	201	0,8658	174	8356

Bending strength moment: $M_{Rd,fi}=z*A_s *k_{moy}*f_{yk}/\gamma_{s,fi}=116.39$ kN.m

Comparison with a software CIM'feu EC2: $M_{Rd,fi}=121.04$ kN.m (+4%)

Continuous beam

Temperature of reinforcing bars (in the west side)

Reduced strength of the reinforcement due to the temperature

- $k_{moy}=1$
- $f_{yd,fi}=k_{moy}*f_{yk}/\gamma_{s,fi}=1*500/1=500$ MPa
- $d_{fi}=0.309$ m
- $A_s *f_{yd,fi}= A_s *k_{moy}*f_{yk}/\gamma_{s,fi}=17.59^{E-4}*500=0.880$ MN

Reinforcement	x (mm)	y (mm)	T (°C)	Asi (mm²)	ksi	ks.As (mm²)	ai.ksi.Asi (mm3)
1	40	50	69	314	1	314	15708
2	140	50	43	314	1	314	15708
1'	160	50	43	314	1	314	15708
2'	260	50	69	314	1	314	15708
3	40	68	82	251	1	251	17090
3'	260	68	82	251	1	251	17090

Strength moment: $M_{Rd,w,fi}=z*A_s *k_{moy}*f_{yk}/\gamma_{s,fi}=$ 206.64 kN.m

Comparison with a software CIM'feu EC2: $M_{Rd,w,fi}=$199.57 kN (- 3 %)

Continuous beam

Temperature of reinforcing bars (in the east side)

Reduced strength of the reinforcement due to the temperature

- $k_{moy}=1$
- $f_{yd,fi}=k_{moy}*f_{yk}/\gamma_{s,fi}=1*500/1=500$ MPa
- $d_{fi}=0.315$ m
- $A_s *f_{yd,fi}= A_s *k_{moy}*f_{yk}/\gamma_{s,fi}=12.56^{E-4}*500=0.628$ MN

Reinforcement	x (mm)	y (mm)	T (°C)	Asi (mm²)	ksi	ks.As (mm²)	ai.ksi.Asi (mm3)
1	40	50	69	314	1	314	15700
2	140	50	43	314	1	314	15700
1'	160	50	43	314	1	314	15708
2'	260	50	69	314	1	314	15708

Strength moment: $M_{Rd,e,fi}$=172.61 kN.m

Comparison with a software CIM'feu EC2: $M_{Rd,e,fi}$=169.01 kN.m (-2%)

Bending moment for a simply supported beam: $M_{Ed0,fi}$=241 kN.m

Total bending strength: $M_{Rd,fi}$=306 kN.m > $M_{Ed0,fi}$=241 kN.m OK R120

Comparison with CIM'feu EC2: $M_{Rd,fi}$=305.33 kN.m (-0.2%)

Column

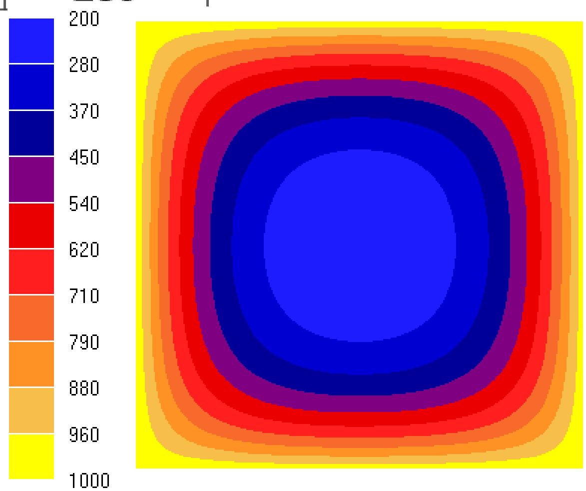
General data

- b=0.30 m, l=2.80 m
- Hot rolled reinforcing steel: 8Φ20, cover =35 mm (a=45 mm)
- Siliceous aggregates, f_{ck}=25 MPa
- N_G= 232.3 kN.m, N_Q= 48.31 kN.m et $\psi_{1,1}$=0.5

« 500 °C isotherm method », b=0.30 m > 0.16 m

Fire resistance	R 60	R 90	R120	R180	R240
Minimum width of cross-section mm	90	120	160	200	280

Temperature profiles: Fire exposure up to 120 min



Reduced cross section

- 500°C isotherm method→ $a_{500°C}$=55 mm
- **b_{fi}=0.190 m**

Column

Taking into account of the 2nd order effect? $\lambda_{lim} = 20 \cdot A \cdot B \cdot C / \sqrt{n}$

- **A**=0.7
- Mechanical reinforcement ratio under fire exposure ω=0.77 → **B**=1.597
- **C**=0.7
- **n**=$N_{ed,fi}/A_{c,fi}.f_{cd}$=0.284
- Limit slenderness $\boldsymbol{\lambda_{lim}}$=29.36
- Slenderness $\boldsymbol{\lambda}=l_{0,fi}/i$=25.52 < λ_{lim} →we can neglect the 2nd order effet

Strength of the cross-section: $N_{Rd,fi}$=1.60 MN

Design normal effort: $N_{Ed,fi}$=0.256 MN

$N_{Ed,fi}$=0.256 MN < $N_{Rd,fi}$=1.60 MN → <u>OK R120</u>

General

A realistic analysis of the structure exposed to fire

Reliable approximation of the expected behaviour of the structure

Include calculation models for:

- Development and distribution of the temperature within structural members = **thermal response**
- Mechanical behaviour of the structure = **mechanical response**

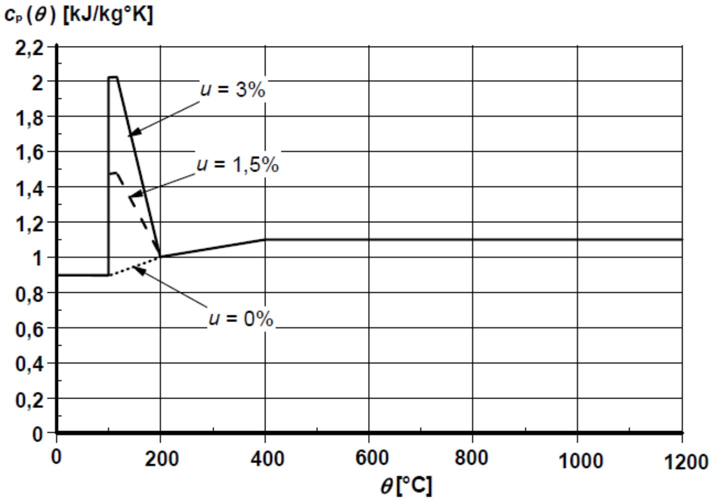
Hypothesis for the modelling

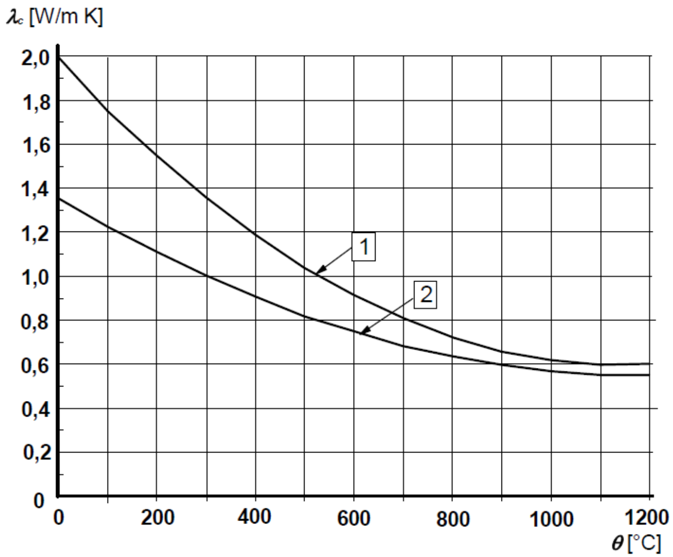
Thermal response (EC1-1-2)

- Based on principles and assumptions of the **theory heat transfer**
  - Convection, radiation
  - Thermal transfert coefficient on the unexposed face (α_c=4 W/m²K)
  - Thermal transfert coefficient on the exposed face (α_c=25 W/m²K)
  - Standard fire exposure

$$\Theta_g = 20 + 345 \log_{10}(8t + 1) \quad [°C]$$

- Include the relevant **thermal actions** (EN 1991-1-2), the **temperature dependent thermal properties of the materials**, the influence of

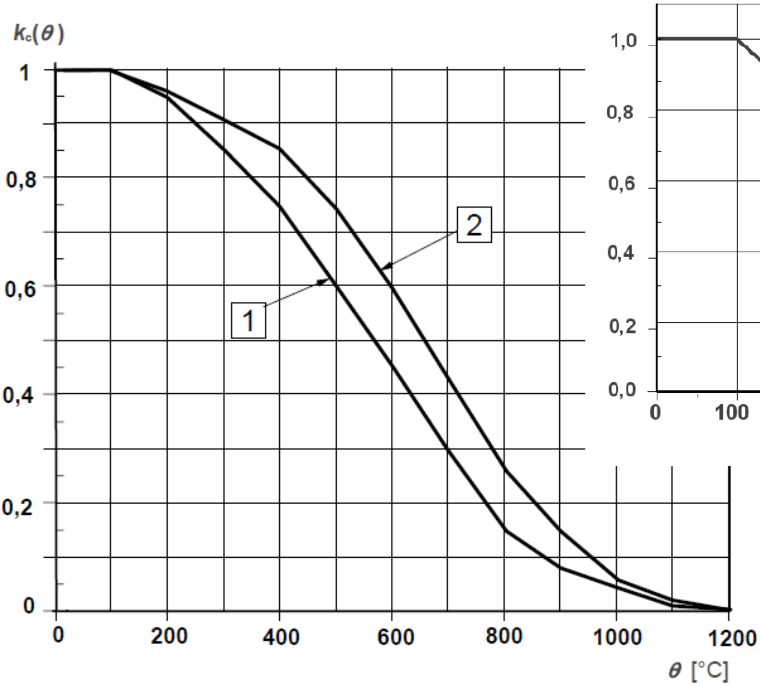


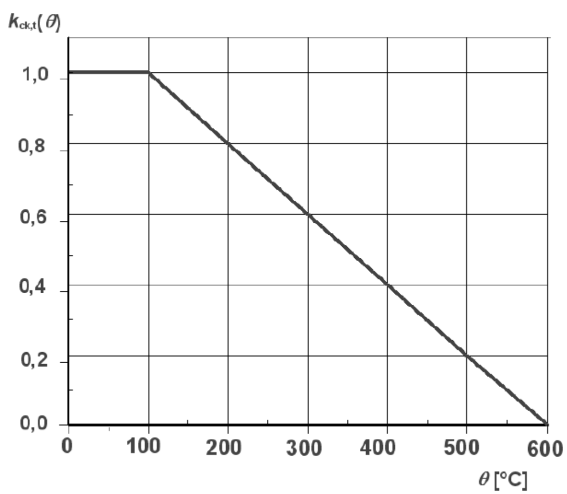


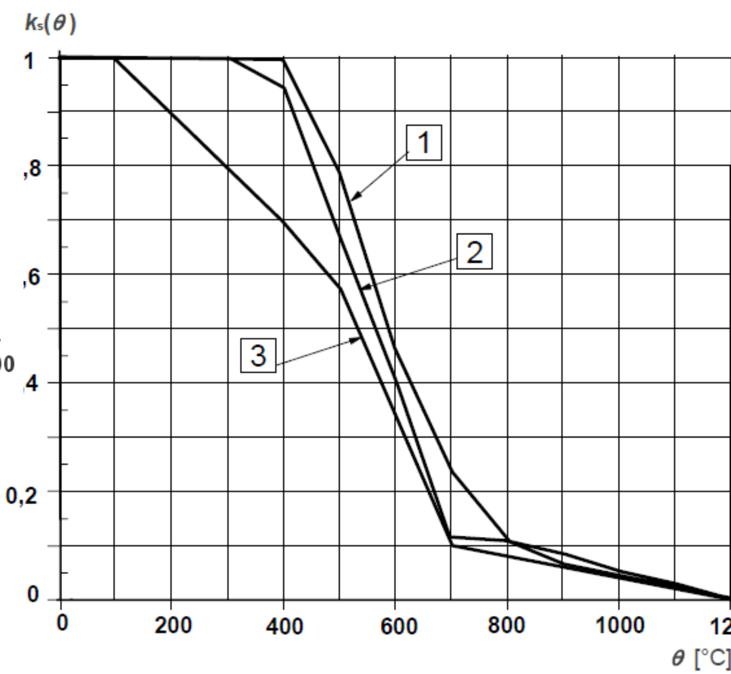
Hypothesis for the modelling

Mechanical response

- Based on the principles and assumptions of the therory of structural mechanics, taking into account the **changes of mechanical properties with temperature**
- **Loads** G, Q



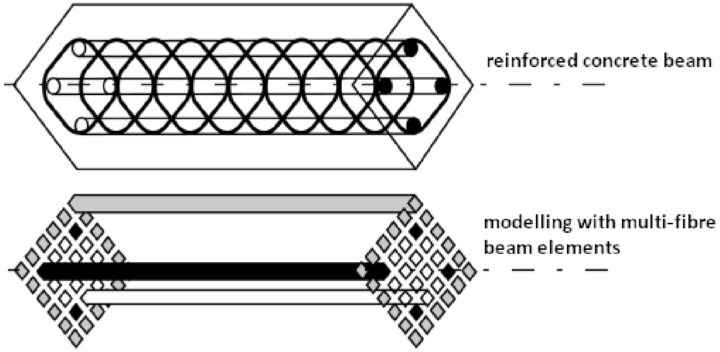


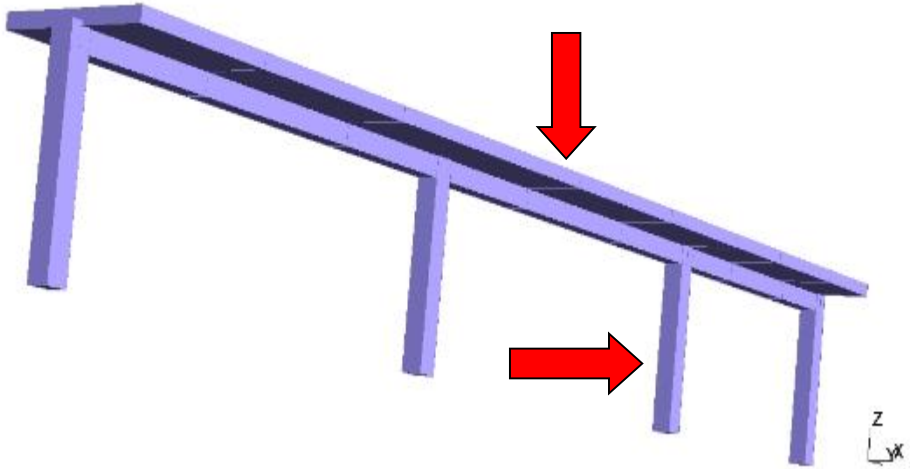


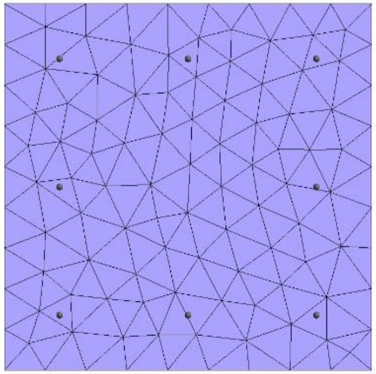
Modeling of the structure

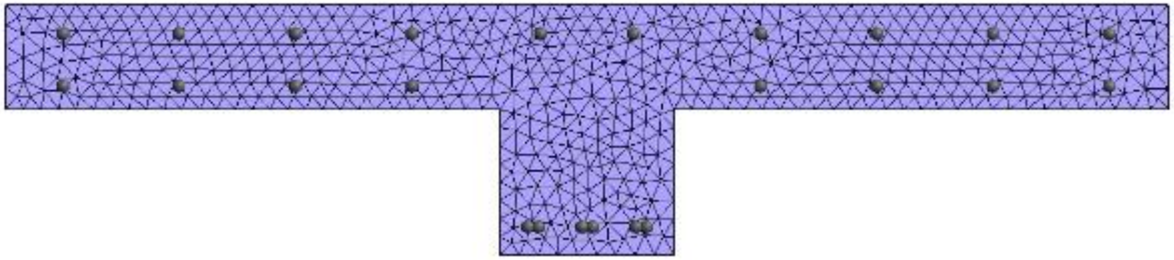
Aster Code

Meshes using multi-fibre beam elements





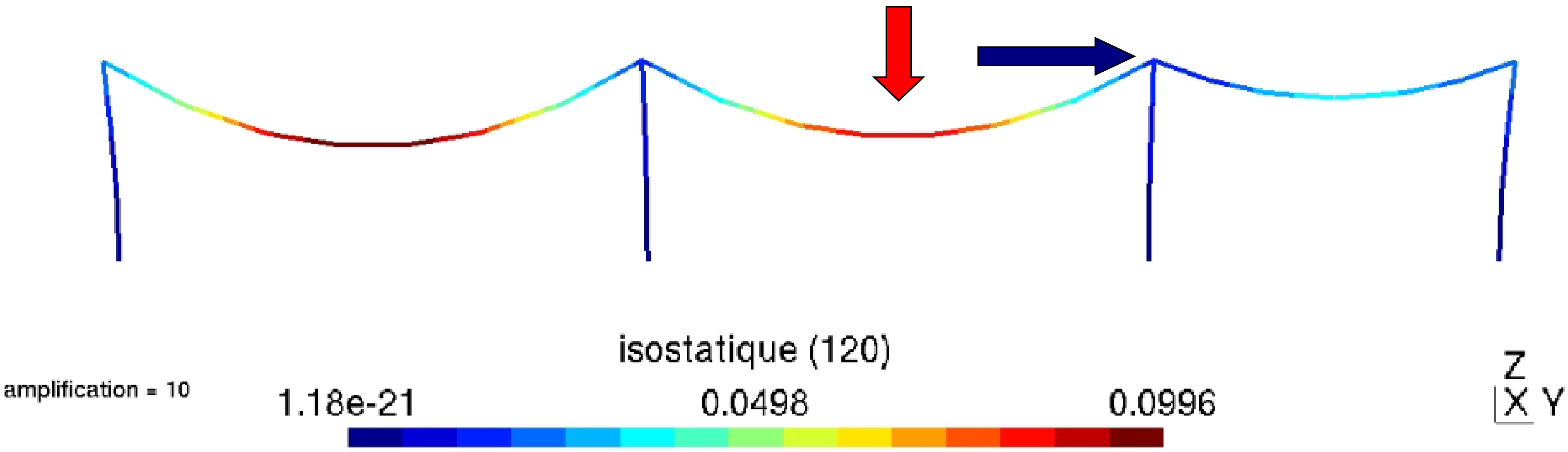




Results & analysis in terms of deflections

Vertical deflection of the middle of the beam (< 10 cm)

Horizontal displacement at the head of the column



Calculations ➔structure strength during 180 minutes (> 120 minutes)